Ground Water Scenario in Major Cities of India

Central Ground Water Board

Ministry of Water Resources

Government of India

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FOREWORD

India is experiencing rapid urbanization, and consequently water demand in urban areas is escalating rapidly. Due to shortage of surface water sources in many urban areas, ground water is now increasingly tapped for water supplies. As a result there is a lot of pressure on underlying aquifers to fulfill the domestic water demand. Besides availability, chemical and bacteriological quality of ground water is becoming a major issue due to increasing volume of human waste and industrial waste.

There are several cities in the country, where even 80-100 % of the drinking water demand is catered through tube wells, hand pumps, dug wells and springs, which basically draw water from aquifers. Consequently, ground water extraction is reaching unsustainable levels in many urban centres and emerging scenario is alarming. Unless effective management interventions are made, the forthcoming impact is likely to be grave for the urban water supply. The urban aquifers are to be properly assessed and tapped judiciously and be protected from contamination.

The imperative need is to have sound planning and strategies for managing, protecting and conserving the urban aquifer systems for sustainable extraction of ground water over a longer period.

Central Ground Water Board published a report on "Ground Water in Urban Environment of India" in year 2000. Since then, ground water regime, urban demography and water demand etc., have changed enormously. Hence, an update of urban ground water scenario has been compiled. The report is a compilation of ground water regime based on field studies carried out by CGWB in 28 major cities of Indian states.

This Report will form a scientific base for in-depth understanding of urban ground water system including aquifer geometry, water level behavior, ground water quality etc. Possibility of Artificial Recharge to rejuvenate the urban aquifers have also been discussed. I am confident that the Researchers, Engineers involved in urban water supply and policy makers will find the report very useful.

(Dr. S.C. Dhiman)

Faridabad
March 2011

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PREFACE

National Water Policy of India has given top priority to the drinking water among various other uses. Though, domestic water supply uses lesser quantity as compared to the overall water consumption in the country, its importance has risen in recent times particularly in case of urban water sector. The stress on urban water supply is likely to increase further to keep pace with the rapid urbanization.

There are a number of major, medium and small townships located in alluvial, hard rock and coastal terrain where community and private tubewell construction has boomed particularly in housing colonies, multi storied buildings and outskirt areas. There is continuous pumpage of urban ground water reserves.

Rigorous urban ground water monitoring is needed for tracking the water table depletion and deterioration in water quality on regular basis. Central Ground Water Board is monitoring the ground water in some of the major cities across the country through a network of observation wells. The water levels are monitored seasonally or monthly basis and water quality is tested annually. Based on the data generated from such monitoring and information obtained from the water supply establishments etc., an effort has been made to assess the ground water potential and its contribution in meeting out the urban water woes.

This report is specially brought out keeping in view the theme of World water day -2011 which is focused to the water for cities. The report elaborates the urban Ground Water Scenario emerging from the studies carried out by Central Ground Water Board in most of the major cities of India. This report has been prepared by the team consisting of Smt Anita Gupta, Dr. D.Saha, Dr. S.K.Jain, Sh. P.K.Das, Sh. A.K. Agarwal and Sh. Y.B.Kaushik. The untiring work of Dr. S.Shekhar assisted by Sh. Ritesh Bhatia has brought the report into proper shape. The individual cities have been written by the authors with the input of field scientists of all the regional offices of the Board.

I wish that the report will be very useful in management of urban Ground Water Resources.

Faridabad
March 2011

(Subrata Kunar)

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Ground Water Scenario in Major cities of India

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Background

Background

Rapid growth of urban population has been the character of Indian urbanisation. The urban population in the country has increased more than 8 times, since the turn of the century, and around 3 fold since Independence. The level of urbanisation was 11-12% during the first three decades of this century. 17.3% of Indian population was living in urban areas in 1951 and that has risen to 25.7% in 1991. The urban population growth rate is significantly higher (3.1%) than the overall population growth rate (2%) the urban population is projected to be about 658 million by the year 2025. The reasons for rapid urban growth rate have been largely attributed to rural-urban migration in search of livelihood and extension of urban zone under master plan programme.

The rivers are the lifeline of the many cities and towns since time immemorial. One of the factors that determined the location of urban centres in earlier times was easy access to water sources, to meet the need for domestic and other purpose. However, in recent decades increasing population, neglect of the existing water harvesting and storage structures, obstructing the water supply channels by people and also by urban planners, due to ill planned urbanisation, have resulted in encroachment and dysfunction of natural drainage. Half a century ago, most of the rivers in India were biologically in good condition, amply met the water needs of the populations and also supported diverse fish and flora species (World Bank 1998: 8). Today, it would be difficult to find a single river in the plains of the country that would have potable water.

Ground water plays a very important role in meeting the water demand of Indian cities. There are three types of situations (i) where the entire water supply is met from surface water (ii) where the entire water supply is met from ground water (iii) where there is a mixed supply, a combination of both. The first option is no longer existent in absence of adequate and consistent supplies. The option of own source is gaining ground and this own source invariably taps ground water. Industries invariably have network of their own wells. Thus the ground water regime beneath cities is being adversely affected. Where there is a mixed supply, generally the core part of the city may have surface water supply and the extensions areas which came in later on depend on the ground water supply. This results in a ground water mound in the central part and a declining trend in the peripheries. In case of the third situation, extraction creates a ground water trough below the city. Besides this, the ever increasing sewerage and industrial waste are polluting the fresh ground water. Various options for sustainable water supply in urban India are augmentation of water supply through rainwater harvesting, conservation and groundwater recharge. This supported by ground water regulation would enable overall improvement of water resources in the cities. In addition there is need for demand management, which the urban policy makers have to emphasise. Though there are novel efforts of the government agencies, what is equally important is innovative measures promoted by private and individuals in cities to augment water supply. The urban centres have to learn from the successful experiences demonstrated by government and NGOs to augment water supply. A decentralised approach, where co-ordination among the state, private sector and civil society, is needed for evolving better water supply options in urban India.

There is also substantial potential for demand side management options. Unaccounted water in urban areas exceeds 50% which if saved can substantially meet the justified water demand. Conservation, which is less expensive and more environmentally sound than new investment, would minimise the future capital requirements. Water conservation can be achieved through more effective maintenance mechanisms, which can help to overcome the problems of pilferage and leakage. Demand management can be achieved through financial incentives and technological interventions.

As per the National Water Policy, drinking water was given the first priority. Accordingly, Central Ground Water Board also started giving greater emphasis to drinking water and in course of time realising the growing demand of the urban sector, studies have been initiated in some of the major cities of the country. This report is a consolidation of the urban studies carried out by the Central Ground Water Board and the contents are very pertinent to the theme "Water for Cities-Responding to the Urban Challenge" of World Water Day 2011. The cities are alphabetically arranged in the report. They cover varying ground water scenarios in the country including the highly developed Metros, the hilly region, the coastal cities, the cities taping unconsolidated and hard rock aquifers etc. The report briefly describes administrative setup, status of water supply and demand, ground water scenario, feasibility of rain water harvesting, ground water development strategy etc. along with maps.

AGARTALA CITY, TRIPURA

G.R.C. Reddy, B.U. Rao, CGWB, Agartala

INTRODUCTION

Agartala is the capital city of Tripura state. The ancient capital of the princely state "Swadhin Tripura" was shifted from Udaipur to Agartala in 1760 by Maharaja Krishna Kishore Manikya of Manikya dynasty. During the British rule Agartala was the capital of Hill Tippera. It became a municipality in 1871 with an area of 7.20 sq km with 875 persons and the city became a planned city during the reign of Maharaja Bir Bikram Manikya Bahadur in 1940's. This erstwhile princely State Capital of Tripura merged with India on 15th October 1949. It is connected by road, rail and air with the other parts of the state and with the rest of the country. The city has been an important border trading town with trading linkages with Bangladesh.

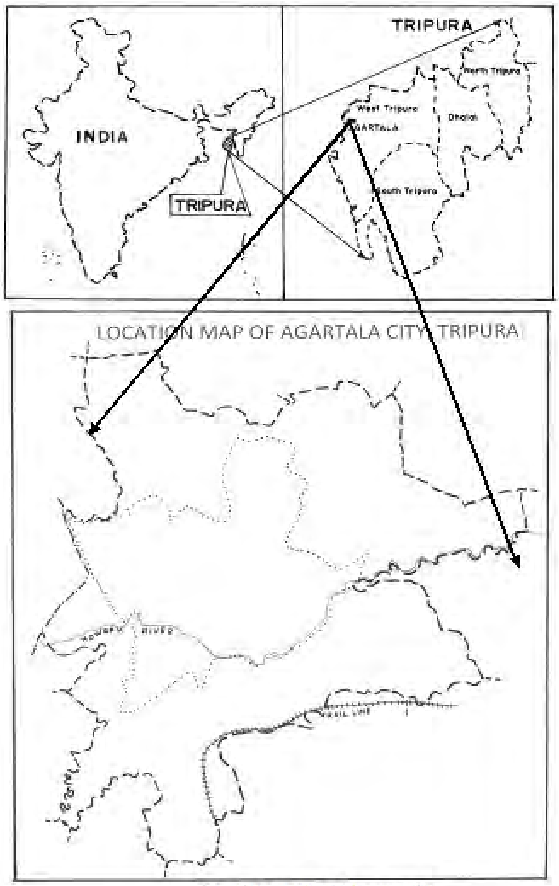


Fig-1 Location Map of Agartala City

GENERAL FEATURES

Area/ Administrative Divisions

The area of the city increased from 7.20 sq km to presently 62.60 sq.km (2004). The city lies between north latitude $23^0 49'15''$& $23^0 53'30''$ and east longitude $91^0 14'30''$ & $91^0 19'15''$ and falls in the Survey of India toposheet no. 79 M/1 and M/5. It lies on the banks of the Haora River. The city has international boundary with Bangladesh in the west of 6.5 km. The city is divided in to 35 words and the administration is looked after by Agartala Municipal Council (AMC) headed by Chairman. The location map of Agartala city is shown in Fig.1.

Demography

The population of Agartala Municipality increased 29.6 times from 1901 to 2001 i.e. from 6415 persons to 189998 persons (2001, Census of India). The population increased from 6415 (1901), to 6831(1911), 7743 (1921), 9580 (1931), 17693 (1941), 42595 (1951), 54878 (1961), 100264 (1971) 132186 (1981), 157636 (1991) and to 189998 (2001). As per 2001 census, there are 44,167 households literates constitute 92% of the total population, the SC's and ST's constitute 11.67% and 8.2% respectively. The density of population of Agartala city was 802 per sq.km in 1901 which increased to 11,866 per sq.km in 2001. The projected population has been worked out as 3,88,335 by 2011. The increase in population and its area over time is given in Fig.2.

Hydrometeorology

The Climate of Agartala city is characterized by humid to sub-tropical climate i.e., moderate temperature and high humidity. The highest mean maximum temperature recorded is 35^{o}C (April) and lowest mean minimum temperature recorded is 10.4^{o}C (January).

The average annual rainfall is around 2200 mm and the average number of rainy days is 100. The area receives rain fall mainly from SW monsoon, which commences in the month of May and lasts till September. The rainfall pattern during the last 40 years indicates falling long term trend at the rate of 19.4 mm per year.

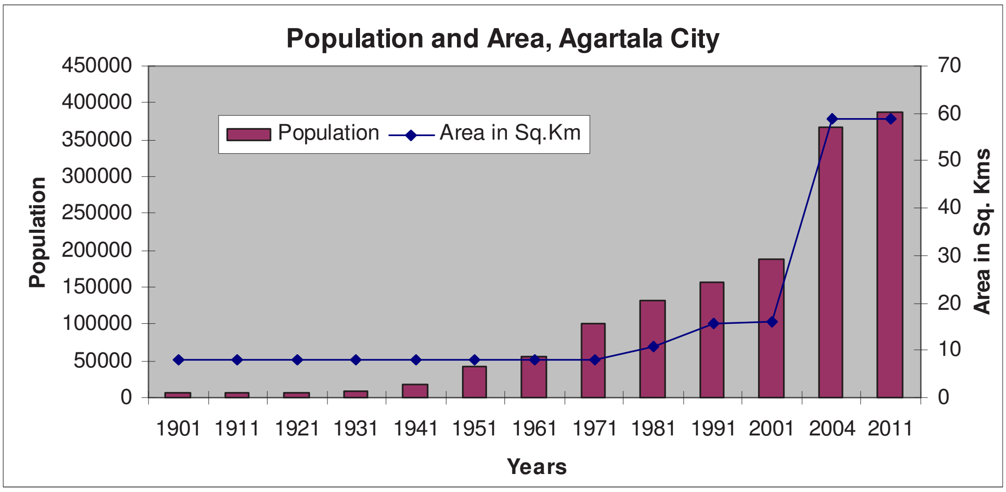


Fig.2. Population and area of Agartala city from1901 to 2011

Physiography and Drainage

Agartala city shows undulating plains with low lying flat topped mounds with narrow to wide valleys. Central portion of Agartala municipal area is more or less flat. The main city part is at a lower level than its peripheral parts which gives saucer shaped appearance. The average topographic elevation of Agartala is 12 m amsl.

The city is drained by two rivers viz. Haora and Katakhal. The Haora River lies on south of Agartala and Katakhal River is on the north. A few streamlets/ cherras are distributed all over the greater Agartala e.g. Bangeswar cherra, Nagi cherra, Kalapania cherra etc. The streams are of 1st and 2nd order and shows sub parallel to parallel drainage pattern. The drainage system of the area is controlled by topography, local and regional structures.

Soil types

Broadly two types of soils are present in Agartala. They are Alluvial soils and Red sandy lateritic soils. The alluvial soi is found in the entire municipal area and along the river courses. The Red sandy Lateritic soil is found in the northern and southern parts of the city.

STATUS OF WATER SUPPLY AND DEMAND

At present the total population within AMC area is 3,88,355 persons and considering 135 lpcd the water demand works out to be 52.42 MLD. With addition of wastage of 10% (5242522 litres) the total demand works out to 57.67 MLD.

To meet this demand there are two surface water treatment plants one at college tilla and the other at Milansangha with a total production capacity of 31.78 MLD. There are 60 no's deep tube wells supplying 28.18 MLD and the total supply is 59.96 MLD. There are 16 no's of elevated storage reservoirs, 4 no's ground storage reservoirs and 477 km length of pipe lines to supply water to residents. In all there are 26,368 water connections in the city to supply water.

The Asian development Bank has sanctioned project of Rs. 292 crores for drinking water supply in Central and North Zone of Agartala Municipal Council, which shall include construction of infiltration galleries at college tilla, augmentation of treatment capacity, rehabilitation of 25 deep tube wells and drilling of 9 new ones, rehabilitation of 17 iron removal plants and creation of 8 new ones, 7 ground water treatment plants, 17.5 ML capacity water reservoirs, 67 km primary pump mains, 140 km secondary pipeline and metered connections to 70,000 houses.

WATER PROFILE

Both surface and ground water play key role in meeting the water demand of the city almost equally. The two surface water treatment plants located on the perennial Haora river suppling 31.78 MLD. There are 60 no's of deep tube wells located throughout the city supplies 28.18 MLD. Hence, both surface and ground water equally meets the water demand of the city. However, ground water is rich in iron concentration up to 12 ppm, which were passed through 26 no's of iron removal plants to bring to make it potable before suppling.

GROUND WATER SCENARIO

Agartala city is underlain by a succession of argillaceous and arenaceous sedimentary rocks, ranging in age from Mid-Tertiary to Recent. The geological succession of the city is given in Table.1.

Table 1 Geological succession of Agartala city

Era	Epoch	Lithology
Quaternary	Recent	Unconsolidated silt, sand and clay found along the river course.
Unconformity		
Tertiary	Dupitila	Unconsolidated to semi-consolidated sediments. (Clayey sandstone with few bands of ferruginous concretions and purple to dirty white silty clay). Thickness of this group is 10-30m and occurs in synclinal troughs.
	Unconformity	
	Tipam	Sandstone of various grades and intercalated with clays, brown to grey with ferruginous concretions Occur in the hill slopes and foothills. Thickness over 2000m.
	Unconformity	
	Surma	Mainly argillaceous material with fine sandstone, grey in colour & occur in the core of anticlines.

Alluvium of recent age made up of faint yellow, fine grained sand, light yellow silt and grey to dark grey clay is found in the valleys and river courses.

Dupitila formation composed mainly of clay and silt, with some thin layers of coarse grained to gritty ferruginous sandstone. These sandstone form the near-surface aquifer, within 10-30 m bgl, and are generally tapped by dug wells. Due to predominance of clay, the permeability and the storage capacity of the formation are very low. Ground water in this formation occurs in unconfined condition. Dupitila group is well developed in synclinal valleys and exposed in disconnected mounds.

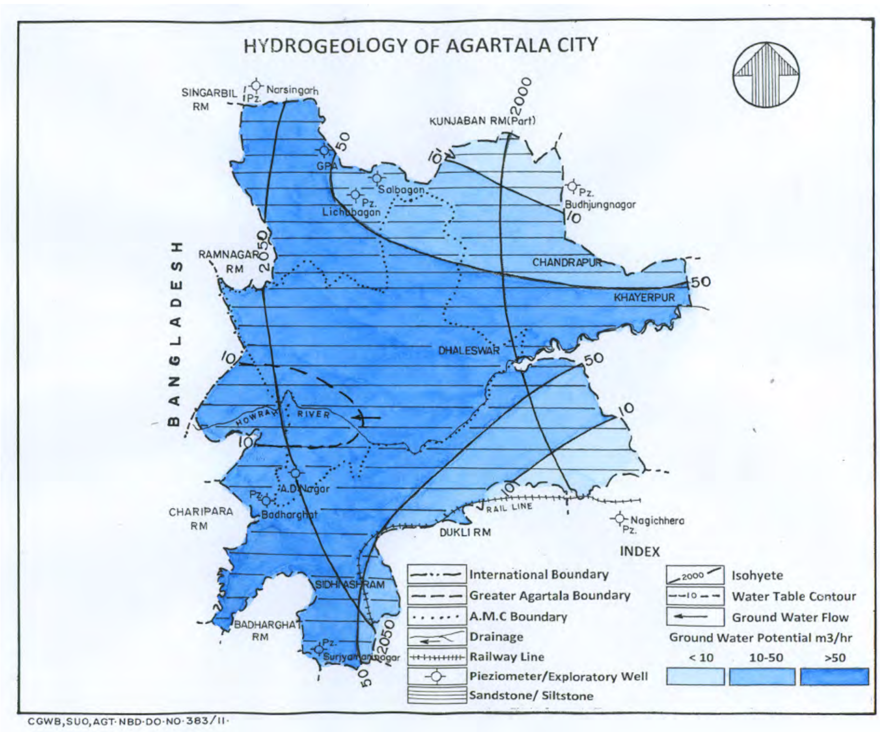


Fig.3 Hydrogeology of Agartala City

The semi-consolidated Tipam group of Upper Tertiary age form the main hydrogeological unit. However, small depositions of alluvial formation also constitute local hydrogeological units along river courses but not very important from the viewpoint of ground water development.

Potential Aquifers

Under Ground water exploration, the CGWB has constructed 4 exploratory wells at G.P.A., Salbagan (2 wells) and A.D Nagar. The Board also constructed 12 peizometers (Deep and Shallow) at six places.

Based on the lithological logs, fence diagram for greater Agartala area was prepared (Fig.4). It reveals that a thick granular zones occur between 20-196 m bgl and is intercalated with sandstone mixed with claystone/ shale. Occurrence and thickness of the granular zone varies vertically as well as laterally. The granular zone consists mainly of fine grained sandstone and grain size comparatively increases with increase in depth

Tipam sandstone is mainly composed of fine to medium grained sandstone, which are semi-consolidated and friable in nature, with alternate layers of clay/shale. These sandstone form the principal and productive aquifers. Ground water occurs under semi-confined to confined conditions.

The aquifer systems in and around Agartala can be divided into two major categories viz.

1) Shallow aquifers within 50 m bgl
2) Deeper aquifers between 50 m to 200 m bgl

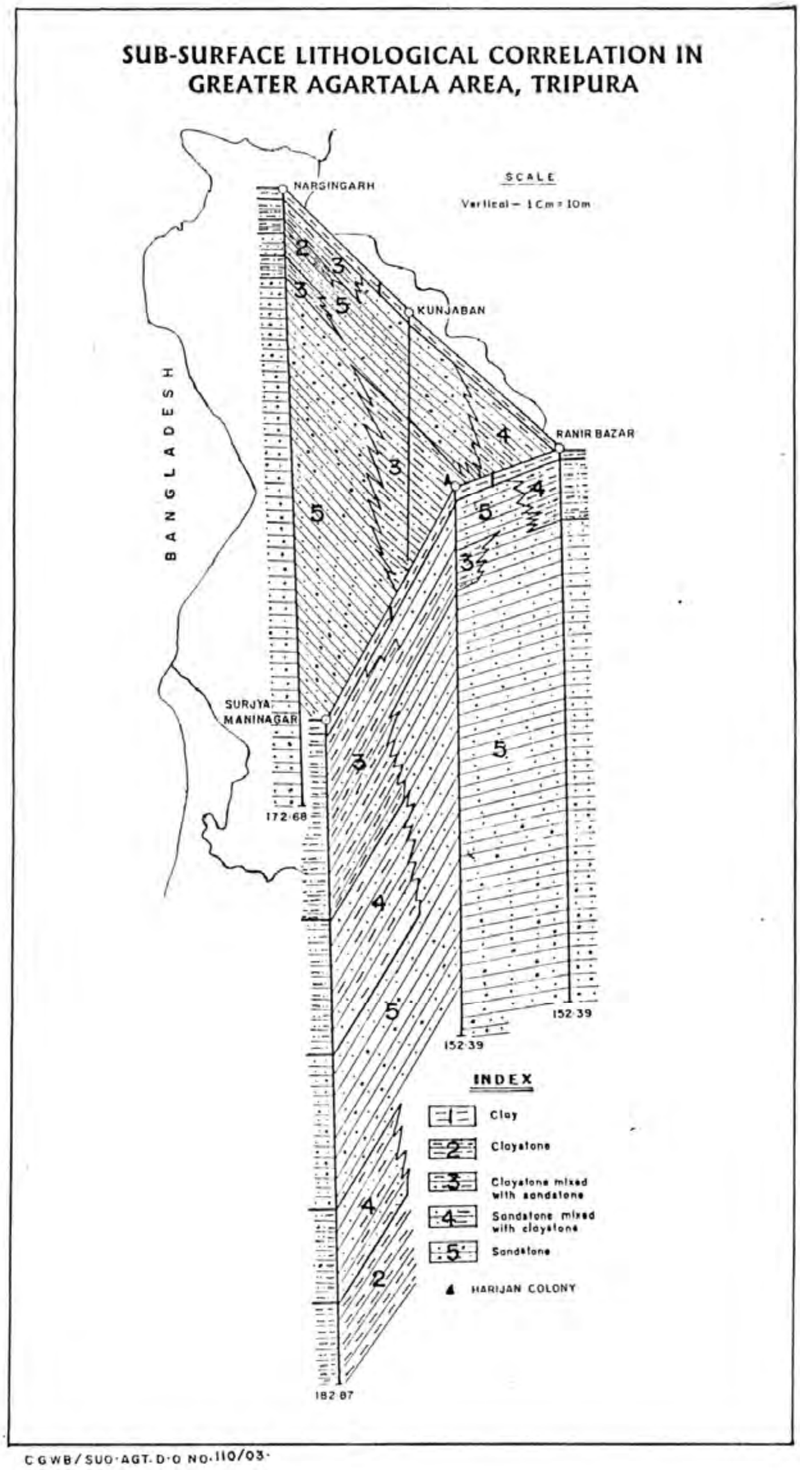


Fig.4 Fence Diagram Showing Sub-Surface Lithology

Shallow Aquifer : Shallow Aquifer occurs in Alluvial and Dupitila sediments and is tapped mainly through dug wells and shallow tube wells. Ground water occurs under unconfined to semi-confined conditions.

Deeper Aquifers : Deeper aquifers consists of semi-consolidated, friable, and fine to medium grained sandstones of Tipam group and form the principal and productive aquifer. The ground water occurs under semi-confined to confined condition. Tube wells having depth more than 40 m bgl are extracting water from these aquifers. A thick granular zone occurs between 40-196 m bgl with intercalating claystone /shale. 4 of

EW's and 12 Pz's drilled upto the depth of 226 m bgl have shown that the cumulative thickness of aquifers ranges from 24 to 54 m. In general the aquifers are capable of yielding 29 to 165 m^3/hr, for a maximum drawdown of 17.5 m. However, the yields at Nagicherra and Bodhjungnagar are low. The transmissivity of the aquifer varies from 933 to 6859 m^2/day, and the permeability as 22.76 to 135 m/day.

Ground Water Levels

The depth to water levels in the phreatic aquifers ranges from < 1 m bgl to > 5 m bgl. The pieziometric heads in the deeper zones varied from 3.73 to 23.45 m bgl during March 2010, and from 2.06 to 22.10 m bgl during November 2010. In general ground water movement is in west - north westerly direction.

Ground Water Resource & Status of Development

The ground water resource as per GEC 97 worked out to be 781.75 ham and ground water draft as 443.7 ham. Ground water resources available for future development worked out to be 338.05 ham. The stage of ground water development is 56.7% and the area falls under safe category.

Hydrochemistry

Ground water is neutral to alkaline with pH ranging from 6.9 to 8. Electrical conductivity (EC) ranges from 70 to 230 µs/cm. Total Hardness varies from 50 to 100 mg/l. Calcium (Ca) is the most abundant cation with concentrations ranging from 31 to 84 mg/l, Sodium (Na) concentration is varying from 5 to 18 mg/l, and Magnesium (Mg) concentration varying from 0.8 to 7.3 mg/. Among anions Bicarbonate is the most abundant. Its' concentration ranges from 20 to 150 mg/l. Concentration of Chloride (Cl) ranges from 10 to 25 mg/l. The relative abundance of cations is $Ca^{2+} > Na^{+} > Mg^{2+} > K^{+}$, while that of anions is $HCO_3^{-} > Cl^{-} > SO_4^{2-} > NO_3^{-}$. Most of the constituents are within desirable/ permissible limit.

High Concentration of Iron in Ground Water : The concentration of iron is beyond permissible limit (1 mg/l) in major part of the area. The Iron concentration in groundwater ranges from 0.1 to 12.38 mg/l. Ground water is potable only after treating for iron. Higher concentration of iron > 5 mg/l are observed in the northern and southern parts. Whereas, in the central part the concentration of iron is <5 mg/l. The iron concentration along the Haora River is less than 3 mg/l. The concentration of iron in shallow aquifer is lesser than that of deeper aquifers.

Major Ground Water Related Problems

The major ground water related problems in the city are high concentration of iron in the ground water, deterioration of ground water quality due to mixing of sewerage water through unlined open drains, increase in ground water dependency due to non-supply of surface water throughout the city, and reduction in ground water recharge in the core areas due to roads and building.

Feasibility of Rainwater Harvesting and Artificial Recharge

A large number of water bodies covering 266.25 ha area already exists in the city and are recharging the aquifer system. The depth to water levels in the central part of the city is less than 2 m bgl. This is due to the fact that the central part is low lying area and the urban demand is mostly met through surface water supply schemes. In surrounding areas the depth to water levels ranges from 2-5 m bgl. This is due to the utilization of both surface and ground water for the domestic needs. The northern and southern part of the greater Agartala Urban Area, which is recently included in the AMC is wholly depended on the ground water source, and the depth to water levels are more than 5 m bgl. Since the water levels are more than 5 m bgl and area is fully depended on ground water resources the rain water harvesting and artificial recharge of ground water schemes may be taken up as pilot projects.

GROUND WATER DEVELOPMENT STRATEGY

The Agartala city is located on the banks of perennial river Haora. At present the river water is not fully utilized. During rainy season much of the water flows to the Bangladesh. If a surface water reservoir is constructed on the upstream side of the Agartala city it will not only enhance the water supply to the city including summer requirements but also improves the ground water levels in the area.

A. In the central part of the city the water levels are less than 2 m bgl. Deep tube wells can be constructed in the central part of the city tapping the deeper aquifer and utilised along with the surface water. To utilise the available ground water resources, additional deep tube wells tapping the deeper aquifers with a spacing of about 500m can be constructed after inventorying the existing wells throughout the city and the water can be utilised after treatment for iron and other chemical parameters exceeding the permissible limit.

B. At present the unaccounted surface water supply is around 35% of the total demand. This is due to severely deteriorated water supply distribution system particularly in the older parts of the city. By reducing the transmission and distribution losses through efficiency in operation and maintenance, replacement of old machinery and network systems etc, water service delivery can be improved. This will also help in reducing recharge of phreatic aquifer where depth to ground water level is shallow.

C. Huge campaigns should be made every year by Government and NGO’s for increase in awareness of people about water conservation.

D. At present an area of 266.25 ha area exists under water bodies in the city and recharging the ground water. The depth to water levels in most of the area is less than 5 m bgl, hence the scope of artificial recharge to ground water is at present very limited. However, area specific pilot project of rainwater harvesting and artificial recharge of ground water should be taken up in those areas where water level is deep. The data generated from the pilot project will help in replicating the project in other areas in the state in future.

AHMEDABAD – GANDHINAGAR TWIN CITY, GUJARAT

P.R.Gupte, CGWB, Ahmedabad

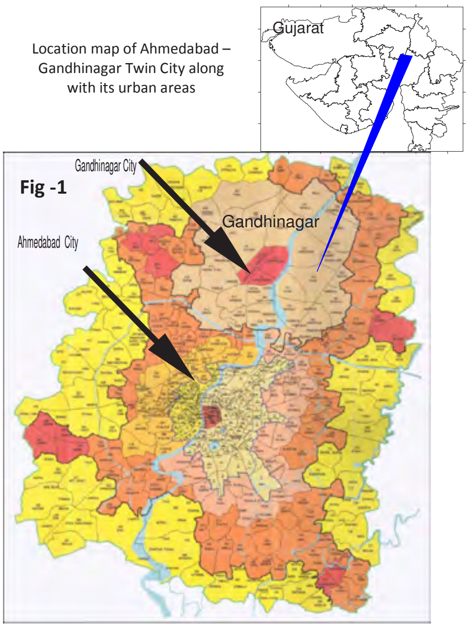
INTRODUCTION

The city of Ahmedabad was founded in 1411 AD as a walled city on the eastern bank of the river Sabarmati, now the seventh largest metropolis in India and the largest in the state. Gandhinagar city came into existence as new capital city of Gujarat State in year 1960. Historically Ahmedabad has been one of the most important centres of trade and commerce in western India. The city was once famous as the 'Manchester of India' on account of its textile industry. It is also a major industrial and financial city and home of several scientific and educational institutions of national, regional and global importance. The city has a great architectural tradition reflected in many exquisite monuments, temples and modern buildings. Gandhinagar is also emerging as rapidly developing urban centre.

GENERAL FEATURES

Area & Administrative Divisions

Location map of Ahmedabad – Gandhinagar Twin City along with its urban areas

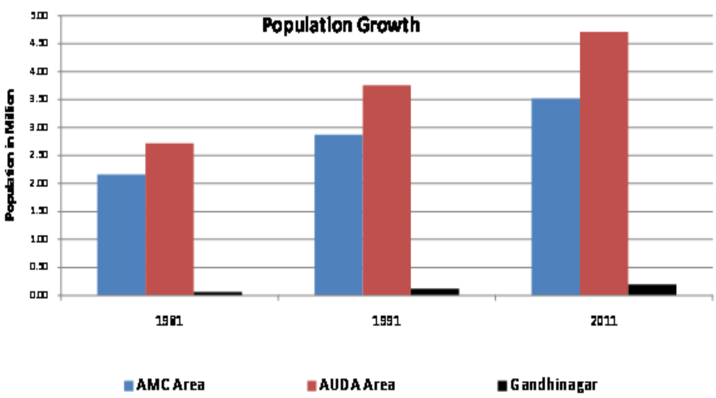


Ahmedabad is situated on both sides of river Sabarmati. It lies between 22°55' & 23°08' North latitude and 72°30' & 72°42' East longitudes where as new capital city, Gandhinagar is at 30 km north of Ahmedabad, on right bank of Sabarmati River, situated between 23°05' and 23°22' North latitude and 72°31' to 72°49' East longitude. The areas around Ahmedabad and Gandhinagar city are rapidly developing and became one of the largest urban agglomerate known as "Greater Ahmedabad". Out of its nearly 4200 sq km area, Ahmedabad Municipal Corporation (AMC) areas is 190.84 sq km, 1200 sq km is under Ahmedabad Urban Development Authority (AUDA), 57 sq. km is under Gandhinagar Notified Area (GNA) as Gandhinagar city and rest is of Chatral, Bopal and 9 other Municipalities and other 150 semi urban / urban villages as Urban Agglomerates (UA) falls in Dascroi taluka and Gandhinagar taluka. (Location Map - Fig -1).

Demography

There is rapid growth of population in the Ahmedabad Gandhinagar urban areas during last three decades (Fig. 2). The population in AMC area in 1981 was 21.5 Lakh which became 35.2 lakh in 2001, Same way the population of AUDA area also increased from 27.2 lakh in 1981 to 47.0 lakh in 2001. The population within the AMC limits appears to approach a stabilization level. The areas adjoining AMC, falling within AUDA limits have shown rapid growth. Gandhinagar is also experiencing relatively high rate of growth 40 % and population of 1.95 lakh persons as per census of 2001.

Fig. -2



Hydrometeorology

Ahmedabad – Gandhinagar area has a tropical monsoon climate, which is hot and dry, except in the rainy season. Summer days are very hot with mean maximum temperature of 41.30C while, nights are pleasant with mean minimum temperature of 26.30C. The mean maximum and minimum temperatures in winter are 30°C and 15.4°C respectively. The average annual rainfall of the area is 782 mm, although there is a considerable variation from year to year. It occurs generally during the months of June to September. The average relative humidity is 60% with a maximum of 80% to 90% during the rainy season.

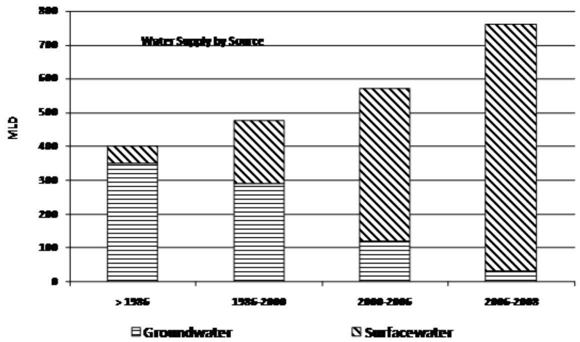
Physiography & Drainage

The area as a whole, in general monotonously flat except few mildly undulating topography owing to the presence of stabilized dunal land forms. The elevation of land surface ranges from 40 to 60m AMSL with master slope towards south. The average elevation of the city area is about 48m AMSL. Isolated high grounds, with elevations more than 60m AMSL, are observed on both sides of river Sabarmati. The most important surface water body in the Ahmedabad Gandhinagar area is the river Sabarmati. The Khari river runs almost parallel to the Sabarmati towards east, beyond the city limits. One of the oldest irrigation schemes of Gujarat 'Kharicut canal scheme' passes through eastern part of Ahmedabad City, which also serve as 'Storm Water Drainage' during monsoon. The Kankaria and the Chandola are two important ponds in the Ahmedabad city area. Under ambitious 'National Lake Conservation Plan', AMC and AUDA have taken up project to interlink 45 surface bodies (ponds & lakes) and recharge it with storm water and surplus surface water of Narmada Canal.

Soil Type

The area is mostly underlain by blown sand and silt deposits of aeolian character, except localized pockets where it is fluvial. The soil is therefore either coarse sandy or fine sandy loam, with less clay content and has good to excellent drainability. The soils in the entire area are deep to very deep, with soil depths more than 100 cm.

Fig -3



STATUS OF WATER SUPPLY AND DEMAND

In decades of 1970-80, water requirement of Ahmedabad urban area was totally met through series of deep tube wells spread in entire city areas. During decades of 1980-90, (fig.3) to supplement groundwater resources, surface water supply from Dharoi reservoirs was planned with construction of riverbed intake wells. With increasing agriculture demand in upstream reach of Sabarmati river and also due to diminishing base flow in Sabarmati river, project could not be succeeded to lessen stress on groundwater resources. As per water supply data of AMC, before 1986, out of total 400 mld water supplied, contribution from groundwater resources was 350 mld (88 %). With implementation of various surface water sources projects at present, out of total 760 mld water supply, only 30 mld (4 %) is from ground water resources (AUDA 2008). The water demand is increasing with rise in population. AMC has projected that by year 2031 projected population of 1,01,44,000 persons would require around 1623 MLD from present 760 MLD in AMC area. Same way, water requirement of Gandhinagar Urban area is mainly meeting through surface water resources as groundwater levels are rapidly declining and deep water has high TDS, making it unsuitable for drinking uses. Preset and projected water demand of Ahmedabad – Gandhinagar urban area is given in Table 1a & 1b.

Table -1 a - Present Water Supply & Projected Demand – Ahmedabad Urban Area

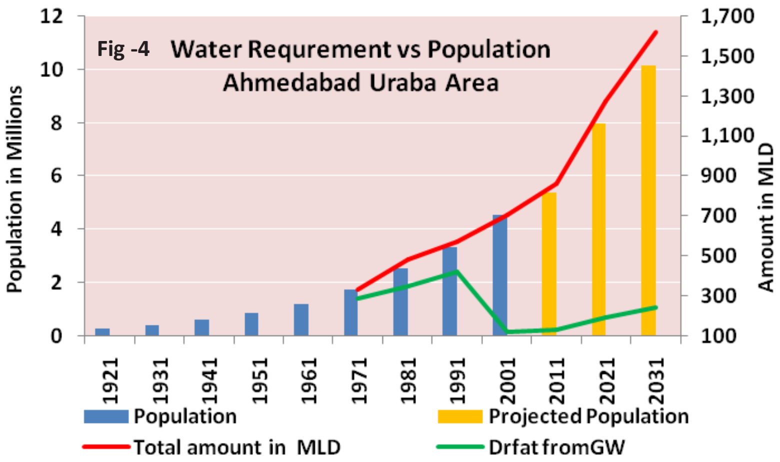
Year	1991	2001	Projection		
			2011	2021	2023
Population in lakh	33.00	44.27	53.99	79.58	101.44
Water Requirements in mld @ 160 LPCD	528	706	863	1273	1623

Table – 1 b - Present Water Supply & Projected Demand – Gandhinagar Urban Area

Year	1999	2001	Projection
			2025
Population in lakh	1.90	2.00	4.25
Water Requirements in mld @ 250 LPCD in 1999 & @ 270 in 2001 & 2025	45	50	120

WATER PROFILE

State has created huge surface water potential in Narmada Canal Networks, large part of urban areas, mainly in Urban Agglomerate (UA), outside Ahmedabad Municipal and Gandhinagar Capital city area which are equally urbanised and have high demand of water resources, depends on local groundwater sources. At present, most of the groundwater development is mainly through private tube wells. It is observed that UA is rapidly developing & with rising population its demand on groundwater resources is increasing tremendously and still there is large gap between supply and demand. Although, there is huge potential of surface water resources, lack of piped supply network in all developing urban areas is creating tremendous pressure on existing groundwater resources. The rapid developments during last four decades in Ahmedabad urban areas have created tremendous stress on its natural environs. Increasing groundwater draft to cater the domestic and industrial requirements has rendered most of the unconfined aquifer zone dry. At places, groundwater is brackish at shallow depth. With increasing urbanization process, groundwater pollution also rendered some of the shallow aquifer unsuitable for domestic need. All such development resulted in exploitation of deep confined aquifers, which in turn has led to sharp decline in piezometric level below 60 to 80 m at places. Projected overall water demand and availability through ground water resources, for Ahmedabad Urban Area, (Fig - 4) indicate that there is urgent need to conserve recharge groundwater resources for sustainable development.



GROUNDWATER SCENARIO

Geologically, the Ahmedabad -Gandhinagar urban area forms a part of the Cambay Basin. The thickness of multilayered Quaternary alluvium system in Ahmedabad – Gandhinagar urban area is around 300 to 600m, which is underlain by Tertiary sediments. The unconsolidated Quaternary formation consists mainly of alternate layers of sand, silt gravels and intermixed *kankars* etc granular materials and yellow to gray colored sticky clay (Table 2).

Table -2 – Geological sequence of Cambay Basin

Age	Lithology	Thickness
Quaternary (Holocene – Pleistocene)	Alluvium	Maximum 700 m ; 400 - 600 m around A`bad –G`Nagar
Tertiary (Miocene)	Sandstone and Shale	Maximum 900 m. 200-300 m near margin of the basin
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(Oligocene)	Sandstones, shale and limestone	Maximum 160 m
(Eocene)	Shale and siltstone with sandstone and limestone intercalation	About 100 m thick in the centre and thinning towards east and west margin
Mesozoic (Cretaceous)	Deccan Trap	
	-- - - - - - - - - - - - -- - -Unconformity - - - -	- - -- - -- - - - - - - - - - - -
	Bagh Beds	

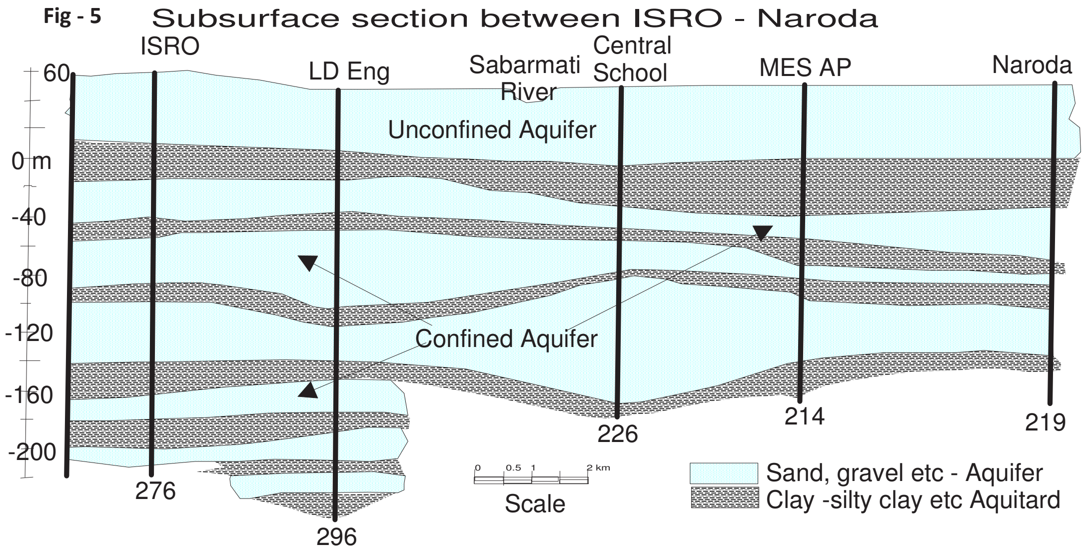
Geomorphologically they represent two types of landforms, i.e. fluvial and aeolian of Quaternary period. The fluvial landforms consist terrace deposit, abandoned channels, cut-off meanders and swampy lands while aeolian landform consist dunes, inter dunes and sandy flats etc, of geological past in Quaternary period. Accordingly, depositional variations due to sea level changes, lateral shifting of river courses, soil formation and aeolian activities etc., were the active environmental agencies responsible for lateral and vertical variation of the lithological characters of Quaternary sediments. The sand horizons are prevalent at different depth levels and form aquifers. Spatial variation in groundwater quality and quantity may be attributed to intermixing / overlapping of various facies, forming aquifer system in the area.

Potential Aquifer

The study of lithological logs and geophysical log characteristic of boreholes drilled in Ahmedabad – Gandhinagar urban areas reveals thickness of various litho units of alternating argillaceous and arenaceous horizons with 'kankar' and gravel beds occurring at depths, exhibits typical multilayered aquifer system. Within 250 m depth of this multilayered aquifer system, two major aquifer units are identified. The sediments at shallow depths extending down to 40-50 m depth in general are uniform in character and composed of medium to fine sands, silt with kankar and minor clay lenses. This sandy-silty horizon is aeolian in character and akin to loess deposits. The sand: clay ratio in the boreholes ranges from 1:0.23 to 1:0.76. The groundwater in the upper unit, down to average 40 m depth, occurs mainly under phreatic conditions. The lower units comprising more than 250 m of alternating sandy and clayey horizons form multiple confined aquifer system. In general, three distinct confined aquifers with thickness varying from 12 to 30 m can be identified. These aquifers lie between 45 & 90 m, 100 & 170 m and 180 & 250+ m bgl separated by clays and sandy clays that form aquitard.

The subsurface aquifer disposition in Ahmedabad urban area, down to explored depth up to 300m, is very well established. One of such sections, showing phreatic and confined aquifer system as per nature of groundwater occurrence condition, is reproduced (Fig. 5).

Fig - 5



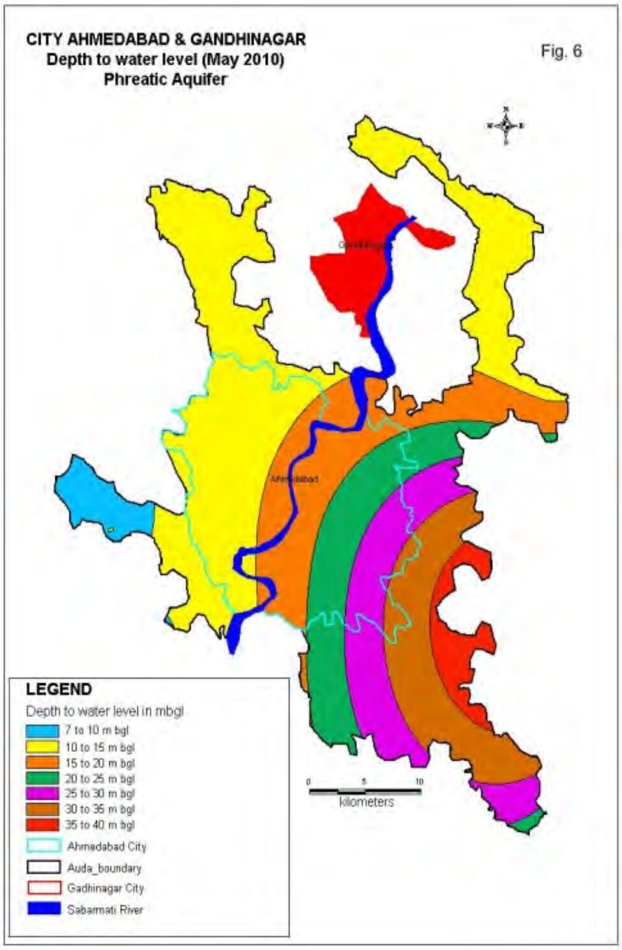
Deep boreholes have penetrated the thick sequence of post-Miocene sediments down to 300 m depth and these sediments continue further below. The Miocene (Tertiary) sediments and/or basement have not been touched within this depth. The marker blue/grey clays representing the Miocene formations, however, occur at shallow depths towards east in the adjoining Dehgam taluka of Ahmedabad district & also in adjoining Kheda, Sabarkantha districts.

Hydrogeological data analysis shows that the aquifer system in this area is regionally extensive and correlates with the aquifer system demarcated by CGWB in Central Gujarat plains (CGWB/UNDP-1978). The Phreatic aquifer and first confined to semi confined aquifer can be correlated with the aquifer "A", which is phreatic at top and becomes semi-confined to confined at lower levels in the central Gujarat plains. The second and third confined aquifers can be correlated with the aquifers "B" and "C" respectively. The sub surface geology and aquifer properties as per earlier studies (CGWB/UNDP,1976) is given in Table 3.

Table 3 : Regional aquifer system established as per CGWB / UNDP Work.

S.No	Aquifer Nomenclature	Lithological Characteristics	Depth range (m bgl)	Thickness (m)	Nature of aquifer
1	Aquifer A	Coarse sand, gravel, pebbles, medium and fine sand & Clay	0- 96.32	96.32	Phreatic & semi confined.
2	Aquitard I	Clay interbeded with sand and sandy clay	96.32-123.14	26.82	
3	Aquifer B	Medium to coarse sand and gravel interbeded with sandy clay	123.14-151.48	28.34	Confined
4	*Aquitard II*	Clay interbeded with sand and sandy clay	151.48-181.96	30.48	
5	Aquifer C	Fine to medium sand interbeded with clay, sandy clay	181.96-200.56	18.6	Confined
6	Aquitard III	Clay interbeded with sand and sandy clay.	200.56-232.86	32.3	
7	Aquifer D	Medium sand interbeded with sandy clay	232.86-278.89	46.03	Confined
8	Aquitard IV	Clay interbeded with sandy clay.	278.59-301.14	22.25	
9	Aquifer E	Fine to medium sand with sandy clay	301.14-317.60	16.46	Confined
10	Aquiclude V	Grey clay and clay stone.	317.60-465.73	148.13	
11	Aquifer F	Fine to medium sand, sand stone interbeded with silt stone	465.73-521.81	56.08	Confined
12	Aquiclude VI	Clay & Clay stone	521.81-546.2	24.39	
13	Aquifer G	Fine to medium sand interbeded with siltstone	546.2-572.41	26.21	Confined

Groundwater Level

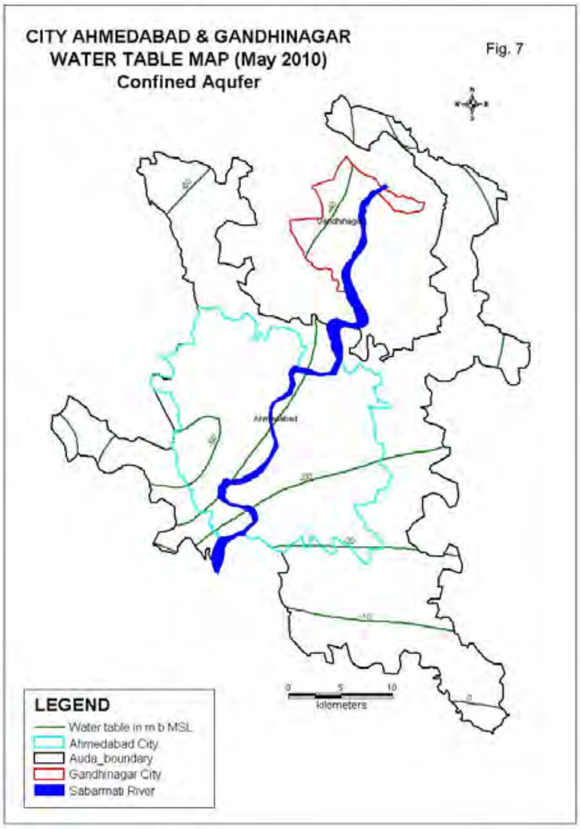


The shallow phreatic aquifer is a regionally extensive and extends down to 30 to 60 m depth (avg. 40m) was reported dried up due to large scale development few years backs , now shows water levels in many parts of Ahmedabad urban areas due to recharges activities and stoppage of groundwater pumping after introduction of Surface water sources based water supply. Based on the observation wells data and select wells monitored in and around the Ahmedabad city, it is observed that the depth to water level ranges between 7m and 40m bgl (Fig. 6) in phreatic aquifer. Water level increasing in depth from northwest to southeast direction. In Gandhinagar city phreatic aquifer is de-saturated and water level is hardly found between 35m and 40m bgl. It is also observed that seasonal fluctuation of water table, between pre-post monsoon periods, ranges from -0.25 to 3.72m in phreatic aquifer.

The aquifers occurring below 50-80 m bgl in the area are under semi-confined to confined conditions and as discussed three such aquifers lie approximately between 45 & 90m; 100 & 170m; 180 - 250+m and so on. Tube wells however screen all these aquifers and thus providing effective interconnection and therefore the information is cumulative of different aquifers tapped.

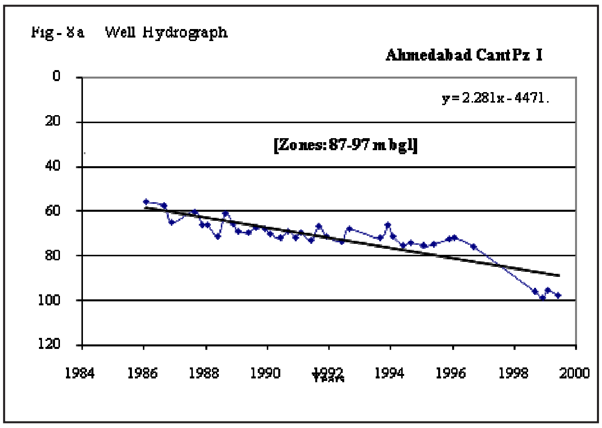
Table 4: Water levels in AMC Tube Wells			
Year	Water level in Tube Wells(m bgl)		
	Central Zone	Eastern Zone	Western Zone
1960	24.38	17.06	23.16
1965	41.45	31.69	40.23
1970	54.86	45.11	53.64
1975	67.05	54.86	64.61
1980	78.03	65.83	73.76
1985	86.56	75.59	83.51
1990	93.87	82.90	91.44
1995	99.97	90.22	96.31

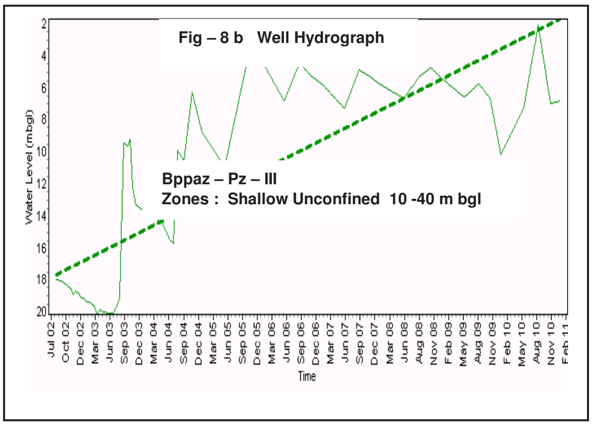
As per earlier reports, in late sixties the water levels in the tube wells ranged from 33.5 to 44.19 m bgl and reported declining trends ascribed to large concentration of tube wells & heavy draft in the Ahmedabad City. Uninterrupted large scale development of groundwater from deep aquifers has resulted in progressive decline in water levels. Presently, the water level rests more than 90 m bgl and as per average water level data given by AMC (White Paper, AMC, 1996), piezometric level ranged around 90 to 100 m bgl in most part of Ahmedabad urban area (Table 4).

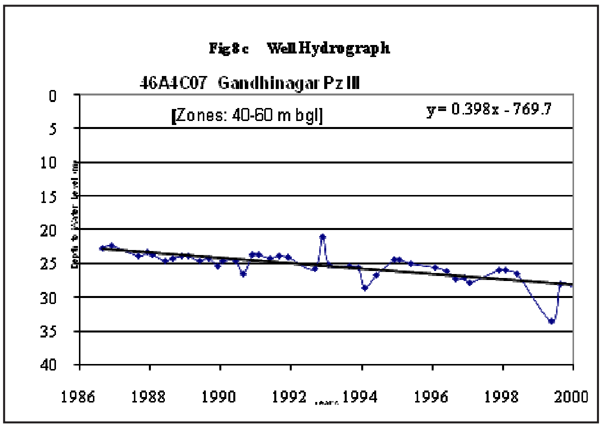


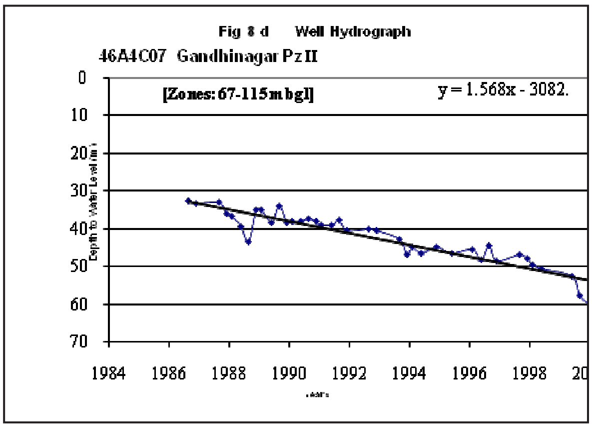
Water table in user confined aquifer ranges from 20 m below MSL to 50 m below MSL in Ahmedabad city and therefore the flow of ground water is towards northwest direction (Fig. 7). In Gandhinagar the water table is approximately 40 below MSL.

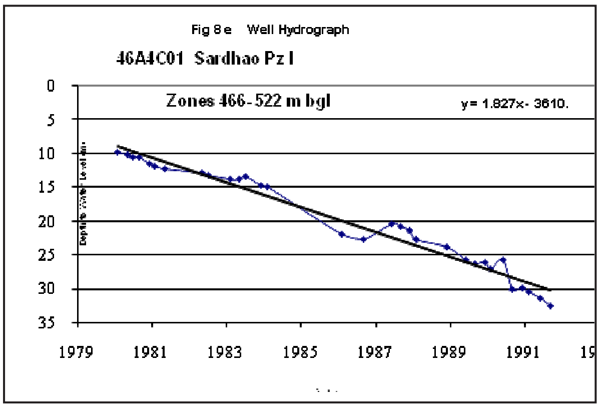
CGWB piezometers in Ahmedabad & Gandhinagar area shows continuous decline of deep water level since last two decades. Data for two piezometers, located at Cantonment, Ahmedabad area, from 1984 to 2000, for aquifer zones between 87 & 97 m reveals a consistent declining trend with rate of decline of about 2.8 m/yr where as Piezometer at Bhopal – 40 m, from 2002 to 2010 shows rise of 1.9 m/yr respectively (Fig 8a & 8b). The unconfined water level at Gandhinagar Pz III, tapping zones between 40 and 60 m bgl, has shown a decline of about 0.40 m/year between 1986 and 2000 (Fig 8c). The Pz II tapping zones between 67 and 115 m bgl show a decline of about 1.6 m/year. The water level data for deeper aquifers is available for piezometers at Sardhao. At Pz I (#466-522 m bgl), there has been a decline of 1.9 m/year and at Pz II (#257-387m bgl), the decline was 2.1 m/year (fig 8e & 8f). Deep aquifer zones at Kalol Pz –I, for period 1996 to 2010 shows decline of 1.84m / year (Fig –8g) while at Bopal, for period 2002 to 2010 shows rise of 0.53.m / year (Fig 8h).

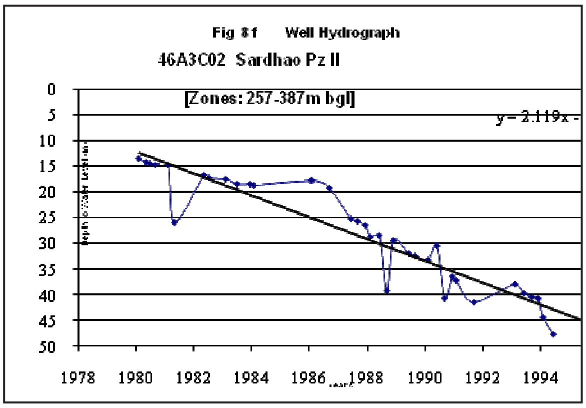


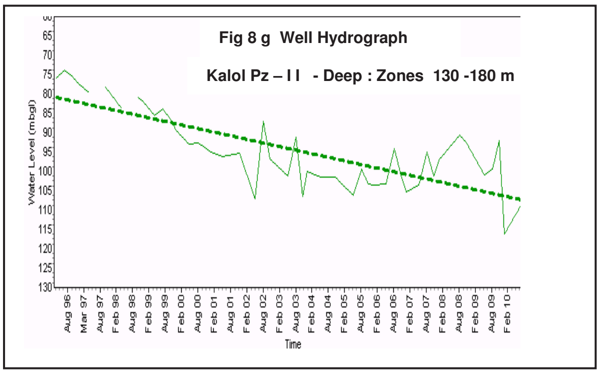


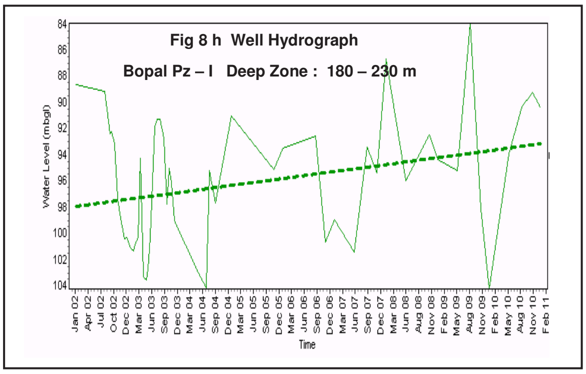












Ground Water Resources & Status of Development

Groundwater formed a dependable, most important source of water in Ahmedabad –Gandhinagar area till year 1980. Groundwater withdrawal in the area is mainly through large number of tube wells constructed by AMC & other public and private sector primarily for domestic water supply as well as for industrial use. In adjoining rural areas, groundwater is also being used extensively for irrigation both by shallow wells and tube wells. Earlier, groundwater recharge to shallow aquifer was taking place through infiltration from rainfall and seepage from river bed during the monsoon period. In changed scenario development of urban areas, however, there is now considerable reduced groundwater recharge due to paved surface area and other factors like rapid storm runoff through water drains, export of waste water collected by sanitary sewers coupled with high drawl of ground water. Groundwater recharge to sustain pumping from the deeper aquifer system mainly takes place from recharge area in the north east by lateral flow, vertical leakages from shallow aquifer and also reverse leakages from still deeper aquifers whose heads are higher than the aquifers under exploitations in the area as revealed by studies in adjoining parts of Gandhinagar, Mehsana districts. With overall development of groundwater resources in all over the State, mainly in Central Mainland Gujarat, groundwater draft has outpaced natural recharge component and same is reflected in groundwater resources computation.

Ahmedabad urban area is a part of part of Daskroi & City taluka and Gandhinagar urban area lies in Gandhinagar taluka. Ground water resources of both unit areas for year 2004 are tabulated below (Table -.5)

For Gandhinagar taluka, the Gross Groundwater Recharge and Utilisable Groundwater recharge for irrigation are 121.04 and 114.99 MCM/yr. respectively while the total groundwater draft is 160.98 MCM/yr. Thus, there is a negative balance of 49.79 MCM/yr. and level of groundwater development is 139.99%. Therefore, the groundwater in the area has been categorised as "Over Exploited". For Dacscroi & Ahmedabad city taluka, the utilisable groundwater resources are 142.56 MCM/yr. With a draft of 215.06 MCM/yr, there is a (negative) balance of -95.75.20 MCM/yr. The stage of development is 150.86 % and the talukas have been classified as "Over Exploited".

Table 5: Groundwater Resources (Year 2004)

S. No.	Groundwater Resource Component	Ahmedabad City and Daskroi Taluka	Gandhinagar Taluka
1.	Gross Groundwater Recharge (MCM/yr.)	150.06	121.04
2.	Allocation for Natural Discharge (MCM / year)	7.50	6.05
3.	Utilisable Groundwater Recharge (MCM/yr.) [80% of "1"]	142.56	114.99
4.	Total Groundwater Draft (MCM/yr.)	215.06	160.98
5.	Groundwater Balance (MCM/yr.)	-95.75	-49.79
6	Allocation for domestic & industrial used for next 25 years	70.91	10.15
7.	Level of Groundwater Development (%)	150.86	139.99
8.	Category	OE	OE

Hydrochemistry

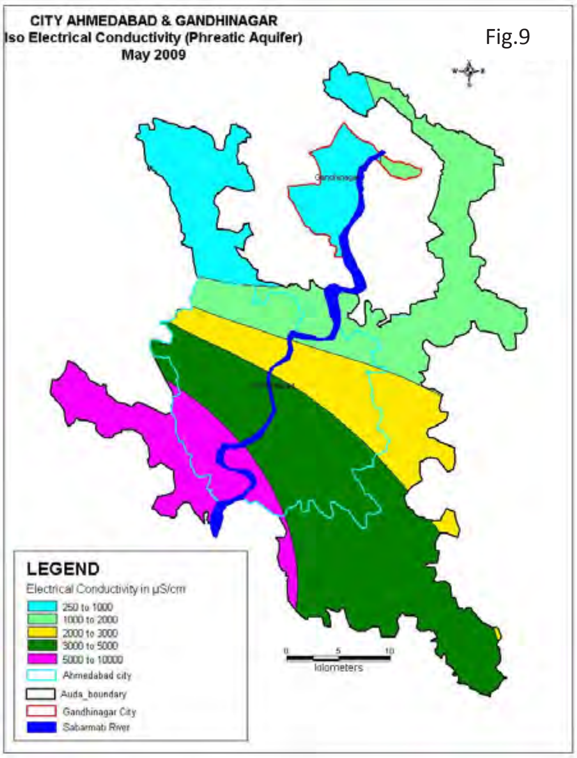


Fig.9

In urban area of Ahmedabad & Gandhinagar, groundwater at shallow depths shows wide variation in the chemical quality. In parts of Ahmedabad urban area, in general, groundwater quality is brackish with EC >3000 µS/cm in most of the area (Fig. 9). It is observed that in the area close to the Sabarmati river, in the central and northern parts, the groundwater quality is better with EC less than 3000 µS/cm where as it is brackish to saline (EC more than 3000 µS/cm) in rest of the area. High nitrate concentration (more than 100 ppm), indicating probable pollution of this aquifer, has been observed at a number of sampling points. High fluoride concentration (more than 1.5 ppm) has also been observed in localized areas. The quality of the groundwater in the deeper aquifers is generally fresh upto 250 m depth for which data is available. However, at places the brackish groundwater is also observed within this depth. In Gandhinagar area Electrical Conductivity (EC) of groundwater varies between 250 to 1000 µS/cm at 25°C in phreatic aquifer. The chloride value in groundwater ranges from 65 ppm to 250 ppm. Thus the groundwater quality in major part of the area is fresh except a small area in the south-western part of the area, around Sertha, is brackish to saline.

The range of different chemical constituents found in the deeper groundwater is given below (Table-6)

Major Groundwater Related Problem

Groundwater resources are depleting at alarming rate in major part of Ahmedabad – Gandhinagar urban areas, although most of the domestic and industrial requirement is meeting through Narmada based surface water resources. The AMC operates about 300 deep tube wells to augment city water supply. Abstraction from river bed aquifer by radial wells other 2000 no of private bore wells / tube wells owned by private housing societies, business houses, industries, cantonment area etc., create huge stress on already exploited deep aquifer system. Over the years, consistent fall in water levels (piezometric surface) and has affected the well yields and pumping costs. Lowering of aquifer potential heads seems to have created a regional groundwater trough in the central part.

Table 6 : Range of different chemical constituents in the deep aquifer

Parameters	Unit	Range
Ph	-	7.9 to 8.2
EC	µS / cm	1500 to 300
CO_3	ppm	Nil
HCO_3	ppm	200 to 787
Cl	ppm	284 to 709
NO_3	ppm	40 to 217
SO_4	ppm	149 to 470
Mg	ppm	10 to 112
Ca	ppm	12 to 86
Na	ppm	80 to 675
K	ppm	2.3 to 5.7
F	ppm	0.65 to 5.7
TH	ppm	80 to 675

Presently only one third of the sewage of the city is being partially treated. Part of the treated water is recycled and used for irrigation and industrial purposes and the excess quantity is discharged in the Sabarmati river. Remaining two thirds of untreated sewage is directly discharged in the Sabarmati which make downstream most vulnerable to groundwater pollution. Industrial effluent of eastern part of Ahmedabad urban area are either discharged in to the Kharicut canal, small nallas or spread over the topographic depressions. This has caused degradation of land in these areas and probably also effected the shallow groundwater.

The vulnerability of deeper aquifers for pollution, in general, is very low because of thick filtration media, i.e., vadose zone and aquitard-aquifer sequence. However, improper construction of wells particularly in private sector, lack of aquifer protection by cement seals and grouts and old abandoned wells can serve as conduits for direct vertical connection and thus aquifer pollution.

Feasibility of Rainwater Harvesting and Artificial Recharge

Large scale exploitation of groundwater resources during last two decades has created major portion of unconfined aquifer system dry, which has good scope to get recharge through suitable structures and sources.. Construction of storm water drainage system and connecting it to various ponds /lakes of the areas during last few years has rejuvenated unconfined system at places. Earlier groundwater recharge experiment by injection under pressure were carried out in the city in 1974 by State Govt in a deep tube well, under pressure varying between 80 to 100 psi and its results established feasibility of injecting nearly 3888 m3/day of water. In another artificial recharge using injection under gravity (By Siphon) technique was taken up by the State Govt. in collaboration with PRL, in 1977 near Hansol involving shallow dug well as source well and deep tube well of tapping aquifer below 75 m (tapping 80 m of granular zones) as target zones. In this experiment also, no clogging in injection well was observed after 220 hrs of recharge. It was estimated that, if the efficiency of injection well could be improved and the frictional losses minimised using PVC pipes for siphon, better recharge rates of up to 980 lpm could be achieved. This method was found more economical and cost, at the time of experiment was found to be 45 paisa per 1000 litres. These two pilot studies on artificial recharge carried out in the city of Ahmedabad have clearly established the technical feasibility of artificial recharge both by pressure injection and syphon transfer. Similarly the technical feasibility and economic viability of artificial recharge of groundwater, in North Gujarat alluvial plains, having similar hydrogeological condition like Ahmedabad –Gandhinagar area, has already been established by CGWB on the basis of pilot studies carried out under UNDP –CGWB project in 1986.

A pilot project for waste water renovation for unrestricted irrigation and groundwater recharge using Soil-Aquifer Treatment System Technique in the Sabarmati bed at Ahmedabad was conducted jointly by NEERI, PRL and AMC(1997). The project studies concluded that the SAT renovated effluent obtained from the pilot plant using the primary settled sewage conformed to the WHO bacteriological guidelines for unrestricted irrigation. Based on the findings, a conceptual design of a 55 MLD SAT system using primary settled domestic water was proposed for the city.

Recently, under 'National Lake Conservation Plan' few lakes in AUDA and AMC area have been renovated and connected through storm water drainage. It has shown good result and rise in ground water level and improvement in quality recorded in few monitoring wells. It is proposed that all the existing water bodies of urban areas of Ahmedabad – Gandhinagar would be renovated and provided with site suitable artificial recharge structure. Moreover, they would be inter linked with each other with storm water drainage, Narmada Canal and Sabarmati River for maximum recharge of monsoon runoff and additional surface water available in Narmada Canal.

GROUND WATER DEVELOPMENT STRATEGY

Groundwater development in and around Ahmedabad – Gandhinagar urban area has reached a critical stage and not much scope exists for further development. Groundwater level has gone down too much to extract groundwater economically even for domestic use. Moreover increasing urban population and industrial requirement create more stress, making situation more critical. There is deterioration in groundwater quality due to geogenic condition of deep aquifer system and also due to an unregulated industrial effluent and sewerage. In the prevailing urban scenario, for better health and hygiene of public at large, protection of water source and natural recharge system should be a priority. The following generalized strategies are envisaged to augment drinking water supply to the city.

Regulating the Development

The phreatic / shallow aquifer being most vulnerable to exploitation as they are easily tapped through shallow bore wells. Development of groundwater resources should be planned such that further decline in water level can be arrested. Construction of deep tube wells, in heavily depleted aquifer zones should be avoided. In such areas more priority should be given to provide surface water source based water supply. With regular monitoring of aquifer for change in water level and also for quality variation, alternate surface water resources should be used conjunctively for optimum utilization of available water resources. For this purpose real time water level monitoring and management systems should be developed. In stressed areas, through suitable regulatory measures, enforcement of directives to uses ground water resources for specific purpose can be worked out.

Multilayered aquifer system down to 300-400 m depth in Ahmedabad – Gandhinagar areas have brackish to saline or high fluoride / nitrite zones at various depths. Unrestricted and inefficient construction of deep tube wells through such multilayered aquifer, tapping the entire available granular horizon mixes inferior quality groundwater with good quality at many places. Some time, through old and damaged tube wells casing, brackish or polluted water mixes with good quality aquifer zones. All such environment degrading incidences can be controlled by regulating tube well constructing activities and suitable remedial measures to restore old tube wells for recharge work. There should be administrative set up to regulate, monitor and provide technical guideline for all such groundwater development work in Ahmedabad – Gandhinagar urban area.

Conserving Available Resources

For this purpose, the surface run off water from roof top of buildings, road surfaces, parks, schools, stadiums, etc., can be diverted to shallow recharge pits, shallow bores, abandoned dried dug wells, etc. The areas where excess rain water accumulates, like the village ponds/talavs and other natural depressions, should be utilised for water conservation purposes. Such measures would also help in reducing urban run off.

There is a directive to construct rainwater harvesting structures in all newly constructed houses / group societies etc, in urban areas of Gujarat State. Suitable regulatory and monitoring system should be established for effective enforcement of this directive. For encouraging such activities of groundwater recharge work by people's participation and with individual efforts, authority should work out some way to award suitable incentive directly or indirectly by waiving or subsiding tax etc.

Similarly, for Gandhinagar area, aquifers below 200m depth are notified as protected aquifer for drinking water use only by CGWA during year 2000. Adequate administrative and enforcement measures should be taken to monitor exiting developing activities for further improvement and conservation of deep aquifer resources.

As a groundwater conservation strategy, serious thinking is required to be given for adoption of dual system of water supply in select urban centers, particularly newer ones. In this system, the supply of water for potable/kitchen use, @30-50 lpcd, can be through deep protected fresh water source and domestic sanitary water supply can be from shallow aquifer. Moreover, mass awareness through peoples active participation to preserve water and avoid wasteful usage should be undertaken. The habit of storing water every day and throwing away the next day should be dispensed with in this semi arid land of scarce water.

Many part of Ahmedabad urban areas is underlain by brackish unconfined aquifers whereas some local patches are polluted by industrial effluents. The drinking water supply (potable use) from this aquifer should be banned completely. However, this aquifer needs to be vitalised and utilised for non-drinking / non-kitchen use and other uses. The sites selected for new tube wells should avoid areas that are polluted and care should be taken to properly seal the supply wells as well as the aquifer to prevent any kind of pollution/ contamination. Therefore, it should be mandatory that all supply wells be sealed down to minimum 5-6 m by providing effective cement grout. The land surface at the site be graded and sloped so that surface water is diverted away from the well. Provision of top concrete platform (say 1 m x 1m x 0.2m) around the well should be made.

Pollutants both industrial and sewage should be treated by appropriate methodology (primary/secondary/tertiary) before discharging in the drains and the river etc. Toxic waste should not be disposed of on natural surface/drains etc. In the areas, particularly outside of city limit, where sewerage is non-existent, there is a general requirement of planned urban development. It should be mandatory to develop infrastructure particularly the sewage disposal system and protected water supply system beforehand. Improper planning may pose a serious threat to underground environment.

Artificial Recharge Projects

Harvesting of rain water for artificial recharge to shallow aquifer needs to be taken up in order to maintain groundwater balance and to make shallow aquifer reliable and sustainable source for supplementing domestic and industrial water supply needs in urban areas. In order to properly manage the over exploited aquifers, to retard, and, if possible, reverse the declining water level trends; there is an urgent need for operational measures for artificial recharge of groundwater. The efficacy and technology of artificial recharge has amply been established in and around the city. Existing surface water bodies – ponds / lakes should be renovated and restored such that they can be fully utilized for groundwater recharge. Surface runoff of monsoon rainfall should be collected by constructing storm water canal for diverting it to artificial recharge structures and lakes / ponds. To start with, existing work taken up under ;National Lake Conservation Plan, should be implemented for each of existing surface water bodies and constructing site appropriate recharge structure ; like recharge well, percolation pits / shaft, percolation tanks, etc in all over the urban areas. There are more than 50 natural lakes identified by the AMC / AUDA authorities which can be interlinked with storm water drainage. Adequate provision of budget should be made in ongoing 'Urban Area Development' projects in phased manner. In Gandhinagar area, under Capital Development Scheme, work is going on to collect all storm water and construction of recharge / percolation tanks. Taking into consideration of aquifer disposition of the area, 25 shallow depth percolation well should be constructed in grid pattern, along storms water drain all over the urban area. Gandhinagar areas have advantage of its open area with plantation and sandy soils, facilitating fact percolation of rainwater. Extra care should be taken to preserve and maintain such area free from encroachment and pollution.

BANGLORE CITY, KARNATAKA

M.A. Farooqi, CGWB, Bangalore

INTRODUCTION

Bangalore, the capital of Karnataka, is one of the fastest growing city of Asia. In the year 1120 AD, the Hoysala King, Veera Ballalla during a hunting trip in the forest lost his way. After a long search he met an old lady in the forest who offered him shelter for the night and served him some boiled beans for dinner. To show his gratitude to this lady for having saved his life, the King constructed a town and named it as Benda Kalooru which means town of boiled beans. Later in 1537, a local chieftain, Kempe Gowda helped design this town and laid the foundation for modern Bangalore. The city was extended by several suburbs, or layouts, at the end of the 1800s. By the 1930s the suburbs had sprawled out and people who could afford to commute by carriage lived outside the city. After Independence, Bangalore grew rapidly in all directions, though with particularly intensive pressure on the inner city. In 1956, Mysore State was reorganised (Now Karnataka), with Bangalore as State capital, resulting in a major influx of migrants and further extension of the city. The old city and the Cantonment were merged into one entity and grew rapidly. Now, the Bangalore city or the Bruhat Bangalore Mahanagara Palike (Greater Bangalore Municipal Corporation) is the key Urban Local Body. It was constituted by the Government of Karnataka vide Notification No. UDD 92 MNY 2006 dated 16.01.2007 including 7 Municipal Councils, one Town Municipal Council and 111 urbanized villages in the Bangalore Mahanagar Palike. The area that Bangalore covers has grown manifold over the past century, from 75 km^2 in 1901, to 801 km^2 as of now.

GENERAL FEATURES

Area / Administrative Divisions

The Bruhat Bangalore Mahanagara Palike (12°45' - 13°10' and 77°25' - 77°45') covers an area of 801 km^2 and is divided into the following zones for administrative purposes:

1. East Zone
2. West Zone
3. South Zone
4. Rajarajeshwarinagar
5. Bommanahalli
6. Yelahanka
7. Dasarahalli
8. Mahadevapura

Demography

In terms of population, Bangalore's growth has been quite extraordinary. In 1961 the city was the sixth largest in India, with 1.2 million inhabitants. It is now the fourth largest. Between 1971 and 1981, Bangalore's growth rate was 76 percent – the fastest in Asia. Between 1991 and 2001, the urban part of Bangalore District witnessed the country's fastest growth after New Delhi, with almost 38 percent. This is in comparison to an average of 17 percent growth in the entire Karnataka, and 21.34 percent in India as a whole during the decade. The 2001 census put the population of Bangalore city at 4.3 million inhabitants and of the urban agglomeration as 5.7 million. The population is estimated to cross 7.5 millions by 2011 census.

Hydrometeorology

According to Koppen's broad climate classification, the climate of Bangalore can be classified as the Tropical Monsoon Plateau Type i.e., characterized by mild summer and mild winter. The pre-monsoon period lasts from January to May. This period can be divided into winter (December – February) and summer (March – May). Winter is generally characterized by very little rainfall. Erratic thunderstorms occur during the month of May.

Table 1 Normal Climatological data of Bangalore Meteorological Station

Month	Temperature (^0C)		Relative Humidity (%)		Rainfall (mm)	PET (mm)	Wind Speed (kmph)	Sunshine (Hour/ Month)
	Min	Max	0830 Hrs	1730 Hrs				
January	15.0	26.7	77	40	3.3	117.4	10.4	259.8
February	16.5	29.7	67	29	10.2	130.0	9.7	248.4
March	19.0	32.3	63	24	6.1	166.2	9.4	268.9
April	21.2	33.4	70	34	45.7	158.2	9.0	252.0
May	21.1	32.7	75	46	116.5	156.5	11.8	239.8
June	19.7	28.9	82	62	80.1	126.5	17.1	135.3
July	19.2	27.2	86	68	116.6	115.7	17.5	99.8
August	19.2	27.3	86	66	147.1	114.2	15.2	108.3
September	18.9	27.6	85	62	142.7	108.2	12.1	145.1
October	18.9	27.5	83	64	184.9	105.1	8.2	171.1
November	17.2	26.3	78	59	54.3	98.3	8.5	182.9
December	15.3	25.7	78	51	16.2	102.9	9.6	213.6
Annual	**18.4**	**28.8**	**77**	**50**	**923.7**	**1500.5**	**11.5**	**259.8**

Temperature is the lowest during December and January with mean minimum and maximum temperatures of 15^0C and 26^0C respectively. Temperature increases gradually thereafter until the beginning of May with mean temperature ranging between 22^0C and 34^0C. Annual normal rainfall is over 900 mm. Normal monthly rainfall varies from a high of over 185 mm in October to a low of less than 10 mm in January. Even during May rainfall of the order of 100 mm is not uncommon. Southwest monsoon in the area starts during the first two weeks of June. Normal Climatological features of Bangalore Meteorological Station are given in Table -1

Physiography and Drainage

Geomorphological landforms predominantly seen in the area are denudational plateau, pediment, pediplain and valley flats. The occurrence of fractures is more significant in pediplain areas. Bangalore city situated on an N-S trending highland with an average altitude of 930 m above mean sea level (amsl), forms a divide between the rivers Arkavathi on the west and South Pennar on the east. The major part of the Bangalore Metropolitan City is situated on a hog back of granite. Hillocks of limited areal extent are seen in the southernmost and south-western parts. Interpretation of Landsat imagery shows that a NNW-SSE trending deep-seated fault cuts across the Closepet Granites west of main Bangalore city. Lineaments interpreted for the area show general directions of NE-SW, NW-SE and E-W, the NE-SW trending lineaments being more prominent. However, NW-SE trending lineaments are seen sporadically in the northern part of the metropolis. The drainage pattern in the area is more or less fracture controlled. More than one third of the Greater Bangalore is drained by Arkavati, a tributary of the Cauvery river. It flows in N-S direction and joins the Cauvery river at the Sangama. The drainage pattern is trellis to sub-dendritic. Remaining two-third area comes under Upper Pennar Sub-basin, with a low drainage density. High drainage density in the western part is mainly due to a higher density of first order streams with lesser lengths.

Soil Type

The area is predominantly covered by red loamy and lateritic soils. While lateritic soils covering more than three-fourth area occur in the upland and transitional zones, on the slopes and in the flood plains of streams with thickness ranging from 0.3 to 1.0 m, the red loamy soils are found to occur in the upland and plain regions having thickness ranging between 0.5 to 3.0 metres.

STATUS OF WATER SUPPLY AND DEMAND

Bangalore Water Supply & Sewerage Board (BWSSB) is entrusted with the task of providing water supply to Bangalore metropolis. The water supply of BWSSB from surface water resources viz., Arkavati and Cauvery Rivers, is presently inadequate to meet the drinking water needs of the people. It is obvious that the citizens of Bangalore and the numerous industrial establishments are thus heavily dependent on ground water to meet the deficiency. The demand supply gap is met by groundwater exploitation.

DEMAND

Present Demand	: 1275 MLD (For a population of 75 lakhs at 170 LPCD)
Projected Demand	: 1700 MLD (For a population of 100 lakhs at 170 LPCD)

PRESENT SUPPLY

1. Surface Water	: 840 MLD
2. Ground Water	: 475 MLD

Projected demand for a population of 10 millions is going to be 1700 MLD for Bangalore city itself. Further, with increasing population and rising income, the lifestyle of urban residents is also changing. Total supply from various surface water sources is going to be 1335 MLD (after the completion of Cauvery stage IV – Phase II) leaving about 365 MLD to be pumped from ground water sources.

WATER PROFILE

Unlike many other major cities Bangalore is not blessed with a perennial river and this may be the reason for construction of many lakes across seasonal streams. Once upon a time, about 262 lakes existed within the Bangalore city limits. This number has come down considerably due to encroachment. Recently, attempts have been made on selected basis to maintain some of these lakes. At present major source of water for domestic water supply, is Cauvery River, situated at a distance of about 100 km from Bangalore. Water is pumped from the source against a head of 510 metres in three stages. It is estimated that almost 40 per cent of the population of Bangalore is dependent on ground water. Various government agencies are maintaining a large number of energised bore wells and about hand pumps in Bangalore City area for augmenting domestic water supply. Various housing colonies, commercial and industrial establishments have come up in the extension areas. These areas are entirely dependent on ground water to meet their domestic and industrial needs. On a rough estimate, there are more than 1.5 lakh ground water abstraction structures in Bangalore. A flourishing ground water market exists in the city and its outskirts, where ground water is sold by tankers to meet the requirements of the city population during emergency. On a rough estimate, there are about 2800 tankers with 3000 litres capacity, supplying/selling ground water daily on an average about 8.4 million litres of ground water, pumped from private bore wells. Peripheral areas, which are solely dependent on ground water, are going to put further strain on ground water resource with sustained urbanization. Hence, share of ground water will in drinking water supply increase manifold in days to come. Ever increasing dependence on ground water has resulted in over-exploitation of the resource.

GROUND WATER SCENARIO

To understand the Ground Water Scenario prevailing in the metroplolis, Bangalore city can be divided into three zones. First and the innermost zone is erstwhile Bangalore Mahanagar Palika (Bangalore City Corporation) area, which is fully covered by piped water supply from Cauvery and Arkavathi. Second or the intermediate zone includes the areas surrounding the Corporation area comprising of 8 C.M.Cs and one TMC. This area/zone is having partial surface water supply limited to small pockets. The third and outer most zone comprises of 111 surrounding villages covered under the green belt area. In other words, wells located in Central part i.e., in old Bangalore City Corporation area have the shallowest water levels in the range of < 2 - 5 m below ground level (bgl) in post-monsoon season and 3 – 10 m in pre-monsoon season. In contrast the depth to water level in the outer zone is of the order of 8 – 15 m in post-monsoon and 10 - > 20 m bgl in pre-monsoon seasons.

In the outer boundaries, the depth to water levels is found to have direct relationship with urbanization of the area i.e. wherever private colonies/layout have come up water levels are found to be deeper like south-eastern parts of the city and north east parts of green belt area. These colonies/layouts supply water to the inmates through individual or group borewells called syndicate borewells and hence put tremendous pressure on ground water resources. With the construction activities on the rise, draft overcomes recharge and as a result water table depletes fast.

Analysis of the well hydrographs based on the water level data of Network Hydrograph Stations and Piezometers monitored by the Central Ground Water Board, show a rising trend in the areas where either BWSSB surface water supply is available or where no significant urbanization has taken place. This rising trend is the combined effect of precipitation along with the contribution of leakage from the BWSSB mains (presumed to represent a proportion of the unaccounted water) and leakage from storm water drains and the sewerage system. Hydrographs of Network Hydrograph Stations located in Jayanagar, Bangalore1 (Fig-1b) and Gottigere show rising trends. Hydrograph of the NH station located at Hejjala (Fig-1a), in the intermediate zone, shows a falling trend. It will be worth mentioning that number of NHS falling in the intermediate and outer zone of the study area namely, Puttenahalli, Chikka Bannavara, Doddakalsandra, Talaghatpura and Chikkajala have all dried up during the last 10 years indicating obvious declining trend with water level falling below 10 m bgl (Fig-1).

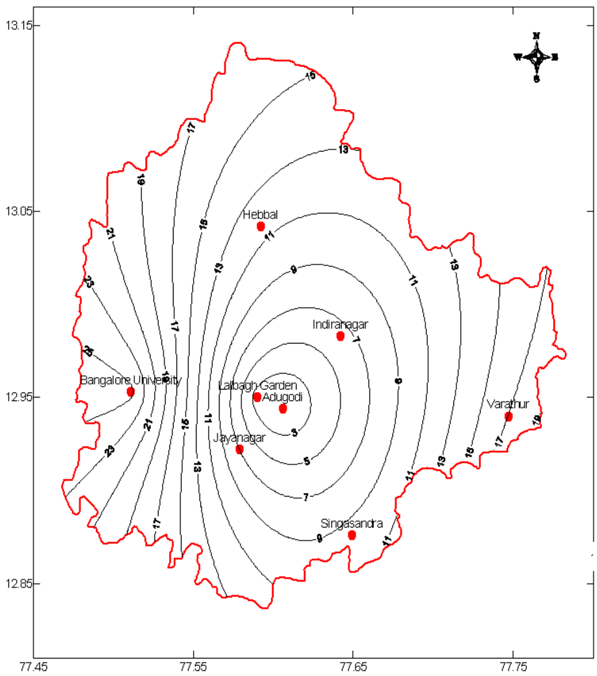


Fig-1: Depth to Water Level Map of Greater Bangalore Area (November 2008)

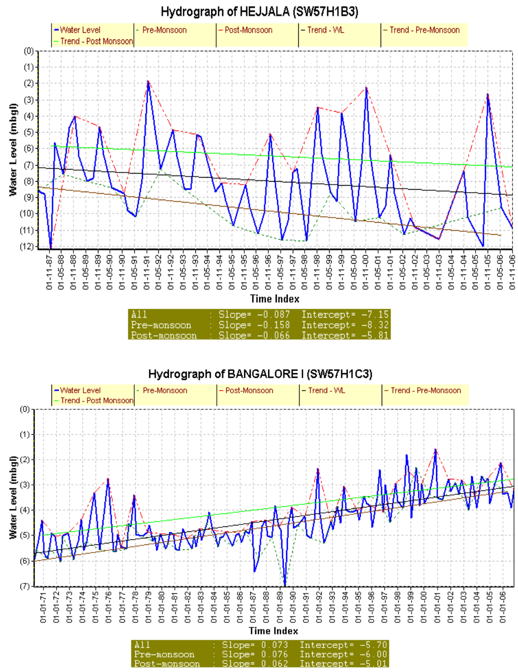


Fig.1a and 1b Hydrographs of Hejjala and Bangalore

Potential Aquifers

Granites and gneisses constitute the major aquifer system in the Greater Bangalore. Groundwater occurs under phreatic conditions in the weathered rock and residuum and under semi-confined conditions in jointed and fractured granites and gneisses. Based upon the exploration studies carried out by the Central Ground Water Board the regional ground water flow system of erstwhile Bangalore district has been described under three zones as per the occurrence and behaviour of ground water viz., Shallow zone, Moderately deep zone and Deep zone. Hydrogeological map and Panel Diagram of Greater Bangalore Area are presented in Fig-2 & Fig-3 respectively.

Shallow zone: The aquifers occurring within depth of 25 m below ground level comprise weathered, partially weathered and fractured granites and gneisses. Ground water occurs in the open spaces of weathered and fractured formations under phreatic conditions. Ground water development in this zone was mainly through dug wells, dug-cum-bore wells and shallow bore wells for domestic and irrigation purposes. About 90% of ground water structures tapping these shallow aquifers were found to yield less than 1 litres per second. Higher yields ranging up to 5 litres per second were reported in localised patches falling in southern parts of the study area. Presently, in most parts of the study area, this phreatic aquifer is drying up as most of the abstraction structures tapping this shallow zone have reportedly dwindling yields/ deepening water levels.

<u>Moderately deep zone</u>**:** Aquifers in the depth range of 25–60 metres bgl are grouped in moderately deep zone category. The aquifers of this category consist of partially weathered and fractured granites and gneisses. Ground water occurs in the secondary porosity developed in the weathered and fractured formations under semi-confined conditions. Ground water development in this zone was mainly through shallow bore wells for domestic and irrigation purposes. Almost eighty percent of the wells drilled tapping this zone yielded less than 2 litres per second. Higher yields between 2 to 6 litres per second were recorded in the remaining parts of the study area. Transmissivity values ranged from 10 to 65 m^2/day.

<u>Deep zone</u>**:** The aquifers below the depth of 60 metres bgl are grouped under deep zone category. Aquifers of this category comprise of fractured granites and gneisses. Groundwater occurs in the jointed and fractured formations, which are overlain by weathered and semi-weathered formation under semi-confined/confined conditions, developed through bore wells. Yield of the wells tapping this zone was in the range of 2-6 litres per second. Higher yields were recorded from the wells drilled in the central and south-western parts of the study area. Transmissivity in these aquifers ranged between 20 to 280 m^2/day. The storativity values ranged from $2.8*10^{-3}$ to $8.4*10^{-4}$. Presently most of the newly constructed borewells tap this zone.

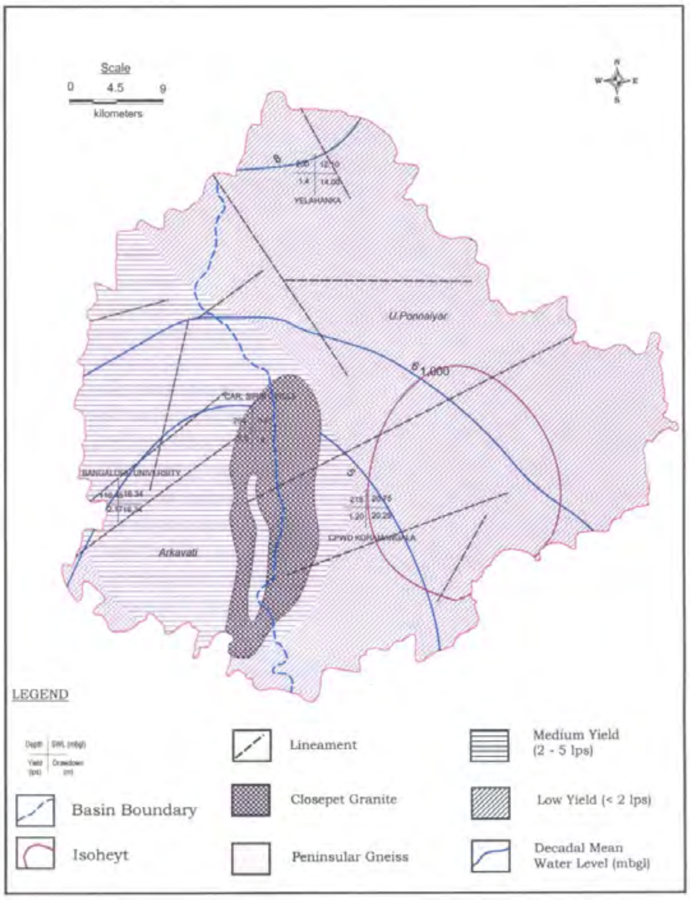


Fig-2: Hydrogeological Map of Greater Bangalore

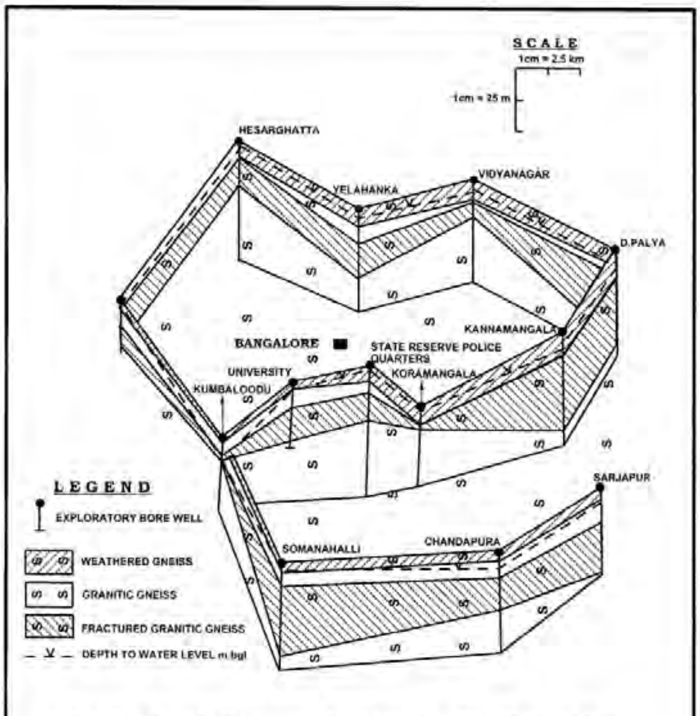


Fig-3: Panel Diagram showing Aquifer Geometry in the sub-surface in Greater Bangalore Area

(After Hunse & Farooqi 1995)

Ground Water Level

Long- term pre-monsoon water level trend shows a general rise in the range of 0-2 metres in the southern, central and western parts covering almost 50% area of the Greater Bangalore. Fall in water levels in the range of 0-2 meters is recorded in northern and eastern parts covering remaining parts of the metropolis. Long term post-monsoon water level trend shows a general fall in the whole area. While decline in almost the entire area is in the range of 0-2 meters, it is even higher (2-4 metres) in a small patch in northern part of the study area. National Hydrographic Stations were all dug wells, which became dry when the water table fell below the bottom of the well (average depth 10 m) as seen in the Hydrograph of Hejjala (Fig-1a). Keeping this changing hydrogeological scenario in view, a number of purpose built piezometers were constructed for long time monitoring of water levels and water quality in Bangalore Urban and Bangalore Rural districts under Hydrology Project by the Central Ground Water Board during 1999. Hydrographs of the piezometers located in the intermediate and outer zones e.g., at Dasnapura, Hebbal, Yelahanka and Bommasandra, show declining trend.

Ground Water Resource and Status of Development

Ground water resource of Bangalore Urban district, which includes the entire Bangalore area, are presented below in Table-2. The resource has been computed jointly by CGWB and DMG. The ground water draft is mainly through hand pumps and heavy duty water supply borewells. Commercial trading of water (water marketing through private tankers) based on excessive pumpage of borewell has also added to the ground water draft. The average stage of development for the Bangalore Urban district works out to be around 142 percent, categorizing the whole of Bangalore Urban district under Over-exploited category, pinpointing a very alarming situation.

Table 2: Ground water resource of Bangalore Urban District, Karnataka as on 31.03.2009.

TALUK	Net Annual Ground Water availability	Existing Gross Ground Water Draft for Irrigation	Existing Gross Ground Water Draft for Domestic and Industrial Water Supply	Existing Gross Ground Water Draft for All Uses	Provision for Domestic and Industrial Requirement supply to 2025	Net Ground Water availability for Future Irrigation Development	Existing Stage of Ground Water Development
	ha m	ha m	ha m	ha m	ha m	ha m	%
Anekal	3377	3787	536	4324	536	0	128
Bangalore East	2400	2813	300	3112	300	0	130
Bangalore North	2975	3661	368	4028	368	0	135
Bangalore South	2971	2649	2590	5239	2590	0	176
Total	**6348**	**6436**	**3126**	**16703**	**3794**	**0**	**142**

Hydrochemistry

Ground water quality has been assessed based on network of sampling stations and it is observed that concentrations of all the chemical constituents in ground water are within the 'desirable to permissible' range except for nitrate. Water quality data of select observation wells is presented in Table 3. The nitrate (NO_3) content in ground water ranges from nil to 554 mg/l. About 50% of the well waters have nitrate more than the permissible limit of 45 mg/l. The areal distribution of NO_3 contents in ground water indicates that northern part of Bangalore Metropolitan Region is more affected than the southern part. In north, about 70% of area is having groundwater with high NO_3 concentration of more than 45 mg/l as compared to the 30% in the south. It is interesting to note that shallow as well as intermediate zone of ground water showed high NO_3 concentration. The cause for high concentrations of nitrate in ground water may be point sources i.e., sewage or anthropogenic activities, or non-point sources like the use of excessive nitrate fertilizers in the rural areas. In the mega city, due to predominantly urban environs, the contamination can only be attributed to municipal waste and sewage Open dumping practices are commonly adopted for disposal of solid waste, which causes deterioration of environmental and ground water quality. The prominent areas of nitrate contamination are Banasawadi, Channasandra, Gottigere, Jalahalli, Kamakshipalya, Laggere, Nagavara and Yelahanka.

Table 3 Water quality data of select observation wells in Greater Bangalore Area

Sl No	Location	pH	EC*	Concentration in mg/litre										
				TH^	Ca	Mg	Na	K	CO_3	HCO_3	Cl	SO_4	NO_3	F
1.	Banaswadi	8.40	605	185	30	27	46	5.5	18	60	64	50	80	0.53
2.	Bannerghatta	7.83	2490	515	120	52	190	220	0	335	330	240	310	0.56
3.	Begur	8.04	3260	520	120	53	275	350	0	586	440	258	280	0.32
4.	Jalahalli	8.24	1100	320	62	40	84	26	0	104	202	78	120	0.37
5.	Kamakshipalya	8.11	1790	620	144	63	103	6	0	134	370	120	120	0.67
6.	Laggere	8.00	1840	725	106	112	80	10	0	140	372	102	185	0.47
7.	Lakkasandra	8.69	905	315	86	24	52	16	60	165	67	61	56	0.65
8.	Maratahalli	7.60	1775	640	148	66	90	5	0	213	376	84	98	0.46
9.	Nagavara	8.26	700	235	52	25	40	12	0	85	85	36	147	0.27
10.	Yelahanka	7.15	2250	610	190	33	210	50	0	290	500	110	85	0.56

* EC in micromhos/cm at 25^{0}C   ^ TH (Total Hardness as $CaCO_3$)

Major Ground Water Related Problem

The stage of development of 142 percent indicates that ground water is being pumping more than that of rechargeable quantity. It leads to continuously fall in water level as the ground water is being pumped from the static resource which accumulated over hundreds of years. If this trend continues, it will lead to serious environmental problem by drying up of the top zone permanently, which supports the bio-sphere. As such, major groundwater related problem is dwindling yield in intermediate and peripheral area, where domestic water supply is wholly dependent on ground water. Nitrate pollution is quite rampant in the city due to improper waste management practices.

Feasibility of Rainwater Harvesting and Artificial Recharge

Rainwater harvesting needs to be adopted for replenishing the over-exploited ground water resources. Rejuvenation of existing water bodies and tanks will also affect increase in groundwater recharge, apart from adding to the city's available water supplies.

GROUND WATER DEVELOPMENT STRATEGY

The Strategy for ground water management should be on the following lines:

- Compulsory rain water harvesting in all the buildings irrespective of the size of the site area.
- Compulsory Artificial recharge to ground water at all feasible locations.
- Conservation and preservation of all the water bodies including wells, tanks, ponds, lakes and streams. Recently, attempts have been made on selected basis to maintain certain lakes like Madivala, Puttenahalli, Dorekere, Vasanthapura, Narsipura, Kundalahalli, Chikk Jalahalli, Yediyur and Moggekere by de-weeding and fencing. Few of these lakes at Madivala, Ulsoor, Sankey, Vasanthapura, Narsipura and Yediyur are even having parks and boating facilities. Some of these lakes are receiving sewage throughout the year in addition to the surface runoff generated from rain water and hence contaminate the water bodies. In many areas the tanks have become the site for garbage disposal. This has to be stopped and spoiling a water body / water abstraction structure including dug wells should be made a criminal offence.
- Dual Water Supply line system should be made mandatory. Water should be recycled, treated and reused for non-domestic purposes.

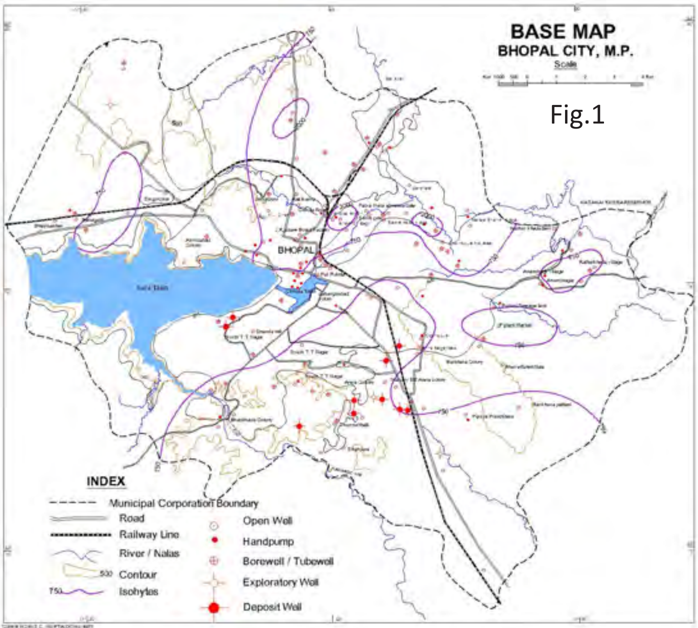
- Ground water pricing should act as a deterrent and a telescopic pricing policy taxing the high end user with higher rates is recommended.
- For domestic use only those appliances should be permitted which use water economically, like Slim Flush Tanks for Toilets, Water efficient Washing Machines, etc., Such acts should be encouraged by way of giving subsidy on the lines of Solar Water Heaters.
- Establishment of Water Award for implementation of such measures.
- New groundwater structures should be permitted even in over-exploited areas and while doing the same the conditions as applicable for existing users should be made applicable to new users also.
- For industrial areas separate methodology has to be worked out and more emphasis is to be given on Rainwater harvesting and the permissible quantity should be worked out based on the land holding and its implementation of rainwater harvesting schemes.
- It should be mandatory to sensitize persons and users at different levels with regard to the need for judicious use and scientific management of ground water. It can be achieved by organizing training and awareness programmes at ward level by involving residents Welfare Associations. Water conservation and protection of the resources should be a part of the curriculum in schools. Media should also be involved in achieving this goal.

BHOPAL CITY, MADHYA PRADESH

L. K. Mathur, CGWB, Bhopal

INTRODUCTION

Bhopal is the capital of the Indian state of Madhya Pradesh and the administrative headquarters of Bhopal District and Bhopal Division. The city was the capital of the former Bhopal state. Bhopal is also known as the *Lake City* for its various natural as well as artificial lakes and is one of the greenest cities in India. The city attracted international attention after the Bhopal disaster, when a Union Carbide India Limited (UCIL) pesticide manufacturing plant leaked a mixture of deadly gases including methyl-isocyanate on the night of 2/3 December 1984, leading to the worst industrial disaster in history and a loss of thousands of lives Bhopal is said to have been founded by the Parmar King Bhoj-2 (1000–1055), who had his capital at Dhar. The city was originally known as Bhopal named after Bhoj and the dam ('pal') that is said to have been constructed by him to form the lakes surrounding the city. The fortunes of Bhopal rose and fell with that of its reigning dynasty. As the Parmar's declined in power, the city was ransacked several times and finally faded away into obscurity. The ruler of Bhopal acceded to India only on 1 May 1949. Sindhi refugees from Pakistan were accommodated in West Bhopal Cities, Bairagarh Sub-Area (Sant Hirdaram Nagar), a western suburb of Bhopal. According to the States Reorganization Act of 1956, Bhopal state was integrated into the state of Madhya Pradesh, and Bhopal was declared as its capital. The population of the city rose rapidly thereafter. In Fig no.1 Bhopal city map is shown with all the water bodies.



GENERAL FEATURES

Area / Administrative Division

Bhopal city is the capital of Madhya Pradesh and it is situated in the central part of India. It lies between N-latitude $23^{0}07'$ & $23^{0}20'$ and E- longitude $77^{0}19'$ & $77^{0}31'$. Bhopal city encompasses an area of 296 sq. km with having 66 municipal wards of which Kaliasot, Gandhinagar & Narela Sankari, become encompasses major area of the city.

Demography

The urbanization and industrialization leads to growth and development of a city but in turn brings adverse impact on precious water resources and there by posing a problem to the planners for arranging sustainable water supply of desired quality for public health. The city particularly the capital of State grow with migration of population from rural areas and water availability meet out various growing needs and generation of waste water multiply every-year and such a critical stage over a period of time. The present population of Bhopal municipal corporation as per census 2001 is 14,37,354 in comparison to the year 1951, in which the population was 102333.

Hydrometeorology

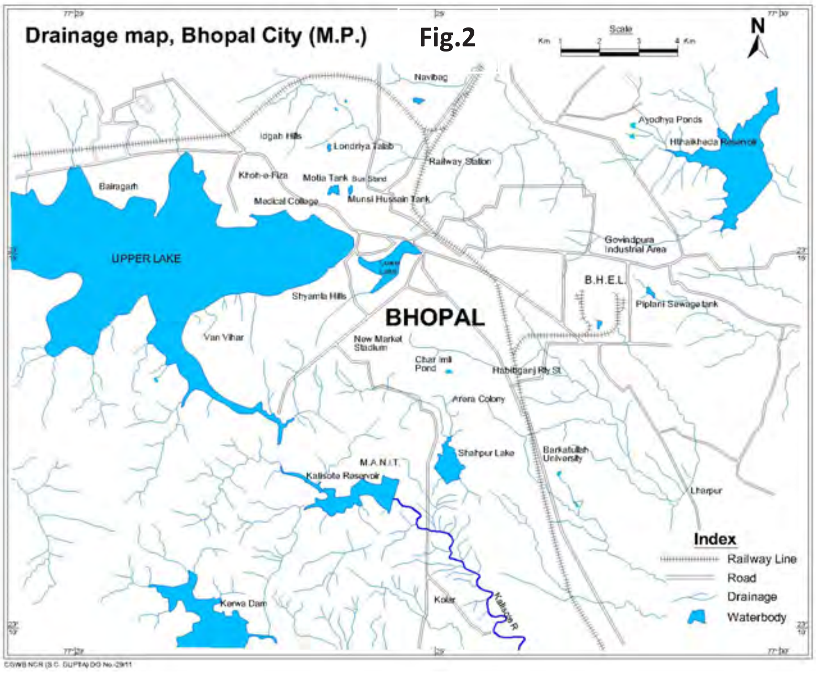
Rainfall: There is only one rain gauge station at Bairagarh maintained by IMD. The normal annual rainfall of Bhopal city is about 1260.2 mm. The southern part of the city receives more rainfall than northern part of the city the rainfall as we move from south to north and towards north west about 92% of the annual rainfall takes place during the south west monsoon i.e. from July to September. The maximum rainfall (about 39%) takes place during the month of July. Only 6% and 2% of the annual rainfall takes place during the winter (November to February) and summer season (March to May) respectively. Hence about 8% of the annual rainfall takes place from November to May. The rainfall in the year 2008 is 697.4 mm only. The rainfall in the year 2010 was 817.2mm

Climate:-The climate of Bhopal city is characterized by a hot summer and well distributed rainfall during the south west monsoon season. There are three well defined seasons. The winter commences from middle to November and lasts till end of February and January is the coldest month. The summer season stretched from March to first week of June and May is the hottest month. The south west monsoon sets in the middle of June and continues to the end of September during which the maximum rainfall occurs in the city. October month is retreat of monsoon and November constitutes the post monsoon season.

The daily mean normal temperature of Bhopal is May is about 40.7^0 C and minimum is 26.4^0 C. The summer season is the driest period of the year. The humidity is lowest (about 25%) during the month of April. The humidity is highest during the month of August about 88%.

Physiography & Drainage

The Bhopal city, as shown in Fig.2, form a part of Malwa plateau with generally undulating topography. The major part is covered by Vindhyan hills ranges & the valleys are occupied by Deccan trap basalt. There are seven hills scatteredly located around upper lake and the highest of them is Singarcholi near Lalghati which has an elevation of 625 m above mean sea level (amsl) the elevation of Bhopal city generally varies from 490 to 601 m amsl and the average elevation is 523 m amsl. In the catchment area of upper lake elevation is a high as 540 m amsl. There is no major river flowing through the Bhopal city. The southern part is drained by river Kaliasot, a small drainage course. It is an outlet of upper lake and becomes a tributary of river Betwa in the downstream. A limited area in the western side is drained by river Kolans. Patra nala, which receives overflow of lower lake, drains the central and northern part of the city.



Soil Type

Black cotton soil covers the major part of the area where as central part of the Bhopal occupies Vindhyan sand stone a thin veneer of red colour soil exist.

STATUS OF WATER SUPPLY AND DEMAND

Sustainable water supply of desired quality in adequate quantity catering to growing need is one of the main sources of Bhopal city. It included 66 municipal wards spread over an area of 296 sq km. The population has increased from 185000 in year 1961 to 1482718 in year 2001 indicating an increase of 800% over a period of 40 years. The major requirement of drinking water supply in Bhopal city is met from surface water sources, namely upper lake and Kolar reservoir besides, more than 400 tube wells and few large diameters dug wells and hand pumps also meet the requirement, in addition, termination development took place resulted number of private and government colonies came up in the out skirts of the Bhopal city unaccounted privately owned dug wells and bore wells installed in individual households, housing colonies, industries, and business complexes also cater the requirement a quantity of approximately 239.40 – 11.71 MLD from upper lake 12.69 MLD from Kolar Dam is released from surface water sources and 11.55 MLD is available from ground water sources. After accounting for distribution and generation loosed the net water supply 210 MLD is available from surface water sources. The total water supply from both the sources is 232 MLD against water demand of 350 MLD. Thus the present water supplies falls short of about 120 MLD there is a proposal to release additional water supply from Kolar reservoir as well as bring the water from Narmada River and revival of old ground water structures existing in the old city.

WATER PROFILE (SURFACE AND GROUND WATER)

Bhopal city is also known as city of lakes (as shown in Fig.3) because it is embedded 18 water bodies of different sizes located in and around Bhopal. These water bodies were developed over period of 900 yrs. Since legendry of Raja Bhoj who has credit for construction of upper Lake Bhopal city is developing very fast is moving to attend the status of mega city within a decade. Therefore it is need of a time to make a consolidate plan for restoring vital water resources.

Out of 18 water bodies, the peoples of Bhopal town are more familiar with only 5-6 water bodies because of their proximity of city some irrigation reservoir such as Hataikheda, Kerwa, Laharpur earlier located in the out Skirts of the city have now become in internal part of city due to expansion of city in all the directions Salient features of Bhopal Lakes is given in Table - 1.

UPPER LAKE **Fig.3** **LOWER LAKE**

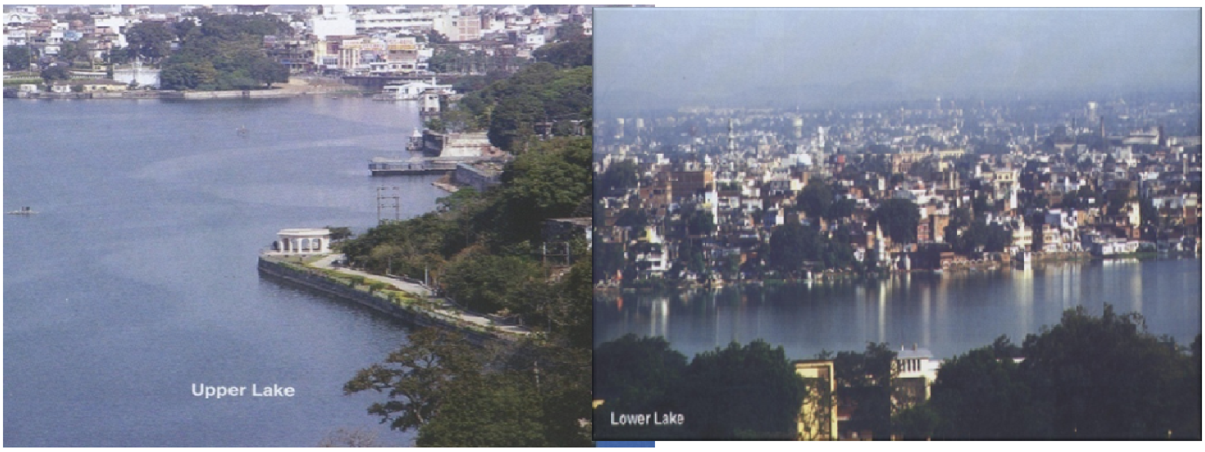


Table -1: Salient features of Bhopal Lakes

S.N.	Name of Water body	Water spread Area (in Ha)	Present Use
1	Upper Lake	3100	Water supply, recreation, and fisheries
2	Lower Lake	129	Raw water supply and recreation
3	Shahpura	96	Recreation & fisheries
4	Motia tank	1.89	Washing
5	Siddique Hussain Tank	1	Abandoned
6	Munshi Hussain Khan Tank	1.2	Fisheries
7	Lendiya Talab.	1.5	Recreation & fisheries
8	Sarangpani	42	Recreation
9	Laharpur Reservoir	350	Irrigation
10	Hataikheda Reserve	113	Irrigation
11	Halali Reservoir	1625	Irrigation
12	Kerwa Reservoir	524	Irrigation
13	Kolar Reservoir	2850	potable water supply & irrigation
14	Char Imli Pond	1.2	Recreation
15	Ayodhya Nagar Abandon stone Quarry pond (4 Nos)	6.5	Recreation
16	Damkheda village pond	2.4	potable water recreation

GROUND WATER SCENARIO

The area is occupied by the rocks of Vindhyan & Deccan trap and alluvial formations as shown in Fig. 4, the general geological succession in the city is as under:

Age	Group	Formation
Quaternary		Alluvium
~~Unconformity~~~~~~~~~~~~~~~~~		
Upper cretaceous to Eocene		Deccan Trap
~~Unconformity~~~~~~~~~~~~~~~~~		
Upper Proterozoaic }	Vindhyan Supper group } Bhander Group }	Bhander sandstone and shales

Potential Aquifers

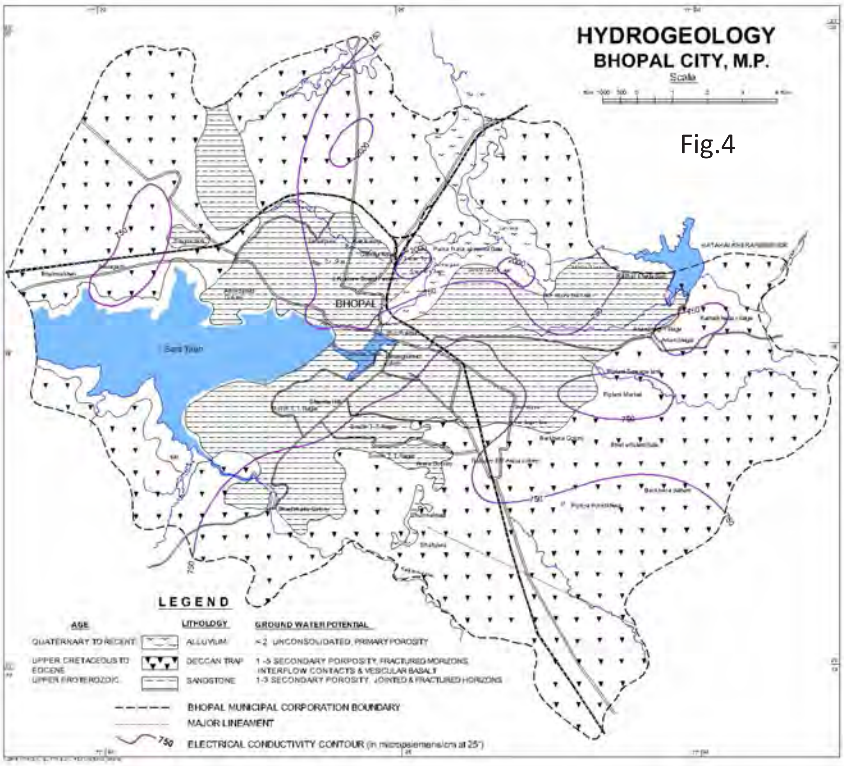


Fig.4

In the major part of the study area, occurrence of promising aquifer zones is confined within shallow depths in 70 m. The shallow aquifer occurs in (1) Alluvium (2) Weathered and jointed fractured portions of Deccan traps and (3) Weathered and jointed of Vindhyan sandstone. Alluvium is deposited in patches along the major drainage and the yield is very limited (1 to2 lps). The Deccan trap basalt forms moderate to good shallow aquifers were thickness of weathering and vesicular zones is adequate. The Deccan traps on weathering generally develop a top layer of black cotton soil and yellow clay of low permeability. The underlying layer of weathered basalts forms the water bearing horizon tapped by most of the dug wells. Sometimes a layer of jointed basalt located at suitable geographic locations show very high permeability and supports high pumping through dug wells. In low lying areas the depth of weathering is greater and often a thick clay layer is also developed which confined the ground water at deeper levels. In the-south-western part of Bhopal (Misrod valley) the basalt exhibits weathering up to a thickness of 30 meters.

The dug wells are the main ground water abstraction structures for the development of ground water in phreatic aquifer of Deccan traps. Large diameter dug wells (6 to 8 in) located in topographic depressions or nearer lo rivers/streams yield, moderate quantity of water. The yield of dug wells in Bairagarh area was recorded up to 600 cum/day. The shallow tube wells around Hataikheda area were found lo yield between 300 and 600 cum/day. In general the shallow aquifer in Deccan traps yield between 100 and 400 cum/day.

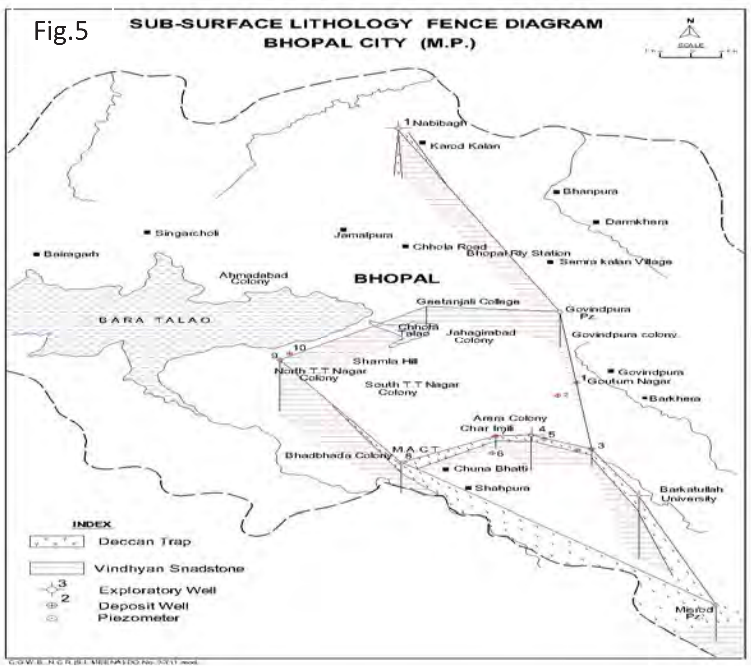
Vindhyan sandstones being general orthoquartzitic in nature are resistant to weathering and do not favour development of thick weathered profile unless the area is predominantly shale. In sandstones groundwater occurs mainly in fractures and along bedding joints. The Vindhyan sandstones in the area occupy mainly higher ground where weathered profile is absent or very thin. It acts as recharge area for the low lying areas. At the base of the hillocks, groundwater occurs in the restricted residuum and joints and fractures of sandstones, supporting dug wells.

It was observed that if at the base of the Vindhyan hillocks infillings of Deccan trap occur as thick weathered profile of basalt, it acts as a conductive layer to arrest the surface water runoff (lowing over the impervious sandstones and recharge the underlying aquifer. In southern part of Bhopal city a potential belt of groundwater occurs all along the base of Vindhyan hillocks of Char Imli Area hills. Shallow tube wells drilled by C.G WB in southern pail show a weathered basalt layer of up to 20 in, thickness overlying the Vindhyan sandstone. The shallow aquifer is formed by the underlying Vindhyan sandstones. The phreatic aquifer formed by the joints and fractures in sandstones, is recharged through the lateral interconnection of fractures in catchment area at higher elevation and also due to downward seepage of arrested surface run-off by the weathered basalts at the base of hillocks lo the underlying joints/fracture in sandstones.

Ground Water Exploration by CGWB shows occurrence of promising aquifer. Vindhyan sandstones in areas at base of Vindhyan hillocks and under the cover of weathered basalt, in the southern and central part of the city. The yield of tube-wells varied from 200-600 1pm. Absence of aquifer in sandstones was observed in areas where Vindhyan sandstones are overlain by massive basalt (Janta Colony D.W.No.3). A borehole was drilled at Shyamla Hill having higher elevation through Vindhyan sandstones down to 146 m. below ground level yet no water bearing horizon has been encountered. However, another borehole drilled in the premises of Manav Sangrahalaya at a favourable location down to 102 m yield around 140 lpm. The yield of shallow boreholes drilled by P.H.E.D. in Vindhyan sandstones in general was measured less than 50 lpm, and was found suitable for installation of hand pumps only. The tube wells tapping relatively deeper aquifer yield between 300-350 lpm.

Under (Indo-British Betwa Ground Water Project of C.G.W.B., exploratory drilling was carried out at Nabibagh. in addition 3 exploratory boreholes were drilled under exploratory drilling program of North Central Region to study the sub-surface geology and delineate aquifer system(s) and their potentiality Subsequently, C.G.W.B. has drilled additional 10 boreholes in Bhopal city under Deposit well drilling program to help the Public Health Engineering Department of Madhya Pradesh, to augmenting drinking water requirements of Bhopal city and of further the aquifer disposition in the area Fig 5 - Fence Diagram.

Fig.5



A fence diagram has been prepared based on the borehole data a perusal plate reveals that on the western side of the major lineament running in NW-SW direction along Misrod valley. The basement of Deccan traps could not be met down to 118.12 m at Sarwar lying outside area of study towards south west. However in the eastern side of this lineament Vindhyan rocks are encountered below the lineament. The thickness of Deccan trap was recorded to be 49.5 m. at Barkatullah University and it gradually decreases towards north up to the out crops of Vindhyan sandstone in and around Bhopal city.

Ground water level

Record of groundwater levels and analysis of their behaviour forms an important tool to understand hydrogeology. In order to study the behaviour of groundwater levels the water levels were recorded from dug wells tapping different water bearing formations in the city. The dug wells generally tap the phreatic aquifer, the location of key observation wells as shown in Fig.6. Depth to Water level.Premonsoon-2010 and Fig 7. DTW, Postmonsoon-2010.

The higher fluctuation in water levels is recorded in Vindhyan sandstones due to low permeability except Nabibagh area which is underlain by Deccan Trap formation.

The water level fluctuation in the major area lies less than 4 m. The higher fluctuation in water levels is recorded in Vindhyan sandstones due to low permeability except Nabibagh area which is underlain by Deccan Trap formation. The water level fluctuation map is shown in Fig.8.

Ground Water Resources & Status of Development

Ground Water Resources

The groundwater resource evaluation for year 2004 indicates that the stage of groundwater development in district has reached to 71% (83% and 61% in Phanda and Berasia block respectively).Bhopal City falls in Phanda block. The Net annual ground water available in the Phanda block is 155.93 MCM and draft from all uses is 128.92 MCM, Net ground water available for future irrigation use is 24.22 MCM only. Thus it has become imperative for further detailed hydrogeological investigation in district for water balance studies making watershed as a unit. Phanda block falls under semi-critical Category.

Status of Ground Water Development

Ground water is the main source for drinking and irrigation in the Bhopal district. About 60% of irrigation in the district is from groundwater, though the level of irrigation in the district is only 28%. The total number of dug wells and tube wells in the district during 2005-06 were 13,080 and 9,708 respectively. On the drinking water front, Bhopal city have water supply from surface water (Upper Lake and Kolar Dam), while the outskirts of Bhopal city is totally dependent on groundwater. 511 villages in the district have tube wells for water supply. It is estimated that there is a steady rise in ground water development in the district. During the year 2004, the stage of groundwater development in the district was 71%, which has increased considerably from 1997 estimates.

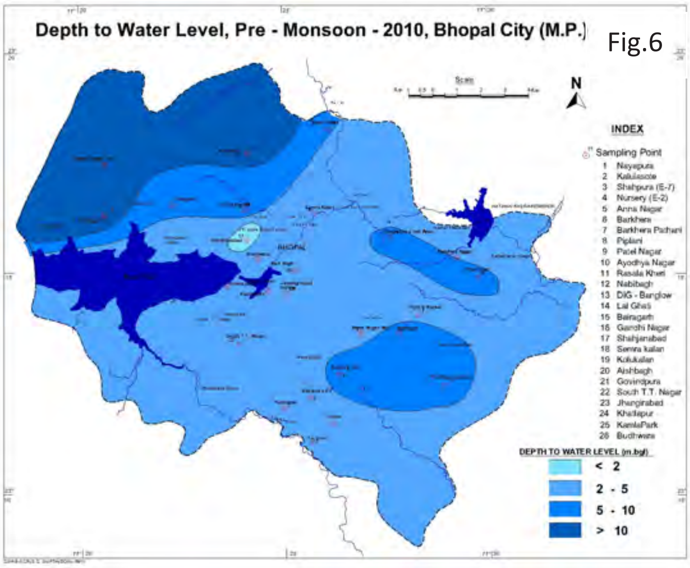


Fig.6

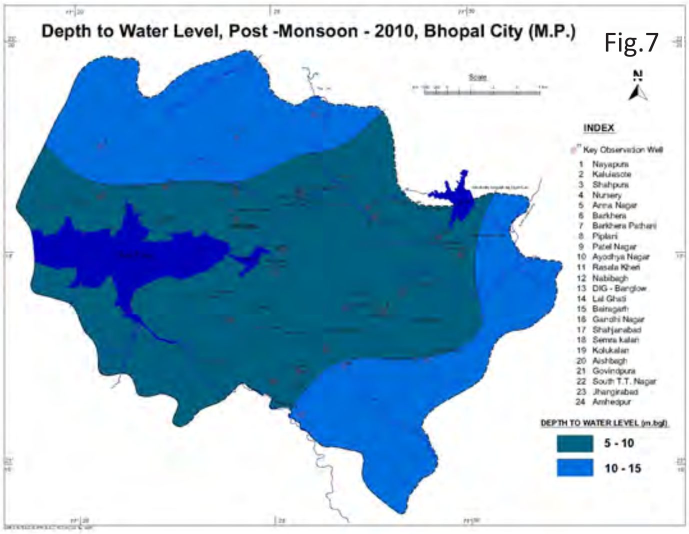


Fig.7

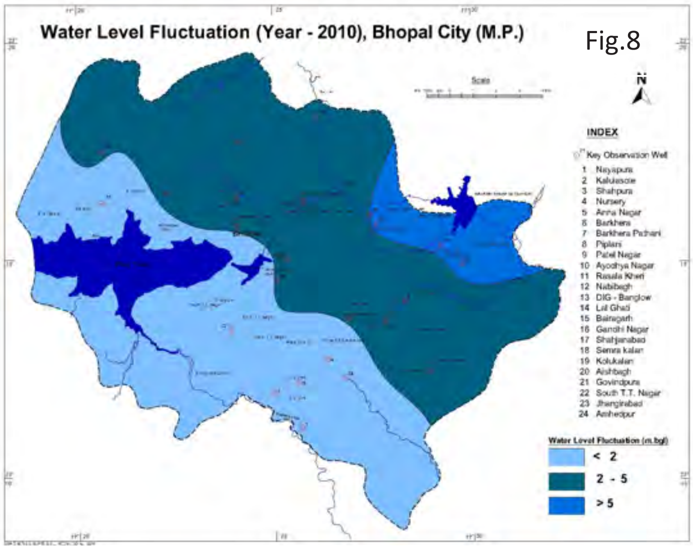


Fig.8

Hydrochemistry

Surface Water Bodies:-Water quality of different water bodies of Bhopal depicted wide variation in its characteristics. The water quality of upper lake, Kaliasot, Kolar, HathaiKheda, Kerwa, Kolar etc are moderate. The relative lower concentration of Nitrate and phosphate reveals the low productivity of the water bodies, while lower concentration of BOD & COD depicts lower content of organic matter in the water body while water quality of lower lake Char-Imli, Sarangpni, Motia, Munsi Hussain, and Shahpura lakes have deteriorated due to urbanization and anthropogenic activities. The high concentration of Nitrate and Phosphate in these water bodies reveals high rate of primary production in the water bodies, while high concentration of BOD and COD depicts the poor water quality with reference to the organic content.

Ground Water Quality:-The water samples were collected from 16 locations in and around Bhopal city during June 2008 and were analysed for major containments to evaluate the chemical quality in the Bhopal city. The chemical analysis data reveals that the water is weakly alkaline in nature as the pH range from 7.16 to 8.09 regarding minerals station of ground water it is good to moderate as evidence by EC values. The highest EC values observed at 1217 µS/cm at 25^0 C Barkhera Pathani followed by 1145 us/.cm at Raslakheri. In remain other locations the values are below 1000 µS/cm at 25^0 C even at four locations it is less than 500 µS/ cm.

Major Ground Water Related Problems

Bhopal city is expanded in all direction and Municipal Corporation is unable to supply water in agglomeration area i.e. Kolar road, Ayodhya by pass, Hoshangabad road etc, these areas are completely depending on ground water and the number of bore hole has increased in many fold high rate of pumping is a main cause in declining water level every year.

Feasibility of Rain Water Harvesting and Artificial Recharge

Ground Water development has resulted in declining ground water levels and depletion of ground water resources in such areas. Artificial recharge efforts are basically aimed at augmentation of the natural movement of surface water into ground water reservoir through suitable civil construction techniques. Occurrence of rainfall in Bhopal is mostly limited to about three months in a year. The natural recharge to ground water reservoir is restricted to this period only in a major part of the Bhopal City. Artificial recharge techniques aim at extending the recharge period in the post-monsoon season for about three or more months, resulting in enhanced sustainability of ground water sources during the lean season.

In Bhopal city 65-70% area is paved and not available to recharge ground water system, roof top rain water harvesting is most suitable technique adopted in the city to recharge phreatic and semi-unconfined aquifer and in the campus of Universities, Engineering Colleges, Government Institutes other various artificial recharge structures i.e. Stop Dam/Recharge Shaft /Percolation Tank can be constructed at suitable site after conducting detail study.

GROUND WATER DEVELOPMENT STRATEGIES

Ground Water Development: The Ground Development in the city is being taken up on need basis without proper back up of scientific investigations. The failure of monsoon of 1989 led to crisis of drinking water in the city. There was a spurt of drilling of boreholes by PHED for installation of hand pump as a measure for augmenting water supply. The desired stress on the scientific selection of drilling sites could not be given due to urgency. The sites for these boreholes were indiscriminately located, even in the proximity of surface pollution sources or near sanitary channels and no sanitary protection was provided in the intake portion of well. As a result many hand pumps have gone defunct due to poor quality of water. Subsequently also the tube wells were constructed to solve drinking water problem at places but selection of sites is not based on scientific approach. In year 2008 again failure of monsoon and city faced great crisis for drinking water, Municipal Corporation at this time drilled large diameter (12”) telescopic gravel pack Bore holes sites were selected keeping in view recharge component

Ground Water Development Possibilities & Recommendations

The share of ground water in the present municipal water supply is only 12.05%.With a view to optimally develop the resource there is need to properly understand the ground water system which would enable to demarcate area feasible for construction of various ground water structures. Bhopal city is mainly hard rock area and the decision for the type of ground water structure to the sunk for ground water development is based on hydrogeological conditions prevailing in different water bearing formation. The different options of ground water development possibilities are as under:-

1. In areas underlain by alluvium, thickness of which is limited to 30m, Dug wells are feasible. The Deccan trap basalt occurs in as lava infillings in the valleys of pre existing Vindhyan topography. The weathered basalt forming phreatic aquifer sustains limited ground water withdrawal mainly through open wells due to low permeability. In areas where vesicular basalt or highly jointed basalt forms the phreatic aquifer dug wells diameter about 3 to 4m may be constructed down to average depth of 15m.The dug wells tapping these aquifer generally yield between 1 to 3 lps and sometime yield is limited i.e. less than 1 lps. The yield of bore holes1 to 3lps drilled in Deccan trap formation down to the depth of 90 to 200 m bgl occur only when thickness of aquifer is more. The average depth of tube well in this formation is recommended to be 60 to 70m.

2. At favourable location Vindhyan sandstone moderate to good aquifer and shallow tube wells are feasible. In general it is found that shallow tube well at the base of Vindhyan hillocks in a narrow belt covered by the weathered profile of Deccan trap basalts are generally successful. Increase in yield is observed at the Deccan trap/ Vindhyan contact and joints/ fractures mat at the depths. In general the higher areas covered by Vindhyans are generally poor in the ground water potential

Conservation of Ground Water Resources

To obtain sustainable yield from groundwater abstraction structures it would be prudent to further recharge ground water resources through suitable artificial recharge structures. Due to highly undulating topography in parts of Bhopal city substantial surplus monsoon run off goes unutilised. There is need to conserve this surplus monsoon run off through simple artificial recharge techniques. The area capable for strong surplus monsoon run off and subsequently to yield the ground water needs to be selected.

Roof top rain water harvesting for ground water recharge is fast catching up as a effective method to conserve water and augment the ground water storage. In the plain areas of basaltic terrain with thick cover of weathered /vesicular basalts forming phreatic aquifer, this method can be implemented. Feasible areas are around Barkatullah University, RGPV University, C.I.A.R, Nabibagh and Various Engineering Colleges etc. where large roof area of Govt. Buildings can be utilised to divert the rain water run- off to dug wells/ shallow tube wells.

BHUBANESHWAR CITY, ORISSA

D.Y. Sirsikar, D.P. Pati, Anirwan Choudhary, CGWB, Bhubaneshwar

INTRODUCTION

Bhubaneswar, the capital of Odisha is known as “Temple City of India”. The city has rich cultural background and represents some of the finest manifestations of Kalingan style of temple architecture. Bhubaneswar at present stands at the confluence of the past and the present and proudly manifests the soaring spire of Lord Lingraj, the Raja Rani temple, the Pagoda of Dhauli, popularly known as the white dome of peace, the Jain temples and the caves of Khandagiri and Udaigiri. Bhubaneswar, once a flourishing capital of ancient Kalinga, is today the largest city in Odisha. The city has a long history and it dates back to the period of great Mauryan emperor Ashoka. During the days of Mauryan Emperor, it was known as “Tosali”, the Capital City of Ancient Kalinga. The serene land has such inherent mysterious power that it could turn the great Mauryan Emperor Ashoka to the compassionate teachings of Lord Budha after horrendous Kalinga war in the 261 B.C. Today, because of its magnificent culture and heritage, Bhubaneswar is an important tourist centre not only in India, but also in the whole world. Tourism is the major industry of the city. The Lingaraj Temple, Mukteswar temple and Raja Rani Temple(1000 AD), Ashok inscriptions at Dhauli, archaeological remains of Sisupalgada (300 B.C.) and Jain monuments of Khandagiri and Udaygiri (between 200 B.C. to 100 A.D.) are some of the important monuments of the city. The old city, popularly known as, Ekamrakhsetra, featured by conglomeration of temples, monuments, mandapas, heritage ponds etc. The city was adopted as the Capital city of Odisha in 1948. Subsequently a number of offices, organizations and other infrastructural facilities developed in the city to keep pace with time. As of now, Bhubaneswar is under tremendous pressure because of the rapid urbanization and tourist importance. The present Bhubaneswar is transforming towards a new identity apart from its cultural heritage, as a major centre for information technology, educational and research organization and attracting millions of tourists both from India and abroad.

GENERAL FEATURES

Area / Administrative Divisions

The Bhubaneswar city lies in the eastern part of Orissa State. The master plan area of city includes major part of Bhubaneswar block of Khurda district and also small part of Cuttack and Puri districts. It is situated between latitudes of 20°12′N to 20°25′N and longitudes between 85°44′E to 85°55′E and falls within Survey of India toposheet nos. 73 H/15 and 73 H/16 (1: 50,000 Scale).The city master plan area covers 233 sq.km. though the municipal area of Bhubaneswar Municipal Corporation covers only 135 sq. km. The city is divided into 30 wards(converted from its original 28 villages). It is situated on the South Eastern Railway line joining Howrah and Chennai at a distance of 435 Km South of Kolkata. Bhubaneswar is well connected with the main cities are Kolkatta, Chennai, Hyderabad and Visakhapatnam by Highways, Railways and Airways. The location map of Bhubaneswar city is given in figure 1.

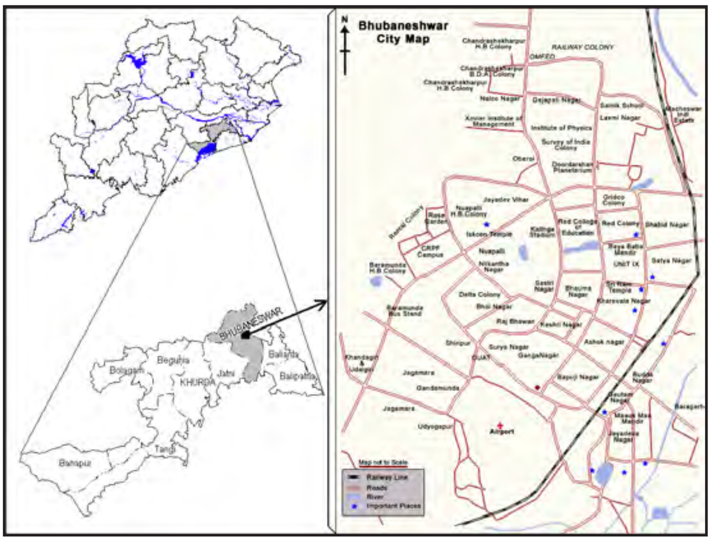


Figure 1 : Location Map of Bhubaneswar City, Odisha

Demography

The extent of infrastructure requirements and urban services mainly depend on size of the population residing in the city. The city has grown from a meager population of 8170 in 1921 to 6,57,477 in the year 2001, which is highest in the state.. There has been steady growth of population in Bhubaneswar city except for the first two decades when there was a drop in the population. This was mainly due to epidemics like cholera, plague etc. There has been sudden rise since 1941. The sudden rise in population was due to the migration of the people from all over Odisha to Bhubaneswar. The city experienced the highest growth rate in 1961-1971. This was the highest growth (176.07%) rate experienced by any other capital cities in the country. This was due to expansion of the administrative, liaison, and institutional and industrial activities.Later on the city experiencing a fall in the population growth rate. The reduced population growth during 1981 to 1991 could be the restricted industrial development due to the declaration of the Bhubaneswar Urban Area as the 'Air Pollution Control Area'. The increase in population from 1991 to 2001 at the normal rate is the normal urbanization trend as is happening in other cities of the country. The Projected Population for 2011 is likely to be around 13,14,954. The average tourist inflow to the city is around 3500 per day.

Hydrometeorology

The city experiences a humid sub-tropical climate. The rainy season is from June to September. The winter extends from December to February. And summer season is from March to May. The average annual rainfall is around 1380 mm (1996 to 2009) and about 80 % of annual rainfall is received from the South-West monsoon from June to September. The analysis of long term rainfall data indicates that on an average the city experiences mild drought in 30% cases and 8% normal drought and no severe drought. May is the hottest month with the mean daily temperature of 38 °C while December is the coldest month with mean daily temperature around 16 °C. The mercury occasionally rises upto 48 °C during summer and it drops to 9.4 °C during the winter. The relative humidity varies from 48 to 85% and sometimes goes upto 95% during rainy season. Wind speed is fairly strong during summer and monsoon months and major directions from SW and South. The average wind speed is around 14 Km/ Hour. The mean monthly potential evapo-transpiration varies from 57 mm during January to 248 mm during May.

Physiography & Drainage

Bhubaneswar city area is characterized by undulating upland topography in western and central part while eastern part shows more or less flat topography with gentle slope towards east or south east. Altitude varies from 60m in the western part to 15m in the extreme eastern part. The East Coast Railway line forms the broad boundary between the above mentioned morphological setups. The upland areas shows lateritic cover while gently sloping area shows mainly alluvial cover with or without thin lateritic cover on the top. The upland areas in the western part are dotted with isolated hillocks made up of shale-sandstone sequence of Upper Gondwana rocks belonging to the Athgarh Formation. The main drainage channel is the Kuakhai River which is a distributary of the Mahanadi River. The Kuakhai River flows more or less along the eastern margin of the city. The Kuakhai River has been subdivided into Bhargavi and Daya River in the extreme south eastern part of the city. The Daya River flows in more or less along the south eastern margin of the city. Besides these, a number of small streams originates from the western upland areas and flows through the city mostly in easterly and south easterly direction and falls either in Kuakhai or Daya River. The Kuakhai and Daya rivers are perennial while the other minor streams are ephemeral in nature. The hydrogeomorphological map of the Bhubaneswar city is shown in figure 2.

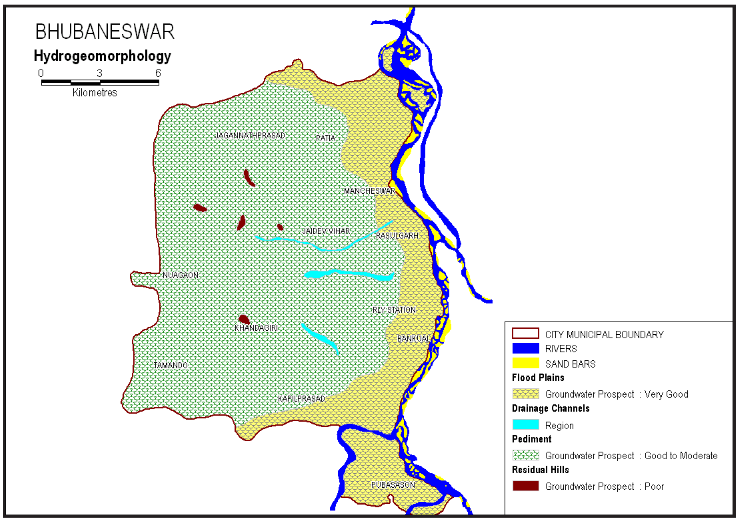


Fig 2 : Hydrogeomorphological Map of Bhubaneswar City

Soil Type

The soils of the city can be divided into Alfisols and Ultisols

Alfisols : The texture of this soil is sandy loam and these occur in the eastern part of the city. The soils are generally deficient in phosphorous and nitrogen and pH ranges from 6.5 to 7.3.

Ultisols : The laterite and lateritic soils cover rest of the city area. These soils are characterized by a compact to vermicular mass in sub-soil horizons, composed merely of mixture of hydrated oxides of Aluminium and Iron and are devoid of the alkali and alkaline earth metals.

STATUS OF WATER SUPPLY & DEMAND

The PHED at present (March' 2010) supplies 206 million litres per day (MLD) of water through pipe water supply scheme and out of which the supply from ground water source is 41.6 MLD and the rest is from the surface water source. PHED generally withdraws 41.6 MLD i.e., 4.16 ham / Day of ground water through 103 deep bore wells for pipe water supply. Besides this, the dwelling complexes like flats and individual house owners also use ground water where PHED pipe water supply is not available. It has been estimated that about 20 MLD ground water is drawn in addition to PHED supply through shallow / deep bore wells and open / dug wells on private capacity which accounts for 2 ham per day. The estimated water requirement for the city by the year 2020 is about 422 MLD at the rate of 165 litres per person per day. Apart from this, there may be additional requirement of water for smooth functioning of city life. The available ground water resource in the city master plan area indicates that ground water can supply 122 MLD maximum considering 85% utilization of the available annual replenishable ground water resources of 5242.5 ham. The balance requirement which amounts to more that 300 MLD is to be met from other resources like surface water sources etc. However, ground water draft of 162 MLD may be feasible considering the fact that the draft during rainy season does not affect the annual replenishable resource and available resource can be utilized for non-rainy seasons. Under this situation also the balance requirement of 260 MLD of water is required to be arranged from other sources. The water supply system of Bhubaneswar is given below in figure 3

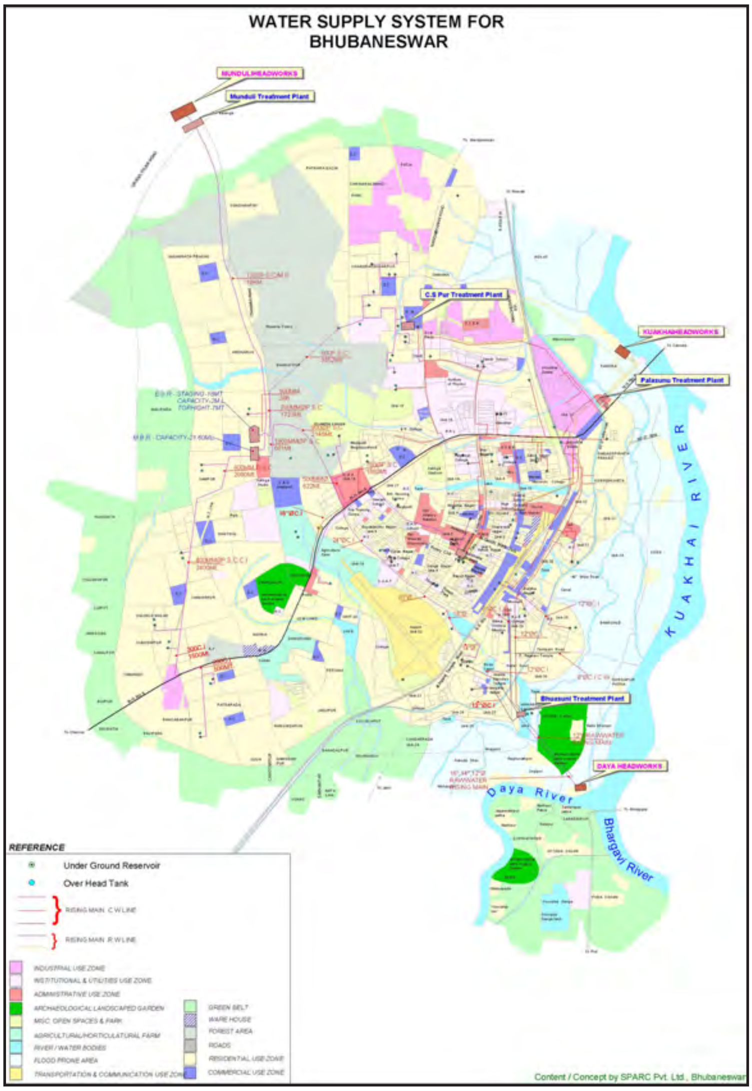


Fig 3 : Water Supply map of Bhubaneswar city, Odisha
(Source PHED, Govt. of Odisha)

WATER PROFILE

Surface Water

Bhubaneswar City gets its water supply from Mahanadi, Kuakhai and Daya River. River Daya and River Kuakhai are needed for drinking water supplies for the current and the future needs of the City and for carrying storm water from the City. Presently, water supplied to the City is about 164 MLD. In addition to this there are about 500 and odd temples mostly confined to the Old Town area. Each temple in this part of the city has one or more water tanks nearby. Some are quite small while others represent huge expanse of freshwater. As regard to their origin, temple ponds are believed to have originated initially as vast depressions created by removing enormous amount of soil needed to built earthen ramps that were used for dragging the huge blocks of stone to heights corresponding to the rising height of the temple under construction. After the completion of the temples, these depressions were sized and lined with the surplus stone available and were converted into temple ponds for use during daily rituals and festive occasions. There are around 10 heritage tanks and another additional 13 manmade tanks covering an area of over 70.39 hectares. There are some minor cold water springs in the western upland areas. The springs are mostly seasonal and discharges of water in these springs are either water trickles down or oozes out or are have 0.5 to 1.5 lps discharge with variation in different reasons.

Ground Water

Ground water development is through open / dug wells, shallow and deep bore wells as well as shallow and Filter point tube wells. PHED, Govt of Odisha is the major organization for withdrawal of ground water for domestic water supply. Besides this, the dwelling complexes like flats and individual house owners also use ground water where PHED pipe water supply is not available. The top weathered zone overlying the gritty and partially lateritized Athagarh sandstones of Gondwana are mainly tapped by dug wells & filter point tube wells. In general it has been found that the ground water from both the shallow and deeper zones are slightly acidic in nature. The deeper aquifer though in general contain a little higher concentration of iron than that of permissible limit but the dug well water normally does not show any higher concentration beyond permissible limit except in isolated cases as the dug well water remains in constant contact of atmospheric air which facilitates oxidation and precipitation of iron.

GROUND WATER SCENARIO

Potential Aquifers

Bhubaneswar city is underlain by geological formations belonging to Upper Tertiary and Quaternary age. The Upper Tertiary formations include shale-sandstone sequence belonging to the Athgarh Formation of Upper Gondwana Group. The Quaternary formations include laterites and alluvial deposits.

The major part of the city i.e., western and central part are underlain by shale-sandstone sequences of Athgarh Formation. The sandstones are fine to coarse grained, white to grey in colour and feldspathic in nature. These sandstones are at times pebbly, conglomeratic, gritty and ferruginous and are intercalated with greyish white, pinkish and carbonaceous shale and kaoline. The sandstones in general though fractured and friable but are hard and compact at places. The near surface parts of the sandstones are generally partly lateritised. The thickness of the Athgarh Formation in major part of the city is more than 200m. The Quaternary formations comprises mainly of laterites and alluvial deposits. The laterite and lateritic gravels mainly occur in the central and western part as capping over the country rocks. The thickness of laterites on average is around 4 to 5m with the maximum around 12 to 13 m at local pockets. The thick laterite cover generally occurs in the western upland part of the city. The alluvial deposits which include mostly Recent alluvium occurs as thin layers along the extreme eastern part of the city. The maximum thickness is around 30 to 40m and composed of clay, silt and fine to medium coarse sand. The Alluvial deposits are underlain by the Athgarh Formation. The hydrogeological map of Bhubaneswar city is given in figure 4.

Athgarh Formation: The aquifer systems in this formation at shallow as well as at deeper depths are mainly formed by sandstones. The shale form mainly phreatic aquifers and that also with limited potential. The weathered zone extends down to 12 to 15m and top weathered part down to an average depth of 5 – 6m is lateritised. The yield from the dug wells on an average is around 20 – 25 m^3 / day, if sandstone predominates. The same is around 10 – 12 m^3 / day, if shale predominates. The yield factor in sandstones generally varies from 1 – 2 lpm / m^2 / m of drawdown while the same in shale is less than 1 lpm / m^2 / m of drawdown. The yield from the deeper fractures varies widely and mostly fractured and friable sandstones form the aquifer zones. The wells were drilled down to a maximum depth of 151 m and the yield varied from 1.5 lps to 30 lps with the average around 7 – 10 lps. The fracture zones are generally restricted within 100 m depth. The depth of static water levels vary between 8 – 12 m below ground level during summer and drawdown of water levels during pumping is restricted within 30 m. The specific capacity values ranges from 9.47 to 252.4 lpm / m of drawdown with the average value around 90 – 100 lpm / m of drawdown. The transmissivity values ranges from 15 - 258 m^2 / day with the average around 100 m^2 / day.

Laterites : The laterites form only phreatic / shallow unconfined (dug well zone) aquifers mostly in western and west central part of the city but in other part the laterite aquifers are seasonal(Perched Aquifers) i.e., holds water upto January or February month due to len thickness 4 to 5 m. In the western part on an average laterite forms aquifers down to 10 – 14 m depth and hold water almost throughout the year. The yield of the existing dug wells in these aquifers upto the month of December / January on an average is around 30 – 35 m^3 / day and afterwards reduces due to depletion of water levels. In the west central part the lateritic aquifers form seasonal aquifers as the average thickness of the laterite is only 4 – 5 m. The dug wells which tap only laterite generally go dry after January / February. During post monsoon season these existing wells yields water around 30 – 35 m^3 / day. As such only lateritic aquifers are not dependable for meeting up water supply throughout the year even for individual house hold unless sandstone aquifers occurring below them are tapped. The yield factor in laterites is generally 2 lpm / m^2 / m of drawdown.

Un-Consolidated Formation : This formation includes sand, clay, silt layers which occurs in the extreme eastern part of the city. The thickness varies from negligible to a maximum of 30 – 40 m. The aquifers are mainly formed by the sand layers and may be divided into shallow unconfined and deeper semi-confined aquifers. The yield of the existing dug wells in shallow aquifer on average, is around 40 – 45 m^3 / day and the yield sustains throughout the year without any variation. The yield factor of the alluvial aquifers is generally 2.5 – 3 lpm / m^2 / m of drawdown. The yield from deeper zones which are generally tapped by tube wells depend upon the thickness of alluvial deposit and also on the cumulative thickness of sand zones (medium to coarse sand). On an average 4 – 6 m thick (individual or cumulative thickness) medium to coarse sand layers may yield upto 35 lps with the average yield of 15 to 20 lps. The drawdown of pumping water level is generally within 6 / 7 m and tube wells may be run for 8 – 9 hours in a day and continuously for 3 – 4 hours. The water level in these tube wells generally rests within 4 – 5 m during peak summer.

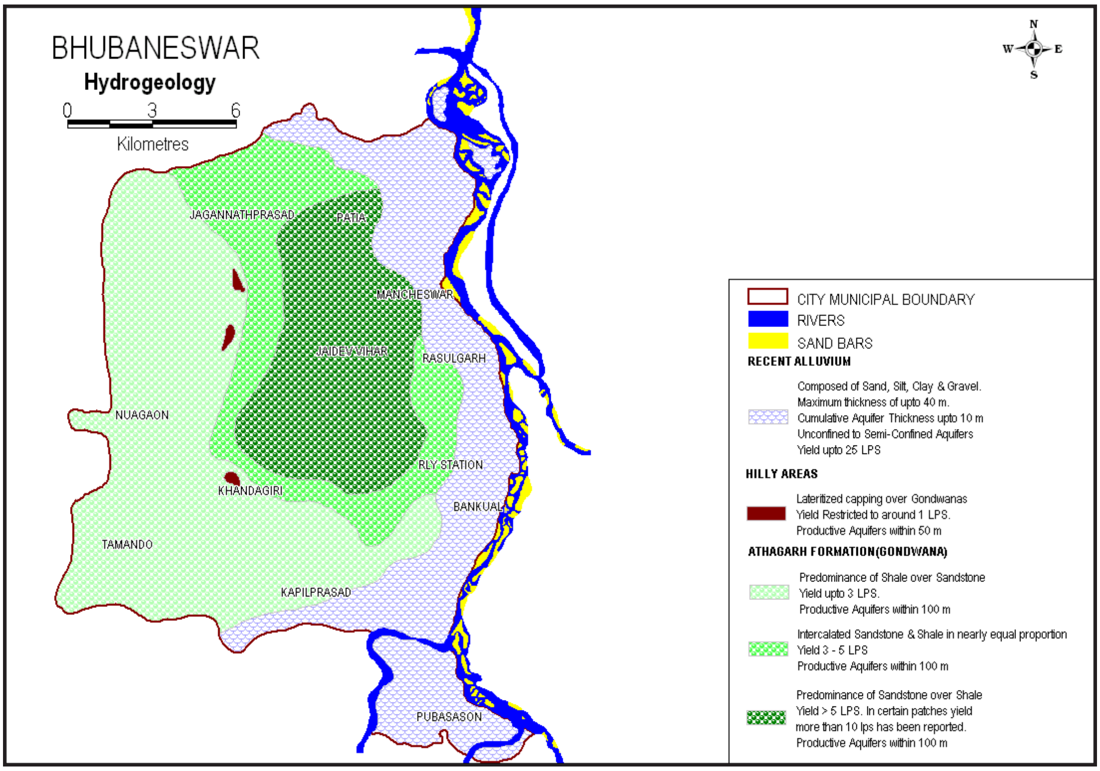


Fig 4 : Hydrogeological Map of Bhubaneswar city , Odisha

Ground Water Level

Ground water regime was earlier monitored by Central Ground Water Board, four times in a year through 5 permanent hydrograph stations which are dug wells and also through 2 Piezometers constructed under Hydrology Project. Since 2009, 51 additional stations have been established in the master plan area and are being monitored on a monthly basis. The pre-monsoon depth to water level(2009) of the phreatic aquifers varies from 1.22 mbgl to a maximum of 11.30mbgl with an average of around 4.77 mbgl. The post-monsoon depth to water level(2009) of the phreatic aquifers varies 1.08 mbgl to a maximum of 9.02 mbgl with an average of around 4.38 metres below ground level. The seasonal fluctuation of pre vs. post monsoon depth to water levels varies from a fall of 2.27 m to a rise of 3.97 with an average rise of about 0.39 m. The depth to water level maps of phreatic aquifers in 2009 are shown in figure 5.

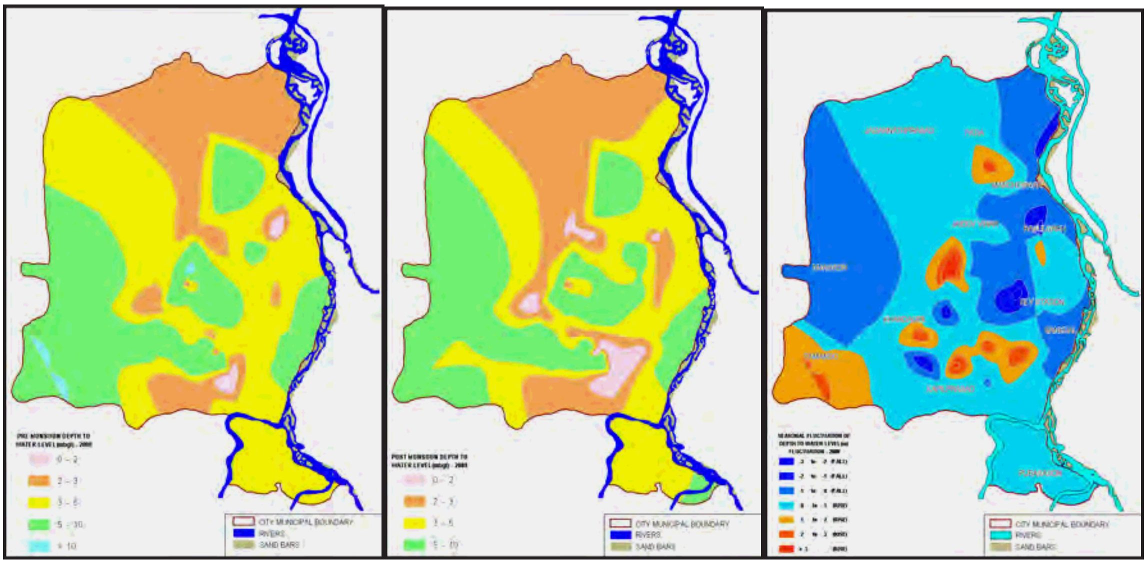


Fig 5 : Pre & Post Monsoon Depth to Water Level 2009 & Fluctuation(Phreatic Aquifer) Map of Bhubaneswar City

Long Term Scenario : The average range of depth to water levels, from 2000 to 2009 is furnished in table 1 below

Table 1 : Average Water Levels (2000 – 2009) of Bhubaneswar City

Location	January	April	August	November
	Metres below ground level			
Saheed Nagar	4.11	4.02	2.41	3.34
Kapilprasad	5.56	5.41	0.96	2.83
Khandagiri	12.71	12.95	10.99	10.59
Patia	5.08	5.52	1.72	3.9
Raghunathpur	1.96	2.53	2.34	2.03

The above table indicates that, the average water level during pre monsoon period along central part of the city varies from 4 – 5 m while in the western part (Khandagiri) the water level is deep. Similarly during post monsoon period the water level along the central part varies from 2 – 3.4m and it is deep in the western part. During pre-monsoon period depth to water level remains between 2 – 4 m depth range in the eastern, southern and north eastern part of the city and water level is deep (> 8m) in the extreme WNW sector of the city. The water level ranges between 4 – 6 m depth in the central part. During post monsoon period water level is less than 2 m depth in the eastern, southern and north eastern part. The water level is more than 6 m deep in the WNW sector. In the rest of the area, water level varies from 2 – 6 m depth range. The average water level fluctuation with respect to pre and post-monsoon is to the tune of 2 – 3 m only.

The trend of water levels on long term basis (2000 – 2009) has been studied for pre-monsoon and post-monsoon season periods based on the data of permanent hydrograph stations and presented in the following table 2 below

Table 2 : Trend of Ground Water level (2000 – 2009)

Location	Pre-Monsoon		Post-Monsoon	
	Rise(m)	Fall(m)	Rise(m)	Fall(m)
Saheed Nagar	-	0.031	0.042	-
Kapilprasad	-	0.025	0.089	-
Khandagiri	-	0.149	-	0.082
Patia	-	0.147	0.065	-
Raghunathpur	0.144	-	0.274	-

The table above shows rise and fall during pre and post-monsoon periods and values of rise and fall are of vary minor magnitudes. Hence the values of rise and fall are ignored and opined that the water levels remain more or less same over the years indicating no adverse affect on the ground water regime quantitatively.

Water Table Configuration : An attempt was made to depict the water table configuration of pre-monsoon period by using water level data of National Hydrograph Stations and other water level data collected during different investigations. Based on the available data, water table configuration could be depicted for central, eastern and southern part of the city and contour indicates that water table varies from 35 m amsl in the central part to 15 m amsl in the east central part. The ground water flow is towards east and south east. i.e., towards the rivers, bordering eastern and south eastern boundary of the city. The water table gradient on an average varies from 0.5 m / Km to 2 m / Km in the major part of the city, which indicates that the nature of the water table.

Ground Water Resource & Status of Development

The Annual replenishable ground water resource for the master plan area (233 Sq.Km.) has been estimated following the GEC norm,1997 considering the available data on water level fluctuation and specific yield of the formation. Based on the data, average water level fluctuation was considered as 3 m and specific yield as 7.5 %. It is found that the annual replenishable ground water resources is to the tune of 5242.5 Hectare Metre (HaM) for the city master plan area. Due to the absence of precise data the resource of deeper zones could not be estimated, however, this resource (5242.5 HaM) can be taken as annual replenishable resource for both shallow and deeper zones down to 100 m depth because major part of the city area is underlain by semi-consolidated highly fractured sandstone. The shallow and deeper aquifers appears to be directly connected.

Ground water development is through open / dug wells, shallow and deep bore wells. PHED, Govt of Odisha is the major organization for withdrawal of ground water. PHED generally withdraws 41.6 MLD i.e., 4.16 HaM / Day. Besides this, the dwelling complexes like flats and individual house owners also use ground water where PHED pipe water supply is not available. It has been tentatively estimated that these flats and individual houses, small industries and PHED hand pumps together draws 20 MLD ground water through shallow / deep bore wells and open / dug wells which accounts for 2HaM per day. The total ground water withdrawal is 6.16 ham per day and annual figure becomes 2248.4 ham (say 2250 ham). But it can be assumed here that during rainy season, the withdrawal of ground water is immediately replenished by the rain water. Hence the draft for rainy season which accounts for 549 ham (6.16 ham per day X 90 days) is balanced by rainfall and actual draft may hence be assumed to be only 1701 ham, which is 32.24 % of the available ground water resource. The balance ground water resource is 3541.5 ham.

Hydrochemistry

The ground water quality of the Bhubaneswar city has been studied by analysing water from dug wells and bore wells. In general it has been found that the ground water from both the shallow and deeper zones are slightly acidic in nature. The deeper aquifer though in general contain a little higher concentration of iron than that of permissible limit but the dug well water normally does not show any higher concentration beyond permissible limit except in isolated cases as the dug well water remains in constant contact of atmospheric air which facilitates oxidation and precipitation of iron. The analysis data also indicated that concentration of different chemical constituent and pH vary in pre and post monsoon period. A perusal of data revealed that pH is low in majority of the cases and in some cases iron content is high particularly in deeper aquifer water. As per BIS norms the water is fit for drinking purpose except for lower pH value in majority of the cases and high iron content in deeper aquifer in some cases. The pollutants like nitrate and fluoride etc. are generally within the permissible limits, though, higher concentration of nitrate is noticed in some isolated pockets. This indicates that proper treatment is needed to raise pH values and reduce the iron content though iron content does not create any major health problem except staining utensils, clothes etc. The seasonal areal distribution of chemical parameters of phreatic and deeper aquifers are given in figure 6 and 7 respectively. The range of chemical parameters for both shallow and deeper aquifer are given in table 3 below

Table 3 : Range of Chemical Parameter of Ground Water in Bhubaneswar

Parameters (in mg / l except pH)	Indian Standard (BIS: 10500, 1991)		Total No. of Samples from shallow and Deeper zones	No. of Samples within Standard Limit	% of Sample above Permissible Limit
	Desirable Limit	Permissible Limit			
pH	6.5 – 8.5	No Relaxation	80	10	87.5
TDS	500	2000	80	80	Nil
Total Hardness	300	600	80	80	Nil
Calcium	75	200	80	80	Nil
Magnesium	30	100	80	80	Nil
Chloride	250	1000	80	80	Nil
Nitrate	45	100	80	79	1.25
Sulphate	200	400	80	80	Nil
Fluoride	1	1.5	80	80	Nil
Iron	0.3	1.0	80	67	16.25

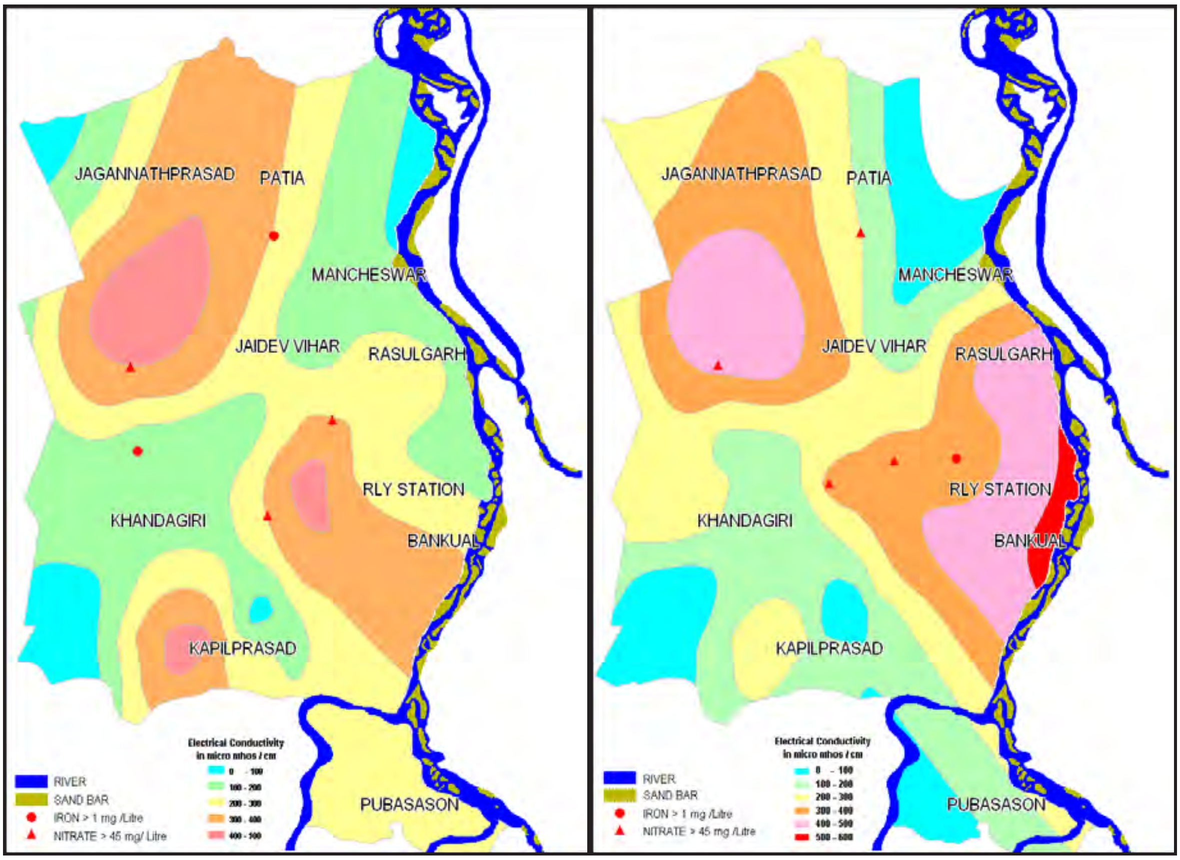


Fig 6 : Pre and Post Monsoon Water Quality(Phreatic Aquifer)

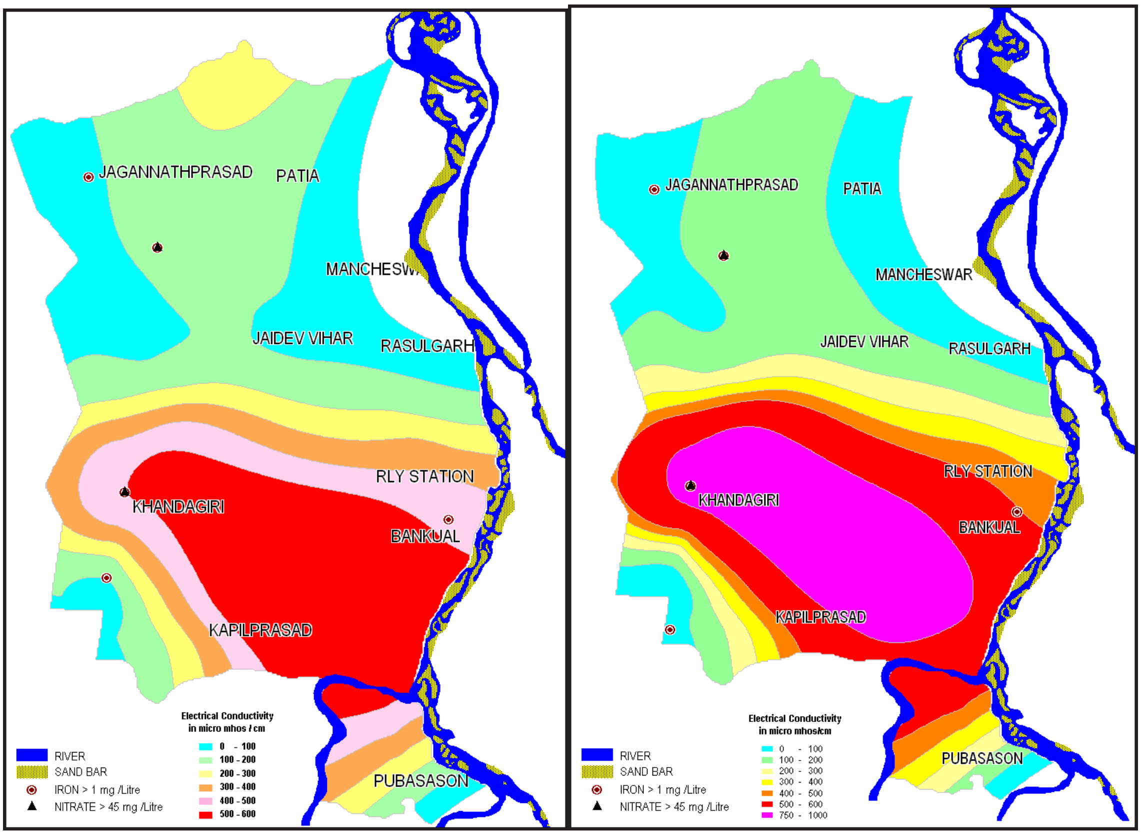


Fig 7 : Pre and Post Monsoon Water Quality(Deeper Aquifer)

Major Ground Water Related Problems

In general it has been found that the ground water from both the shallow and deeper zones are slightly acidic in nature. The deeper aquifer though in general contain a little higher concentration of iron than that of permissible limit but the dug well water normally does not show any higher concentration beyond permissible limit except in isolated cases as the dug well water remains in constant contact of atmospheric air which facilitates oxidation and precipitation of iron. The analysis data also indicated that concentration of different chemical constituent and pH varies in pre and post monsoon period. A perusal of data revealed that pH is low in majority of the cases and in some cases iron content is high particularly in deeper aquifer water. As per BIS norms the water is fit for drinking purpose except for lower pH value in majority of the cases and high iron content in deeper aquifer in some cases. The pollutants like nitrate and fluoride etc. are generally within the permissible limits, though, higher concentration of nitrate is noticed in some isolated pockets.

Feasibility of Rainwater Harvesting and Artificial Recharge

The PHED at present utilizes 41.6 MLD of ground water for domestic supply. The expected requirement of water by 2020 is 422 MLD. Apart from this, there may be additional requirement of water for smooth functioning of city life. The available ground water resource in the city master plan area indicates that ground water can supply 122 MLD maximum considering 85% utilization of the available annual replenishable ground water resources of 5242.5 ham. Considering the huge requirement of water, steps are to be taken for augmentation of ground water resource by artificial recharge method. Rain water may be used as a source for artificial recharge. The entire rainwater precipitating on the roof top of any building may be collected at one or more place on the ground surface and same may be injected underground through pits, trenches etc. This will facilitate in augmenting ground water resources. The roof top harvesting of rain water should be made mandatory for each building in the city area. Apart from this, surface storage facilities like tanks, lakes, ponds etc. should also be created and / or renovated as far as possible.

GROUND WATER DEVELOPMENT STRATEGY

Augmentation of Drinking Water Supply from Existing Ground Water Resources

The PHED presently supplies 206 MLD of water through pipe water supply scheme out of which ground water source supplies 41.6 MLD. The estimated water requirement for the city by the year 2020 is about 422 MLD at the rate of 150 litres per person per day. Apart from this, there may be additional requirement of water for smooth functioning of city life. The available ground water resource in the city master plan area indicates that ground water can supply 122 MLD maximum considering 85% utilization of the available annual replenishable ground water resources of 5242.5 ham. The balance requirement which amounts to more that 300 MLD is to be met from other resources like surface water sources etc. However, ground water draft of 162 MLD may be feasible considering the fact that the draft during rainy season does not affect the annual replenishable resource and available resource can be utilized for non-rainy seasons. Under this situation also the balance requirement of 260 MLD of water is required to be arranged from other sources. However, pumping schedules should be clearly be synchronized in different part of the city specially in the high population pockets and in areas with higher density of ground water abstraction structures to reduce the effects of cumulative drawdown. Also people should be encouraged to use dug well water for both potable and non-potable use to reduce the stress on the underlain deeper confined to semi-confined aquifers. The ground water development possibility map is given in figure 8

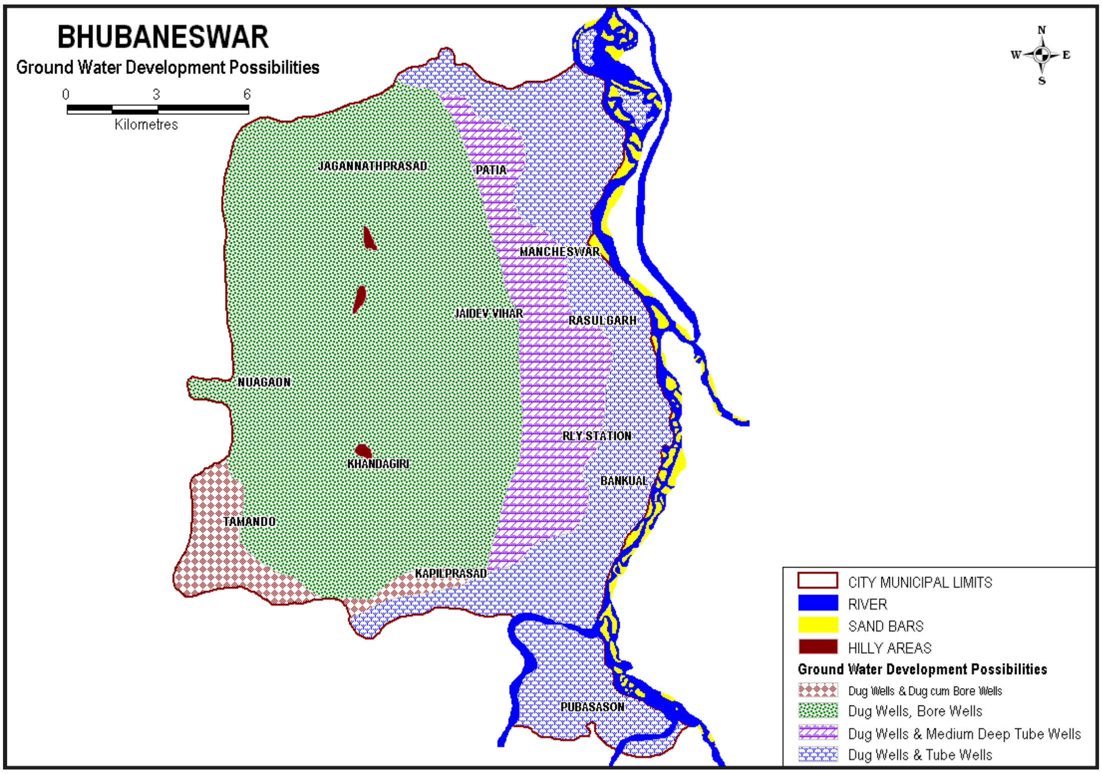


Fig 8 : Ground Water Development Possibility Map of Bhubaneswar City, Odisha

Augmentation of Water Resources by Water Conservation etc.

As described earlier there are more than 10 heritage tanks and about 13 man made tanks in Bhubaneswar. These have been the traditional spots for rainwater conservation since time immemorial. In addition to this there are a number of small nallahs, drainage channels, springs. Due to the rapid stress of urbanization, most of these natural drainage channels have now become obscured or blocked. Efforts must be made to demarcate these areas and make them encroachment free. This will improve drainage congestion and restore hydrological equilibrium of the city area. Apart from this, under JNNURM, Bhubaneswar Development Authority undertook steps to study the feasibility of renovation / restoration of old tanks and other water bodies. Once implemented, this will enhance the ground water recharge in the environs and improve both the quality and quantity of the ground water.

Considering there is 70.39 hectares(≈ 7,03,900 m^2) area of water bodies and 50% of it to be repaired / restored / renovated. Once renovated, considering 60 days monsoonal storage about 10,55,850 m^3 / year of water can be potentially recharged to the phreatic aquifer from these existing water conservation structures. The renovation / repair / restoration cost on an average @ Rs. 50/- per square metre will amount to Rs. 1,75,97,500/-

Augmentation of Water Resources by Artificial Recharge etc.

Considering the huge requirement of water, steps are to be taken for augmentation of ground water resource by artificial recharge method. Only rain water should be used as a source for artificial recharge. Besides above, it is very much necessary to keep a vigil on ground water regime of Bhubaneswar city both quantitatively and qualitatively. The ground water level monitoring periodically by construction of piezometers in the city area on a grid pattern should be initiated to reveal the exact ground water scenario in finer detail. Indiscriminate boring, particularly in the municipal area by multi-storeyed dwelling or other complexes should be restricted, otherwise ground water depletion in local pockets may happen. Additionally, proper disposal of huge city garbage should be ensured, so that ground water should not be polluted. This should be checked by Periodic monitoring of ground water quality.

As per the latest comprehensive development plan for the city of Bhubaneswar(as per Bhubaneswar Development Authority) a total of 96.21 sq. km. of area is earmarked for buildings which includes residential, commercial, Industrial, Institutional and Utilities and Administrative areas. The envisaged land use pattern is given below in table 4.

Table 4 : Envisaged land use pattern of Bhubaneswar City(CDP)

Sl	Landuse	Area in Sq. Km.	% of Total Area
1	Residential	75.40	32.7
2	Commercial	4.94	2.14
3	Industrial	5.86	2.54
4	Institutional & Utilities	7.11	3.09
5	Administrative	2.9	1.26
6	Open Space	13.77	5.98
7	Transport & Communication	18.91	8.21
8	Water Bodies	33.82	14.7
9	Drainage Channel	2.59	1.10
10	Green Belt including Protected Forest & Reserve Forest	68.15	28.3
	TOTAL	**233.3**	**100**

In view of the above it is expected that a huge surge of population will live within the city municipal limits. This would in turn trigger an accelerated water consumption which in turn will evolve to an addition dependence ground water and add stress to the existing ground water regime.

Under such circumstances the following measures for artificial recharge is proposed for the city of Bhubaneswar.

1. Roof top rain water harvesting to be made mandatory to all new constructions hence forth. First all the governmental building and infrastructures(existing/ under construction / under consideration) should adopt roof top rain water harvesting. For around 20 such buildings feasibility studies may be undertaken.

2. As per CGWA guidelines, all commercial establishments, hotels, Apartment complexes, Malls etc should mandatory implement a Rain water harvesting scheme which should include a component of Artificial recharge to ground water as well. Around 20 such complexes exist and feasibility studies may be carried out for the same.

3. In all the green belts, in addition to renovating & restoring the existing ground water conservation and storage structures, new cost effective structures may be constructed. On a pro-rata basis it is estimated that an additional 100 such structures are feasible in the city.

Considering 60 days of monsoonal storage, the potential recharge from 100 proposed water conservation structures is expected to be around 45,000m^3 / year to the phreatic aquifer. Again considering at least 40 recharge bore wells is feasible in the City which are capable of taking 1 lps of water on an average, for 60 monsoon days, potential recharge to the underlain deeper aquifer is expected to be around 3,11,040 m^3/year. Thus if feasible and implemented the water conservation and rain water harvesting is expected to recharge around 15,05,850 m^3 of water per year to the phreatic aquifer & around 3,11,040 m^3 of water per year to the deeper aquifer. The areal distribution of the proposed rainwater harvesting plan are given in figure 9

Expected Cost Component for Water Conservation and Artificial Recharge:

1. Feasibility Studies for Roof Top Rain Water Harvesting @ Rs. 5,000/-each X 40=	Rs. 2,00,000/-
2. Roof Top Rain Water Harvesting @ Rs. 15,00,000/- each Govt. Buildings X 20 =	Rs.3,00,00,000/-
3. Roof Top Rain Water Harvesting @ Rs. 5,00,000/- each Commercial Complex X 20=	Rs.1,00,00,000/-
4. Operational & Maintenance cost per year @ Rs. 10,000/- each X 40 =	Rs. 4,00,000/-
5. Impact assessment studies @ Rs. 2000/- each per year X 40 =	Rs. 80,000/-
6. Construction of Water Conservation Structures @ Rs. 1,00,000/- each X 100 =	Rs.1,00,00,000/-
7. Repair/ Renovation / Restoration of Existing Water Conservation Structures =	Rs.1,75,97,500/-
TOTAL	Rs. 6,82,77,500/-

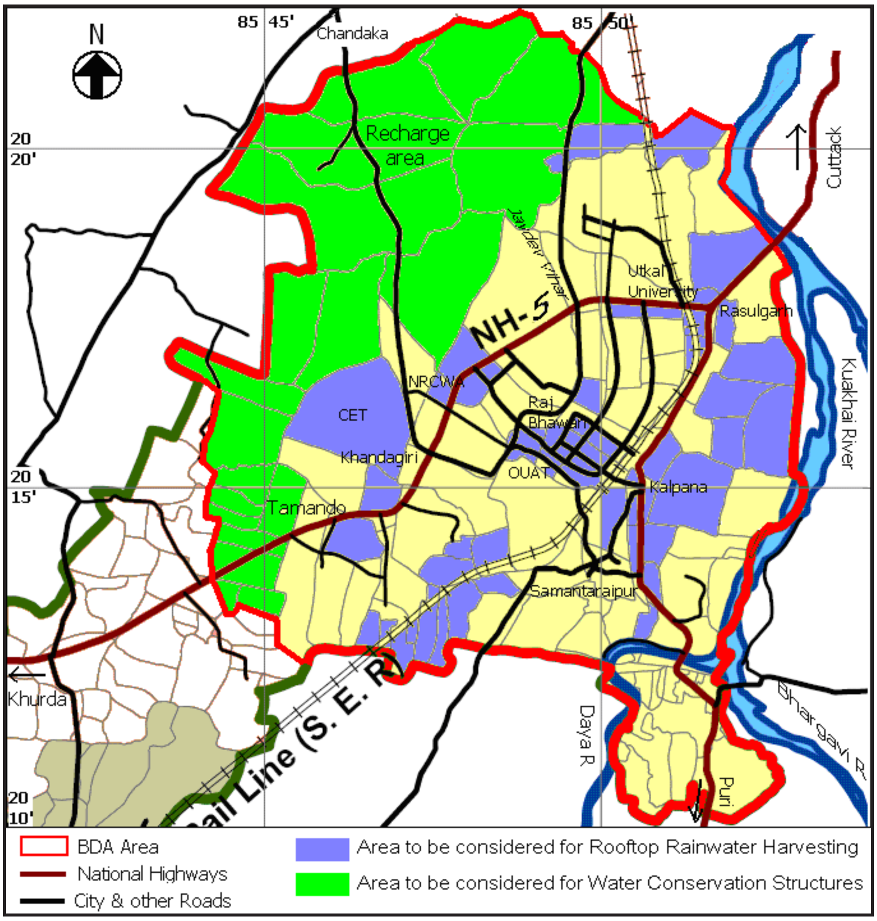


Fig 9 : Proposed Rainwater Harvesting Plan for Bhubaneswar City, Odisha

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CHANDIGARH CITY, U.T.

Reena Borana, Dinesh Tewari, Y.B. Kaushik, A.K .Bhatia, CGWB, Chandigarh

INTRODUCTION

Chandigarh, known as the "City Beautiful" is a Union Territory (U.T) located at the foothills of the Siwaliks about 250 kms. north of New Delhi. The city also has the distinction of being the joint capital of Punjab and Haryana states even though it does not form part of any of the two states. It lies between north latitudes 30^{O} 40' and 30^{O} 46' and east longitudes 76^{O} 42' and 76^{O} 51'. Punjab state borders the UT in the south and southwestern sides and Haryana state on eastern side. It is first planned city of Independent India, and was designed by Le Carbousier in 1951. It was named Chandigarh after a temple dedicated to the goddess, Chandi, and a fort (garh) which were situated in one of the villages acquired for the city. Chandigarh was the capital of Punjab until 1966, when the state was bifurcated into Punjab and Haryana, and it was then made the joint capital of both states. At the same time, it was also designated as a Union Territory to be directly administered by the Central Government.

GENERAL FEATURES

Area / Administrative Divisions

The total area of Chandigarh UT is 114 sq. km. with 1 tehsil, 80 sq. km. of the city is urban with 55 sectors (Fig 1) and 34 sq.km is rural comprising 18 villages.

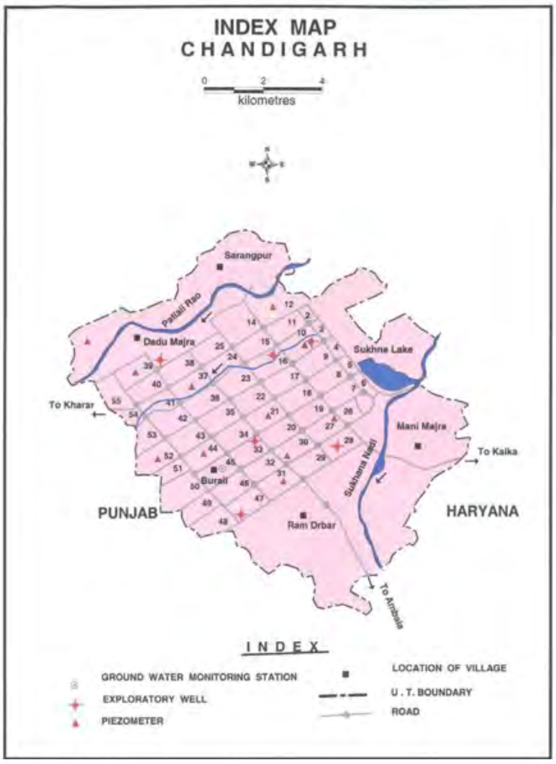


Fig 1 Administrative map of Chandigarh

Demography

As per the 2001 census, Chandigarh had a population of 9.00,635, 89.8% of which was urban population and 1 lakh (12%) was slum population. The decadal growth in population between 1991 and 2001 was 40%. In 2009, the city had a projected population of 12.97 lakh. The city is also one of the most densely populated cities in the country with a population density of 11373 per sq. km.

Hydrometeorology

The climate of Chandigarh can be classified as sub-tropical with hot summer and cold winter except during monsoon season when moist air of oceanic origin reaches the area. The hot weather season starts from mid March to last week of the June followed by the southwest monsoon, which lasts up to September. The transition period from September to November forms the post monsoon season. The winter season starts late in November and remains up to first week of March. The normal annual rainfall of the UT is 1059 mm, which is unevenly distributed over the area in 49 days. The southwest monsoon sets in from last week of June and withdraws in end of September, contributes about 80% of annual rainfall. July and August are the wettest months. Rest 20% rainfall is received during non-monsoon period in the wake of western disturbances and thunderstorms.

Physiography & Drainage

Four physiographic units are encountered in Chandigarh. The Siwalik hill range trending NW-SE forms the northeastern boundary and is exposed in a small patch on the north eastern side. Southwestern slopes of the foothills are covered with loose talus material deposited by hill torrents forming alluvial fans. These alluvial fans coalesce to form Kandi Formation running parallel to the hill ranges. The kandi formations merge into Sirowal

Formations in the south and southwest. The Sirowal merges with the main alluvial plain towards south and southwest. The alluvial deposits belong to Quatenary age and comprise layers of fine sand and clay. Two major streams Sukhna Choe and Patiali ki Rao, originating from Siwalik hill ranges forms the natural drainage of the city. Both are ephemeral in nature and carry high flows during monsoon. The Sukhana Choe has been dammed in the north east side of the city, which has given rise to an artificial lake known as Sukhana.

Soil Type

The soils are loamy at surface and calcareous sandy loam in subsurface layers. The soil is sandy to sandy loam in northern part while loamy to silt loam in southern part. Almost all soils are deficient in nitrogen, phosphorous & potash with colour varying from light yellowish brown to pale brown.

STATUS OF WATER SUPPLY AND DEMAND

As per the projected population figures compiled by the Office of the Registrar General & Census Commissioner of India, Chandigarh's Population was 12.97 lakh in 2009. The domestic water demand of this population is 204 MLD. Adding it with other demands, the total demand goes up to 452.77 MLD, while the total water available for supply through canal water and ground water is 396.72 MLD leaving a Demand/Supply gap of 56.05 MLD. The projected water demand for the city for 2025 is 800.75 MLD and estimated supply would be 469.98 MLD thus leaving a gap of 331.07 MLD. A major part of water requirement of the city is met by canal water. There are 200 deep tube wells in the city and 39 in rural areas for drinking purpose and 30 deep tube wells for irrigation purpose.

WATER PROFILE

The city was being supplied with water from ground water through tubewells till 1983. The city administration augmented the water supply through water from Bhakra Main canal in 1983. Today, Chandigarh city gets 67 MGD of water from the Bhakra main canal and 20 MGD of ground water from 239 tubewells in the city, making the total available water at 87 MGD. The Chandigarh Administration has planned for further augmentation of surface water supply to provide additional 32 MGD. Thus the total canal water supply available will be 103 MGD or 469.68 MLD. In Chandigarh, the use of private tubewells has been banned. Ground water for drinking water supply and for irrigation is being provided solely by the municipal corporation. Water is pumped from the deep aquifers below 100 m. There are about 239 tubewells for both urban and rural areas, out of which water from 200 tubewells is used for urban water supply. The responsibility of water supply rests with Public Health Department of the municipal corporation.

GROUND WATER SCENARIO

Potential Aquifers

Based on the exploratory drilling carried out by Central Ground Water Board down to a depth of 450 m bgl, it can be concluded that fair to good aquifer horizons occur in most part of Chandigarh except in south-western parts near sectors 37, 38, 39, 40 and 41. An aquifer, 20 meters thick, occurring at a depth of 160 mbgl, comprising medium to coarse sand, occurs in almost all of Chandigarh except around sector 38. It has also been inferred that the sediments are relatively coarse-grained down to a depth of 180 m bgl below which they become finer. The yield of the deep aquifers is also less as compared to the shallow ones. The formations encountered in a borehole drilled down to 465 mbgl in sector 28, close to Sukhna Choe, are well-defined coarse sediments up to 240 mbgl. Below this depth the formations are finer grained. The shallow formations comprise coarse sand to gravel and pebbles intercalated with clays, whereas the deeper ones are fine sand and silt. In sector 47, the aquifer material is coarse grained down to a depth of 174 m bgl below which it becomes finer. The aquifer material encountered at sector 33 is coarse down to 180 m bgl. This indicates that the thickness of coarser sediments is greater in northern parts of the city as compared to the southern parts. Along Sukhna Choe, three prominent sand beds occur (inter-bedded with clay beds) within a depth of about 100 m. The upper sand bed is about 15 m thick and occur 8 m below ground level. Middle sand bed is about 18 m thick and occurs at depths varying from 21 to 38 m bgl. The deeper sand bed occurs at depth varying from 39 to 76 m bgl and is about 27 m thick. These beds are more persistent in the downstream direction of Sukhna Choe. Hydrogeology of Chandigarh and indicating ground water development potential is produced in Fig. 2.

Ground water in the area occurs under water table, confined as well as semi-confined conditions. Good confined aquifers occur around sector 10, 33, 38 and 47 while leaky aquifers are encountered around sector 28. One interesting feature is that the aquifers in the southern parts of the city are restricted in aerial extent due to lithological boundaries. Ground water occurs under unconfined conditions down to about 80 m in Manimajra area. In other areas the semi-confined conditions prevail up to 20-30 m below land surface. Barring Manimajra area ground water below 20-30 m exist under confined conditions. The depth of the shallow aquifer system is less than 30 m below ground level whereas the depth of the deeper aquifer system ranges from 40 to 450 mbgl of explored depth, while in Manimajra area confined aquifers occur below 90 m. The transmissivity values for the deeper aquifer system ranged between 74 m^2/day at Sector 10 to 590 m^2/day at Sector 28. The storativity values ranged between $1.5x10^{-4}$ to $7.5x10^{-4}$ indicating confined nature of aquifer systems. The transmissivity values of shallow aquifers up to 100 m depth range obtained during these tests ranged between 70 and 466 m^2/day.

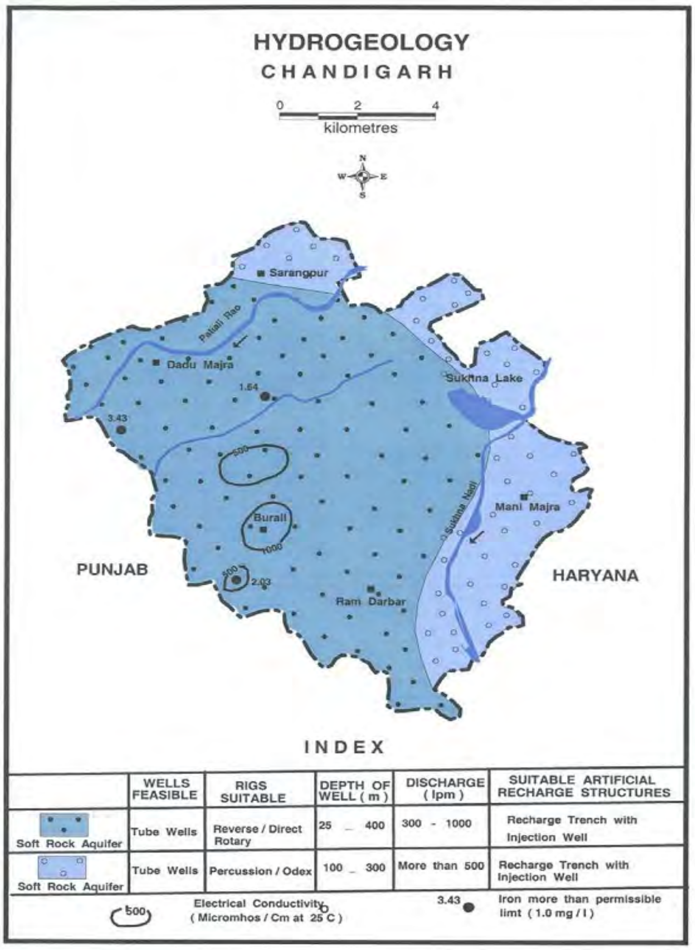


Fig. 2 Hydrogeology of Chandigarh urban area

Ground Water Level

The depth to water level in the shallow aquifer system in pre-monsoon season varies from 2.92 m in the southern sectors to 13.44 m bgl in the northern sectors. In the western and southwestern part of the city covering sectors 37 to 46 the water level is shallow i.e. <5.0 m bgl. This is due to fine nature of sediments and lithological boundaries. In the northern sectors, the water levels are more than 7.0 mbgl. During the post monsoon, the water level varies from 2.15 in the southern part to 11.79 m bgl in the northern part of the city. The long term (decadal) water level shows declining trend for the shallow aquifers system. The decline in water level fluctuation ranges between 0.01 to 0.36 m/year. The water level in the deeper aquifer system ranges between 9.64 to 27.96 m bgl during pre monsoon and 8.50 to 22.30 m bgl in post monsoon. The long term water level of the deep aquifer system shows that in all part of city, there is significant decline trend in the range between 0.32 to 1.55 m/year. This fall in water level is attributed to heavy pumping from the deeper aquifer for domestic and irrigation purposes. However, the water level data and draft from the deeper aquifer has not been considered for the estimation of the dynamic ground water resources of Chandigarh UT.

Ground Water Resource & Status of Development

It has been estimated that the annual replenishable ground water resource (Net Ground Water Availability) of Chandigarh are 1956 hectare meter (ham) and groundwater draft from unconfined aquifer is nil, since all the tubewells are deep and are drawing water from deeper aquifers. The details of the assessment are given below:

The Ground water resource of shallow aquifer in Chandigarh UT is

Recharge from rainfall during monsoon	= 1545 ham
Recharge from other source during monsoon	= 53 ham
Recharge from rainfall during non- monsoon	= 488 ham
Recharge from other source during non-monsoon	= 87 ham
Total annual ground water recharge	= 2173 ham
Natural discharge during non-monsoon	= 217 ham
Ground water draft as on 31.03.2010	= nil
Net annual ground water availability	= 1956 ham

Since, there is no draft from shallow aquifers, The stage of ground water development is nil and the Chandigarh UT falls under **SAFE** Category (Fig 3).

Fig 3 Ground water development potential of shallow aquifer of Chandigarh Urban area

Hydrochemistry

Based on the data generated from the analysis of ground water samples from hand pump and tube wells, it is found that the ground water is fresh and suitable for drinking as well as irrigation purposes. Normally, the ground water from the deeper aquifers is less mineralized as compared to water from shallow aquifers. Geochemical facies evaluation of ground water indicates that most of the waters, both from shallow and deeper aquifer, are of Ca-HCO_3 type. Concentration of some of the vital parameters such as F, NO_3, salinity, and hardness is within permissible limits of drinking water standards (BIS -1991).Analysis of trace elements in ground water indicated that concentration of copper, iron and manganese in some of the shallow hand pump waters is above maximum permissible limit for drinking purpose. As far as deeper ground water is concerned, none of the water sample registered higher concentration of any of the metal analyzed. It can be safely concluded that most of ground water samples are free from heavy metal contamination.

Major Ground Water Related Problems

Groundwater has been used for water supply since creation of the city and presently Chandigarh is sourcing 22% of its water supply from ground water through deep tube wells tapping below 100 m. There is considerable decline in the ground water level of the deep aquifers. The pre monsoon data for the period 1991 to 2010 (20 years) reveals that in sector 10 in north, shows a maximum decline of 16 m and in sector 31 decline of 10m. The remaining part of the city show on an average a decline of 5-8 m. Every year about 10% of such tubewells become defunct.

The Water Supply Bye Laws of Chandigarh ensure that all water supply is to be met from government tubewells and no private tubewells are allowed to be constructed. Also, only the deeper aquifers, below 100m, are to be exploited and thus at present there is none or negligible withdrawal of ground water from shallow aquifers in Chandigarh city. This is also evident from the fact that whereas there is heavy decline in the water levels of the deeper aquifers due to sustained pumping, there is hardly any decline in the water levels of the shallow aquifers (except in the central parts where the decline can be attributed to leaky confined conditions). Chandigarh city has the twin problem of ground water decline as well as rise. Whereas the deeper aquifers are under great stress and are depicting declining water levels, the shallow aquifers are not being put to any use and the water levels are rising leading to near water logging conditions in the southern areas of the city. To balance this problem, it is essential that pumping from the deeper aquifers is reduced and that from the shallow aquifers be increased. Another interesting observation is that while the water levels of the deeper aquifer are in the range of 15 to 70 mbgl, those in the shallow aquifer are in the range of 2 to 17 mbgl. The water levels are quiet shallow in the southern sectors (where in certain areas water logged conditions exist). It is worth mentioning that the chemical quality of ground water of all the aquifer systems in Chandigarh is good and within the permissible limits prescribed by BIS(1991) for drinking water except at a couple of locations where water sample drawn from hand pumps that are about 15 m deep, the iron concentration was higher than the permissible limits. This may also be due to corrosion in the pipes of the tube well.

Feasibility of Rain Water Harvesting and Artificial Recharge

Chandigarh is a highly urbanized city and the rooftop of the buildings can be suitably used for artificial recharge of the rainfall falling. There is a lot of green area and water bodies that can be effectively utilized for recharging from the rainfall. In Chandigarh, there are two distinct aquifer systems – shallow and deep. Shallow aquifer occurs under semi-confined conditions and exists down to 20 to 30 m below ground level. Deep aquifers below 40 m are under confined conditions. The piezometric head of the deep aquifers stands much below the water table of shallow aquifers and thus it can receive water easily on being recharged artificially.

It is estimated that about 30.71 MCM (18.45 MGD) surface runoff is available in the city for recharge to ground water during monsoon season from the roads (15.89 sq.km), from rooftops of residential areas (30.19 sq.km) from shopping areas (3.97 sq. km) and public and institutional building (7.94 sq. km). This is almost equivalent to the water pumped out from aquifers and therefore, harvesting and recharging rainwater will go a long way in contributing towards sustainability of water supply. The total runoff generated during an hour of 30 mm of rainfall would be 870000 m^3. As per the prevailing hydrogeological conditions, the most suitable structure for artificial recharge to ground water in Chandigarh UT is trench cum recharge well. The dimensions of the trench would be site specific and will depend on the water availability. A recharge trench of 8 m X 2 m X 3 m capacity with twin recharge wells of 40 – 80 m. depth would store and recharge ~ 100 m^3 of rainfall. It is estimated that a total of 8700 recharge structures would be required to be constructed at cost estimate of Rs. 652.50 crores @ Rs. 7.50 lakh per structure. Rain water harvesting will also address the problem of flooding due to overflowing of the storm water drains.

GROUND WATER DEVELOPMENT STRATEGY

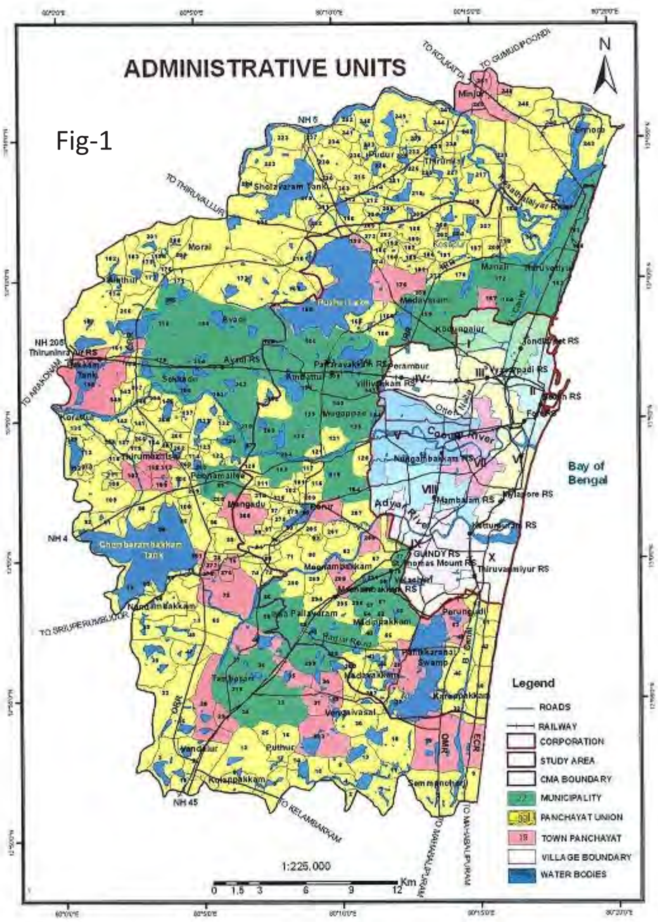
Chandigarh is a rapidly growing city with population growth rate of 40%. Against the background of the envisaged economic growth and the resulting population growth, the water needs of Chandigarh will grow at an explosive rate. It is estimated that by 2025, the water demand will be 800 MLD, an increase of 76% over the 2011 demand of 452.77 MLD. But water availability will not grow in parallel leading to water stress and resultant conflicts. There is a need to put in place a number of measures to create awareness among the people about the importance of water and incentivize them to use water carefully and wisely. As already mentioned, Chandigarh city has the twin problem of ground water decline as well as rise. The deeper aquifers are under great stress and are depicting declining water levels, the shallow aquifers are not being put to any use and the water levels are rising and also causing near water logging conditions in the southern areas of the city. To balance this problem, it is essential that pumping from the deeper aquifers is reduced and that from the shallow aquifers be increased. There is also a shortage of about 56.05 MLD (12.29 MGD) of drinking water in Chandigarh as on date. This can also be partially met through shallow dynamic ground water resources of the city. Annual replenishable ground water to the tune of 1956 ham are available in the city. Pumping out at least 70% of this resource i.e. 1369 ham annually is not likely to have any negative impact on the ground water regime. This can augment drinking water to the tune of 37.5 MLD. The exploitation from the shallow aquifer should be concentrated in the southern sectors, especially 39 to 55 because of shallow ground water levels.

CHENNAI CITY, TAMIL NADU

D. Dayamalar, CGWB, Chennai

INTRODUCTION

Chennai erstwhile Madras is the capital of Tamil Nadu state and is one of the oldest of the presidential cities of India. It is one of four metropolis of the country. The corporation of Madras established in 1688. The increase in population density coupled with industrial development has given rise to a greater demand far exceeding the available resources. The efforts of the State Govt. to bridge the gap from other sources including transport of ground water have not completely mitigated the water scarcity. The status of water supplies, demand and availability vis-à-vis the hydrogeological conditions are discussed. An attempt has been made to compile the existing data and carryout the analysis to bring out sustainable development strategies.



GENERAL FEATURES

Area/Administrative Divisions

Chennai city is located in the northeastern corner of the state. It is bounded by Bay of Bengal in the east, Tiruvallur District in the north and West and Kancheepuram District in the south. The district is bounded by Latitudes 13°02'30" to 13°14'00" and Longitudes 80°12'00" to 18°18'30". The geographical area of Chennai city is 176 Sq.km while Chennai Metropolitan Area (CMA) is 1189 sq.km. The administrative set up is given on Fig-I. The Chennai metropolitan area consists of 214 villages, 20 town panchayats and 16 municipalities situated in 6 taluks of Chennai, Tiruvallur and Kancheepuram districts.

Demography

The population of Chennai city was reported to be 50,000 in 1674 by Sir William Langhorn (Vestiges of Old Madras 1640-1800), which increased to 5,40,000 by 1901. The population of Chennai City as per 2001 Census is 43,43,645.The-projected census is given in Table 1.

Table 1: Projected Population for CMA and Chennai City (In Lakhs)

Sl. No.	Description	Actual	Projection					Gross density Persons / hectare
		2001	2006	2011	2016	2021	2026	2026
1	Chennai City	43.44	46.28	49.50	52.39	55.40	58.56	333
2	Municipalities	15.81	18.52	21.75	25.60	30.20	35.69	149
3	Town Panchayats	3.86	4.73	5.89	7.41	9.45	12.22	78
4	Village Panchayats	7.31	8.70	10.59	12.96	15.99	19.88	32
5	CMA [total]	70.41	78.96	88.71	99.66	111.97	125.82	105

Hydrometeorology

Chennai City receives rainfall during South-West Monsoon (June-September) and also from North-East Monsoon (Oct-Dec). The major portion of the rainfall is during the North-East Monsoon. Some times, the city also receives rainfall during January and February, but that is uncommon. The annual rainfall in Chennai is in the range of 1200-1300 mm. The rainfall generally occurs during short spells with high intensity. Because of the short duration, most of the rainfall is wasted through runoff leaving a small portion to recharge the ground water system. Chennai district enjoys a tropical climate with mean annual temperature of 24.3°C to 32.9°C. The temperature is usually in the range of 13.9°C to 45°C. The humidity is usually in the range of 58 to 84% and sea breeze in the evening hours is a blessing to combat the high temperature and humidity during summer months.

Physiography and Drainage

Major part of the area is characterized by a flat topography with gentle slope towards east. The altitude varies from 10 m a msl in the west to sea level in the east. Fluvial marine and fluvio marine land forms are noticed in the area. Marine transgression and regressions have resulted in the present day landforms.

Sand bars are scattered along the course of the Adyar river. Sharp and angular trends in the course of the river shows the control of structural features. Further, the man made bunds and structures at the mouth of the river to control flood water and movement of seawater has altered the natural erosional processes. The sea erosion in the northern Chennai in Tiruvottiyur is very active and in recent years, the area affected is of the order of 4 km long and 200 m wide. Various landforms in Chennai metropolitan area are shown in Fig –2.

Adyar River of 42 km length flows through the city with a catchment area of 800 sq.km. The river has perennial flow with an average discharge of 89.43 mcm/yr. at Kattipara cause way and during high tides, the backwater from Bay of Bengal enters inland up to 3 – 4 km. (CGWB, 1993).

Cooum is the other river draining through the city. It originates from surplus flow from Cooum tank in Tiruvallur district and surplus flow from other tanks enroute adds to its flow. The flow of

Fig –2

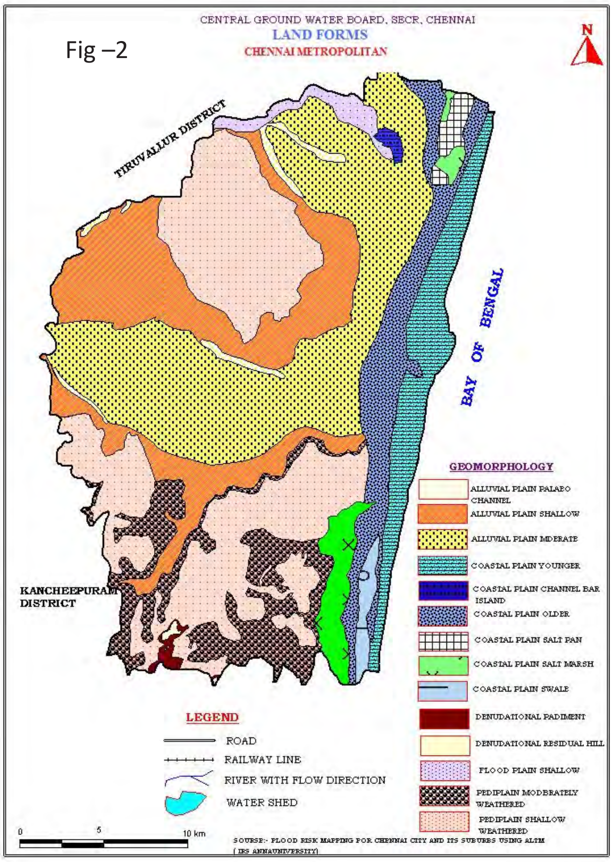
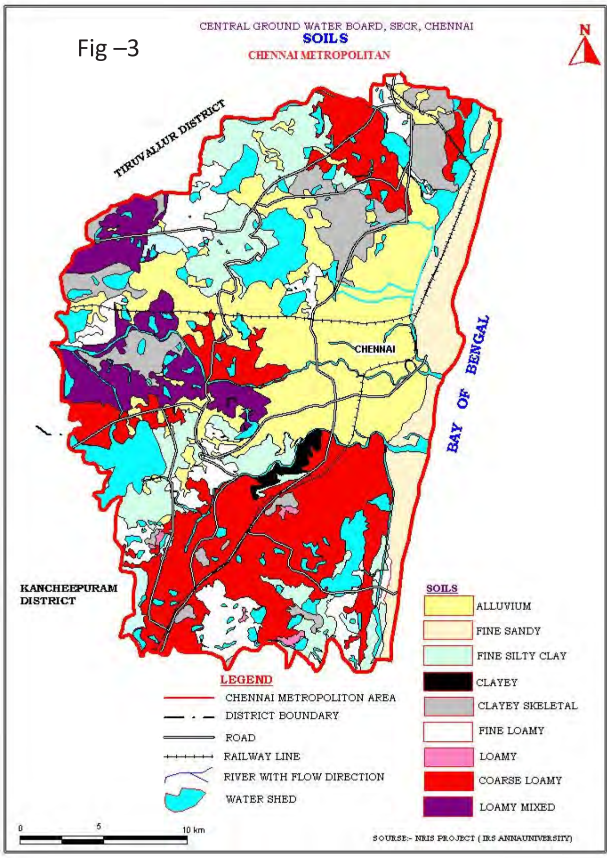


Fig –3



the river at Korattur is 40.2 Mcm/yr for a flow for 31 days in a year. However, due to discharge of sewerage into it after the entry into the city, the river is highly polluted. (CGWB, 1993). Buckingham canal is a manmade navigation canal, not in use for last four decades and presently act as sewerage carrier within the city.

Soil type

The major soil-types encountered in the metropolitan area are Alluvial, Clayey and loamy soils. Alluvial soils are commonly observed in the central part along the rivers and in coastal area and have high permeability. Clayey and clayey skeletal soils are seen in the northern part of the metropolitan area. These soils are alkaline in nature, have poor permeability and are highly calcareous and cracking. A generalised map showing the distribution of major soil types in the district is shown as Fig -3.

STATUS OF WATER SUPPLY AND DEMAND

The present water supply and the projected scenario by the year 2021 are presented in Table 2. The analysis of the water supply position gives the real magnitude of the problem even after all the possible measures taken by the government so far. A perusal of the Table 2 shows that the demand would be around 1026 MLD (2001) & 1980 MLD (2021), while the supply is expected to be around 1586 MLD, if full capacity of surface reservoirs and the ground water supply projected were to be considered.

Table 2 Demand, water supply for Chennai city and urban agglomeration

S. No.	Parameter	2010	2021
A.	***DEMAND***		
1	**Chennai City**	752.91	942
	Municipalities	190.29	330
	Town panchayats	30.90	511
	Village panchayats	52.16	197
	Total	1026.26	1980
B.	***SUPPLY***		
3	Existing Planned Sources (On full capacity MLD)		
	(a) Surface Water		
	i) Puzhal water treatment plant	300	
	ii)Kilpauk water treatment plant	270	
	iii)Vadakuthu water treatment plant (Veeranam source)	180	
	iv)Chembarambakkam water treatment plant (Krishna water)	530	
	Total of (a)	1280	
	(b) North Chennai Well Fields (MLD)		
	i) Minjur	27.3	
	ii)Panjetty	31.8	
	iii)Tamaraipakkam	36.4	
	iv)Kannigaiper	13.6	
	v) Poondi	27.3	
	vi) Flood plains	13.6	
	Total of (b)	150.0	
	(c) South Chennai well Fields (MLD)		
	i) Palavakkam	1.5	
	ii)Porur well field	4.5	
	iii)Belur near Kilpakkam	45.5	
	iv)Palavakkam	4.5	
	Total of ©	56	
	(d) Desalination (Proposed)	100	
	Total of a, b, c & d	1586	

The growth profile in water supply since the formation of the CMWSSB is given in Table.3.

Table 3 Water supply – Chennai city

Details	1978	March 2008
Operational Area	City 176 Sq.km.	City + surrounding areas (176 + 7.88 Sq.km.)
Population	30 Lakh	55 Lakh
Water produced (Normal years)	240 MLD	660 MLD
Area covered with piped supply	80%	100 %
Treatment capacity	182 MLD	1398 MLD
Length of water mains	1,250 km.	2,930 km.
No. of consumers	1,16,000	4,97,811
Distribution Stations	3 No.	16 Nos.

WATER PROFILE (SURFACE AND GROUND WATER)

Ground Water

Ground water occurs in all geological formations in the city and is developed by means of dug wells, filter point wells, tube wells and bore wells. Crystallines are prominent aquifer in southern part of the city. The groundwater is essentially limited to weathered mantle and fractures in the crystalline. Ground water occurs under unconfined condition in weathered mantle and under semi confined to confined condition in fractures. The yield also is moderate to poor yielding up to 3 lps.

Surface Water

Three rivers viz. Koratalaiyar, Cooum and Adyar pass through Chennai Metropolitan Area. These rivers are placid and meander on their way to the sea. Buckingham Canal, a man made canal, is another large waterway which runs north south through this Metropolis. The major surface water bodies in the metropolitan area form main source of water supply to the city. The three lakes, viz., Redhills, Cholavaram and Poondi, having an aggregate storage capacity of 175 million cu.m. Since January 2000, Chembarambakkam is also used as storage. Besides this two small lakes namely, Erattai Eri and Porur lake are also utilized as a source of supply.

GROUND WATER SCENARIO

Chennai district is underlain by various geological formations from ancient Archaean crystalline to the Recent Alluvium. The geological formations of the district can be grouped into three units, namely i) the Archaean crystalline rocks ii) consolidated Gondwana and Tertiary sediments and iii) the unconsolidated Recent Alluvium. The Archaean crystalline rocks of the district comprise chiefly of charnockites, gneisses and the associated basic and ultra basic intrusives.

Potential Aquifers

The crystalline rocks are weathered and jointed/fractured. The degree and depth of weathering varies from place to place and the thickness of weathered mantle varies from less than a metre to about 12 m in this district. The successful borewells drilled tapping the deeper fractured aquifers in Saidapet, Adyar, Kasturba Nagar, Gandhinagar and Ashok Nagar revealed the existence of fracturing down to depth of 60 m below ground level.

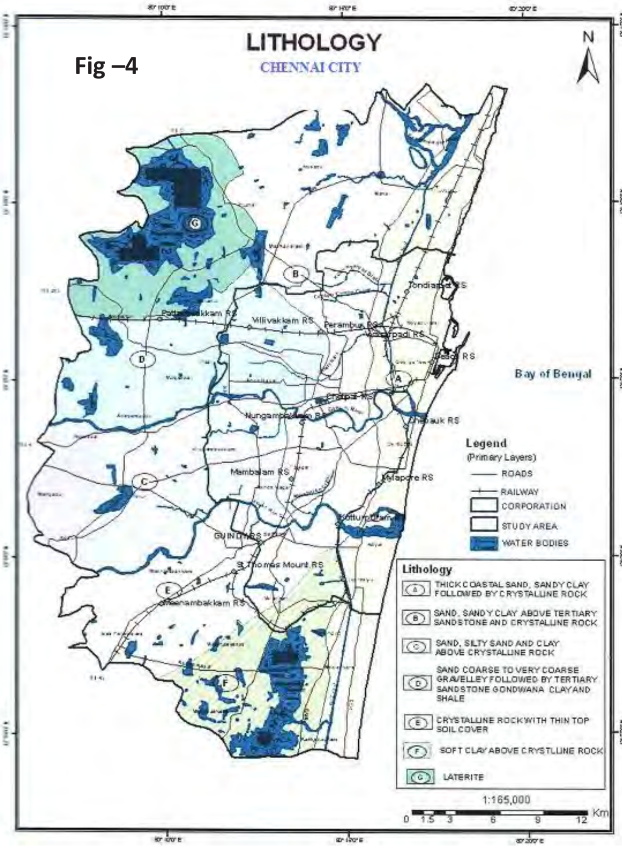
The Gondwana shales are black to dark grey in colour and are jointed and fractured. They are encountered in a number of boreholes and their thickness varies from 24 m in Kilpauk area through 20 m in Ashok Nagar area to more than 130 m in Koyembedu area.

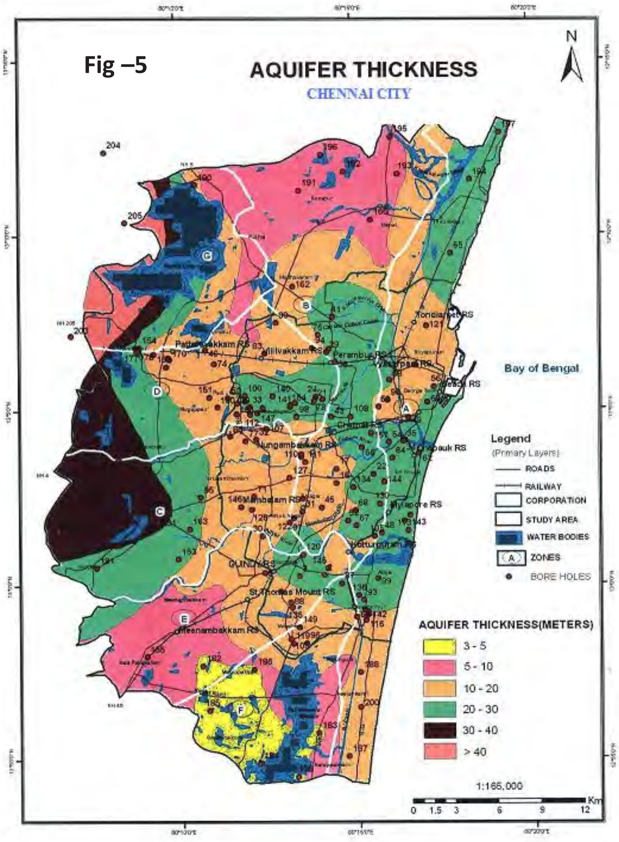
The occurrence of Tertiary deposits in Chennai is not well demarcated. However, the sandstones encountered in some of the boreholes below alluvium in Binny Road, Poes Garden, Anna Nagar and Rayapuram areas, which may belong to Tertiary group

Ground water in Chennai district occurs in all the geological formations viz., the Archaean crystallines, Gondwanas, Tertiaries and alluvium and is developed by means of ring wells, dug wells, filter point wells, bore wells and tube wells.

The alluvium covers the major part of the district. The alluvium consists of sand, silts and clays. The thickness of alluvium varies from place to place and a maximum of 28 m thickness has been encountered in north Chennai near Perambur. Kilpauk water works area has 24 m thick alluvium.

The yield of the exploratory wells at Kilpauk and Tirumangalam tapping the productive granular zones met within the alluvium is 25 lps to 6 lps for a drawdown of 7.21 to 0.22 m. The yield of four borewells tapping the productive granular zones met within the Gondwana sediments were found to range from less than 1 to 4 lps for drawdowns varying between 8 to 9 m. The specific capacity ranged from 8 to 32 lpm/m of drawdown.



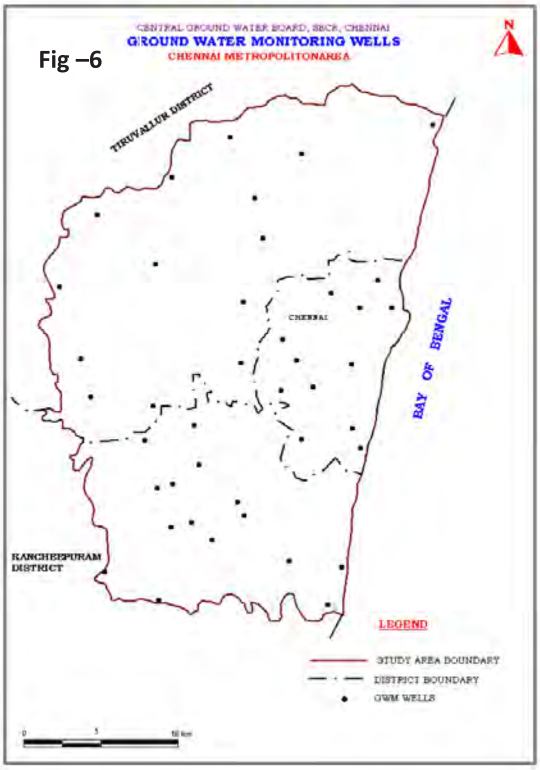


In Velacherry area there is a sheet of black clay over crystalline rocks. The open wells located in Velacherry area are giving low yield and the yield of wells varies from 2 to 10 m^3/day depending on the diameter, topography and thickness of weather zone tapped. Many wells are dry in summer months due to limited thickness of productive zones or over development. There are a few fractures developed in the crystalline rocks and bore wells encountered such fractures down to 90 m depth. The yield of these bore wells are as high as 4 lps at certain areas. There are no indications of any prominent lineaments. There are number of bore wells in the city piercing the top 10 to 15 m thick alluvial cover and penetrate the crystalline rocks. The failure of many bore wells in Velacherry area may be due to absence of potential fracture down to 60 m. The map showing the areal distribution of the lithology and aquifer thickness are given in Fig-4 and 5.

In general, yield of dug wells varies from 2000 to 50,000 lit./day depending on their dimension, lithology and season, while that of bore well and tube well vary between 1200 to 45,000 lph. However, the yield of wells is subject to change due to over stressed aquifer during the past decade.

Based on the UNDP studies carried out during 1966 to 1969, ground water aquifer was identified at Tamaraipakkam, Panjetty and Minjur in the Araniar-Koratalaiyar Basin (A.K. Basin) located north of Chennai. These three Well fields were developed for abstracting water at an estimated yield of 125 MLD. Ground water abstracted through bore wells from these well fields was supplied to Industries in Manali from 1969 by the PWD Ground Water Wing, later on, after taking over by CMWSSB in 1978.

Fig –6



GROUND WATER LEVEL

Central Ground Water Board monitors water levels in Chennai city every month and on quarterly basis in the metropolitan area and for water quality once in a year (May). The pre monsoon and post monsoon water level have been presented as Figs 7 and 8. The analysis of water level data shows that during pre monsoon, 62 % of wells recorded shallow water levels in the range of less than 5m bgl and water level in 38 % of wells in the range of more than 5 m bgl observed in southern part of the CMA. During post monsoon 91 % of wells have recorded shallow water level in the range of 0 to 5 and nine percent of wells have recorded deeper water levels in the range of more than 5 m bgl and noted in Vepery, Aminjikarai and Thiruneermalai area.

Fig –7

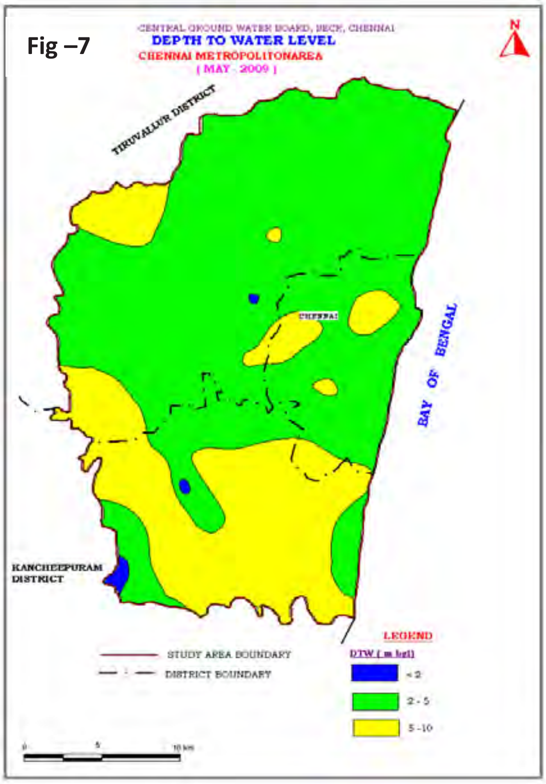
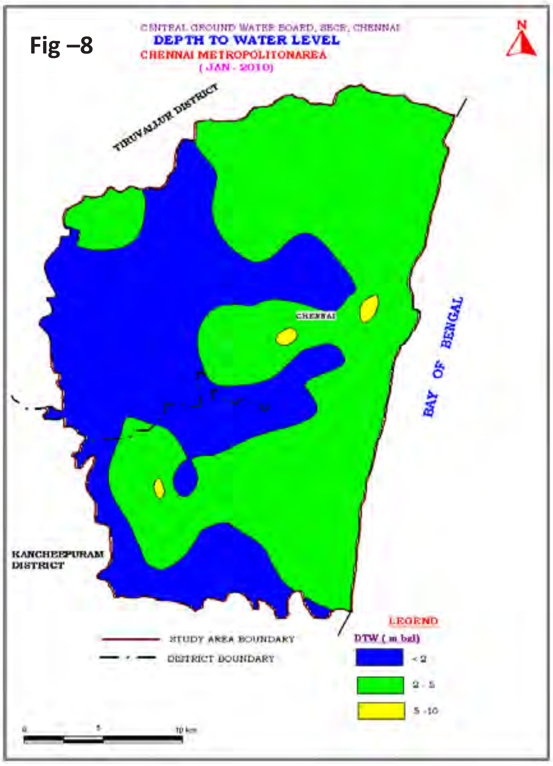


Fig –8



GROUND WATER RESOURCES & STATUS OF DEVELOPMENT

The ground water resources have been computed jointly by Central Ground Water Board and State Ground & Surface Water Resources and Development Centre (PWD, WRO, Government of Tamil Nadu) as on 31st March 2009. The salient features of the computations are furnished in Table 5. The computation of ground water resources available in the district has been done using GEC 1997 methodology.

Table 5 Ground Water Resources and Status of Development (As on March 2009)

District	Net annual ground water availability	Existing gross ground water draft for irrigation	Existing Gross ground Water draft for domestic and industrial water supply	Existing gross ground water draft for all uses	Requirement for domestic and industrial requirement supply to 2025	Net ground water availability for future irrigation development	Stage of ground water development %	Category
Chennai	1020.74	0.00	4141.00	4141.00	4141.00	-3120.26	406%	Over Exploited

Hydrochemistry

The quality of unconfined aquifer has been evaluated by sampling and analysis of water sample collected from Chennai metropolitan area. About 39 water samples were collected for water quality analysis during May 2009 representing pre-monsoon water quality. The summarized results given in Table-6.

In general the ground water quality in the Chennai metropolitan area is fresh and in about 18% of the wells as indicated by the EC value less than 750 µs/cm at 25°C. In about 62% of the Ground Water wells the EC varies between 751 -2250µs/cm at 25° C and 7 % of wells are reveal between 2251-3000 µs/cm at 25° C indicating that the ground water is slightly mineralized and about 13% of Ground Water samples the EC is more than 3000 µs/cm at 25°C indicating that the ground water is highly mineralized. The highest value 4860 µs/cm at 25° C was observed in Kovilpathagai. Distribution of EC is shown in Fig 9.

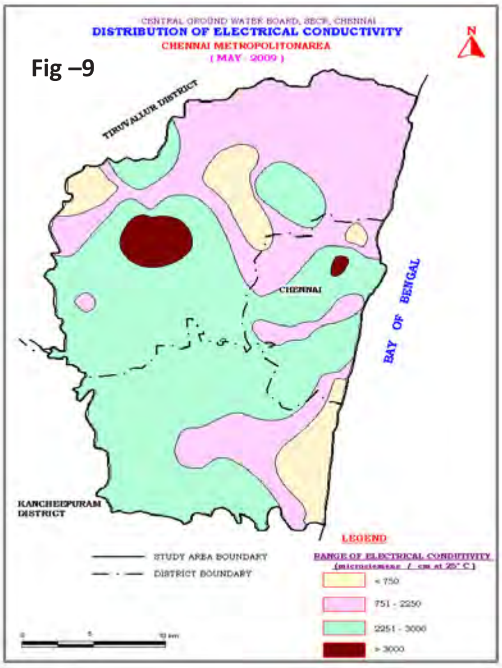


Fig –9

Table 6 Ground water quality, May-2009

S.No	Parameters	Range	No. of sample	Percentage (%)
1	Electrical Conductivity (EC) µs/cm at 25°c	< 750	7	18
		75 1- 2250	24	62
		2251- 3000	3	7
		> 3000	5	13
2	Chloride mg/l	< 250	21	54
		251-1000	7	44
		> 1000	1	2
3	Fluoride mg/l	< 1.0	30	77
		1.1- 1.5	6	15
		>1.5	3	8
4	Nitrate mg/l	<4 5	16	41
		46- >100	23	49

In the case of Chloride 54% of wells analysed show Chloride concentration within the desirable limit (less than 250 mg/) , 44% of the sample are show within permissible limit (between 251 – 1000 mg/l) and rest of the samples (2%), in which it exceeds permissible limits, is found in Kovilpathagai, shows more than 1000mg/l. Distribution of chloride is shown in Fig 10.

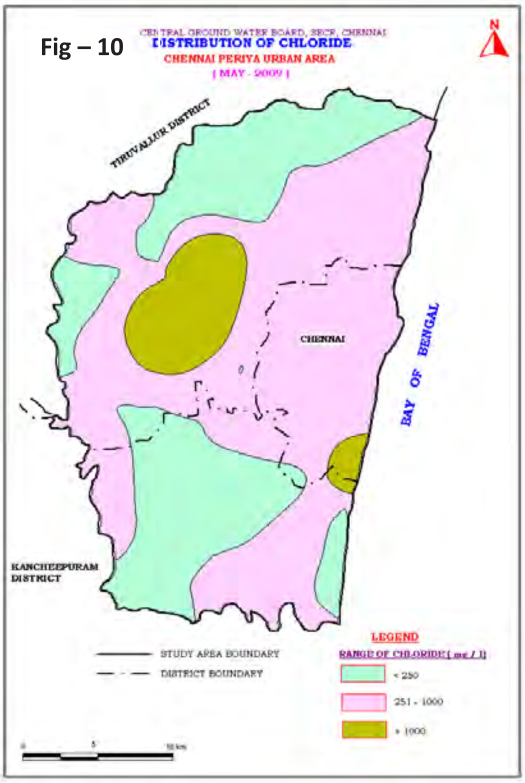


Fig – 10

The Nitrate content is less than 45mg/l in about 41% of the sample analyzed and 41% of the water sample is within the permissible limit of 46-100 mg/l and 8% of sample exceed the permissible limits, (more than 100 mg/l) which are from the location of Manali, Mathravoyal, Pattabiram,Ambattur, Vepery,, Aminjakarai and Vengaivasal. Distribution of nitrate shown in Fig. 1.

The Fluoride content is less than 1.0 mg/l in about 77% of the sample analyzed and 15% of the sample shows within permissible limit (1.0 to 1.5 mg/l), and 8 % of the sample shown more than 1.5 which are from Vengaivasal, Velacherry and Vepery. Distribution of fluoride is shown in Fig. 12I.

Major Ground water Related Problem

Sea Water Intrusion-The quality changes due to marine transgression in the past is evidenced from the high mineralization in Mandaveli, Anna Nagar, Indira Nagar and Taramani areas. The presence of thick clay bed with fossils are indicative of lagoon and estuary environment and or the reducing condition due to water logging condition of low-lying ground. The landward invasion of sea water into low-lying areas during storm and the high tide periods also results in sea water spreading over land.

The intrusion of sea water due to over development of Araniyar-Koratalaiyur alluvial aquifer system is also

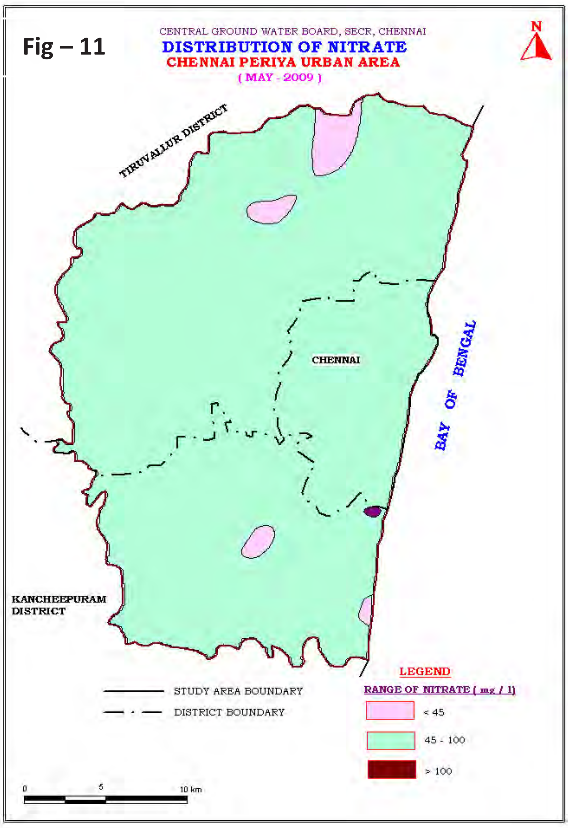


Fig – 11

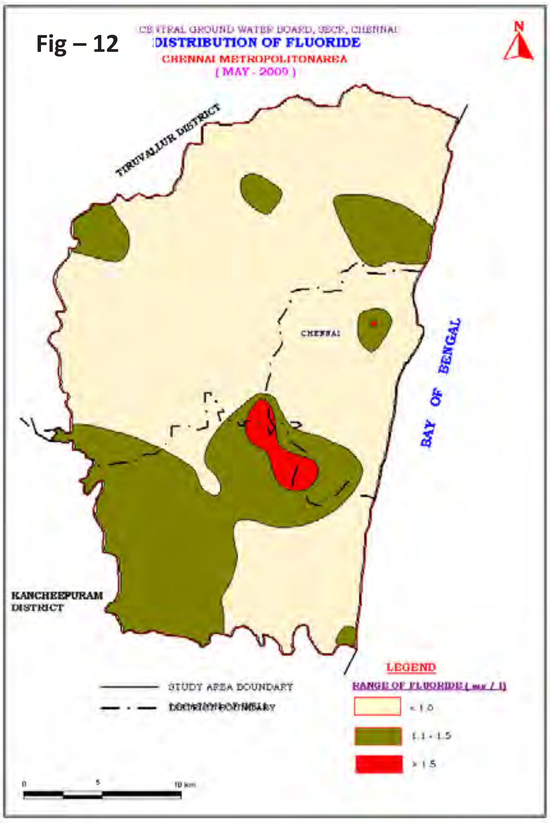


Fig – 12

noticed in north of Chennai. The excess ground water development in Koratalaiyar alluvium has resulted in reversal of hydraulic gradient in coastal area and already the movement of interface to a distance of 3 km westwards is established in north of Chennai. However, the discontinuous nature of granular zones in city area do not favour such interface movement due to local ground water abstraction far inland.

Most of the fresh-water zones are floating lenses over saline water zones. Tiruvanmiyuyr-Covelong belt is one such potential fresh water aquifer in dunes. The same is harnessed extensively resulting in local ground water mining in Besant Nagar area and there is danger of seawater intrusion locally, which necessitates detailed monitoring.

Buckingham canal constructed at sea level for navigation has resulted in extensive seawater percolation in to the freshwater aquifer. The usage of canal in the part has allowed the seawater movement inland and the unlined nature of canal has resulted in seawater seepage into the ground water system. Further, the use of the canal for transporting sewerage in recent years has caused contamination in the ground water system adjoining the canal. This is evident from the high dissolved solid in ground water of Indira Nagar area. In addition, the spurt in the building activities has resulted in the reduction in net recharge area and hence the effective freshening is lacking in recent years.

Pollution by Industries-The industrial belts also add to the groundwater contamination and special study was taken up by CGWB in Manali (CGWB, 2003). The Manali Industrial area falls in Manali Town Panchayat, Puzhal Panchayat Union, Ambattur taluk, Tiruvallur district. About 85 sq.km has been taken up for the study. The study area is a coastal plain drained by Korttalaiyar river and its tributaries. Surface water flow in them is seasonal and major part of the year backwater occupies them. Buckingham canal traverses the central part of the study area from south to north and also functions as a carrier of various types of pollutants. All the surface water sources are highly polluted. About 59 Red (Large, Medium, and small) category industries are located in the study area.

Feasibility of Rainwater Harvesting and Artificial Recharge

The topography of Chennai district, in general, is suited for construction of various artificial recharge structures such as percolation ponds, check dams and recharge shaft/well. However, detailed studies are necessary to formulate a comprehensive scheme for artificial recharge of phreatic ground water in the district in view of the variations in the geomorphic set-up and the complex hydrological and hydrogeological conditions. Roof top rain water harvesting made mandatory by the State Government has improved the water level condition but due to lack of periodical maintenance, the effect has reduced over the period of time.

GROUND WATER DEVELOPMENT STRATEGY

The budgeting of ground water resource potential attempted for Chennai district has brought to light that the ground water balance available for further development is rather limited. The number of existing abstraction structures, their withdrawal and reasons for failure, if any, has to be documented by a strict ground water legislation.

The district being completely an urban area, the ground water resources available are exclusively used for domestic and industrial requirements only. In order to have better management of the coastal aquifers, proper design of wells is necessary.

Design of Ground Water Abstraction Structures

The dug wells, filter point wells, tube wells and bore wells are the most common abstraction structures in the district. The dug wells are constructed in the alluvium as well as in hard rock area sin the city. The depth of the wells generally range between 8 to 10 m and as shallow as 4 m in Marina beach and the masonry structures are common and wells are 1 to 2.65 m in diameter and few wells are 4.5 m in diameter. Some of the wells in coastal tract are tapping beach sands and are brick lined with cement plastering on the top 6 m. The deepening of structures with small diameter ring well inside the open well is commonly practiced, but fails to get desired results.

The following well design are recommended for the Chennai city area are:- (i) infiltration well with horizontal and extrusion bones (ii) shallow tube well (Hand auger) (iii) shallow/medium tube well (Rotary rig) and (iv) deep bore well. Infiltration wells of 4.5 m diameter and of 6 to 7 m depth in beach aquifers of Besant Nagar are likely to give 10,000 to one lakh litres per day. Shallow tube wells of 100 mm /125 mm diameter and of 10 to0 20 m depth are likely to yield 1000 litres per hour and shallow medium tube wells with proper gravel packing will give 1000-30,000 litres per hour. The deep borewells of 45-60 m depth are likely to give 1000 to 45,000 lph.

Problems in Ring Well Construction

The common problem is sand filling inside the rings during and after the lowering of rings, thereby practically eliminating the scope of deepening of wells to tap more saturated column in summer months. The weep holes provided in the rings allow water with fine sands and gets filled up as and when sand removal is in progress thereby making it difficult for lowering of rings in highly saturated sands.

Problems in Tube well / Bore Well Construction

In case of filter point wells drilled with hand bores, the depth of penetration is variable and whenever the Kankar or any other compact layers are encountered, further drilling becomes difficult. When portable rotary rigs m (Calyx) are deployed for drilling, the drilling operations become very slow and the pore spaces in fine grained layers are invaded by drilling fluid as a result the discharges tend to be poor. Proper well development is seldom carried out by private drillers and as a result fine sands get deposited in the bore. Some times caving of wells are commonly reported particularly when the top alluvium is cased and the bottom shales and crystallines are drilled with down the hole hammer rig.

Rainwater Harvesting in Chennai City

CGWB has rendered technical guidance to local residents and a few central government organizations in implementing RWH in the city. In addition it has also given financial assistance for construction of Percolation ponds in CLRI under Central Sector Scheme and the impact assessment is in progress.

In view of deficit in Demand –Supply, Govt. of Tamil Nadu has taken lots of efforts in rainwater harvesting and water conservation measures. Chennai Metropolitan Water Supply and Sewerage Board (CMWSSB) is the nodal agency for water supply in Chennai city. It has constituted a fully dedicated “Rainwater Harvesting Cell”. Further, Govt. of Tamil Nadu has made it mandatory that all buildings in Tamil Nadu should have provision for RWH. It has also been informed by CWWSSB, Chennai that they have covered 99.77% of buildings by December 2003. Further they have also identified 759 locations to study the impact of RWH on water quality and water level.

More awareness has been created by the Central and state government agencies regarding rain water harvesting and its benefits within a short span of time and every citizen felt it as mandatory for the present and future generation for protecting the precious ground water resource. Though the rainwater harvesting was implemented in large scale in the coastal area of Chennai particularly in Thiruvanmiyur and Valmiki nagar areas of south Chennai city, no appreciable improvement in chemical quality of ground water has been observed. This is mainly due to the seawater ingress in the fresh water aquifers and it is over riding the rainwater harvesting at ThIruvanmiyur area. This situation can be tackled by implementing alternative large-scale artificial recharge schemes as suggested in the following section.

Heavy rains in urban areas results water logging and submergence of low-lying areas. Encroachment on waterways is often root cause of such problems. Various measures to solve the issue is planned and partly implemented. This issue could be tackled on more scientific lines by minimising the adverse impacts. In this regard the possibility of utilising the heavy runoff for improving the ground water regime and preventing the seawater ingress in the coastal aquifers is explored.

The isolated over development of ground water from the Thiruvanmiyur aquifer due to urbanisation has resulted seawater ingress. The area from Velachery to IIT tract, occupied by crystalline formations, has limited scope for ground water recharge and during normal low intensity monsoon rains leads to water logging conditions.

The observations from the ground water monitoring study revels the need of artificial recharge of Tiruvanmiyur aquifer which is under great stress for augmentation of ground water resources in respect of quality and quantity. The water logging at Velachery and Taramani areas and recharging of Thiruvanmiyur aquifer can be combined for improving the local ground water source and prevention of sea water ingress further. Two recharge cum pumping water line with booster pumps and recharge tube wells are recommended. The surplus runoff channel from IIT area and partly reclaimed Buckingham canal in Adyar Muthukadu section can be used to store fresh water and continuous supply to recharge system. The time lag for the recharge phenomena and the fast rate of flood water collection needs proper understanding and creation of collection chambers and drains without mixing of sewage which is important to get suitable quality source water for recharge.

There is a possibility of desiltation and improving the storage capacity of Pallikaranai marshy land in south side of Velachery railway line. Dewatering of water logging prone areas in and around Velachery, Taramani and IT corridor can be made with separate storm water system and transport to new pond and pumping system along the Buckinghum canal. Surplus weir to drain excess water to the sea along the canal and a well-planned direct canal to sea can be implemented with this artificial recharge scheme.

The Velachery and Pallikaranai lakes can be cleaned and used for fresh water storage to augment Chennai water supply in the long run. The uncovered locations poorly connected sewage lines in the entire catchment area needs to be modified and disposed while the storm water can be treated and used for water supply as well as ground water recharge and protection of coastal ecosystem.

DEHRADUN CITY, UTTARKHAND

D. Bagchi & R.A.Pir, CGWB, Dehradun

INTRODUCTION

Dehradun is the capital of Uttarakhand State. Dehradun is located in the foothills of the Himalaya at the centre of an intermontane, structural valley known as the Doon Valley. The name Dehra Dun literally comprises two words Dera (or Dehra) meaning a camp, while Dun (or Doon) is a local term used for a river valley. Doon Valley is one of the largest and picturesque tectonic valleys having an area of ~1600 km^2, which is surrounded by Siwalik Hills to the south and Mussoorie Hills to the north. The valley is historically important and culturally famous due to its pleasant climate and a number of reputed institutes., Dehradun is believed to be one of the oldest cities of India and was occupied at different times by the Sikhs, Mughals and the Gurkhas before coming under the reigns of the British. The present city was founded in the early eighteenth century by Guru Ram Rai, the elder son of Guru Har Rai. Guru Ram Rai came to the place on exile after being banished by the Mughal emperor, Aurangzeb. Guru Ram Rai first settled in village Dhamawala in 1675 AD. The name "Dehra" refers to his Dera (or settlement) around which the present city of Dehradun developed gradually. One of the first settlements was a Gurudwara known as "Guru Ram Rai Darbar", which was built in 1699 AD with the help of Fateh Shah, the then Raja of Garhwal. The architecture of the Gurudwara resembles the tomb of Mughal Emperor Jehangir. In Skanda Purana, Dun is mentioned as a part of the holy region "*Kedar Khand*", meaning the abode of Lord Shiva.

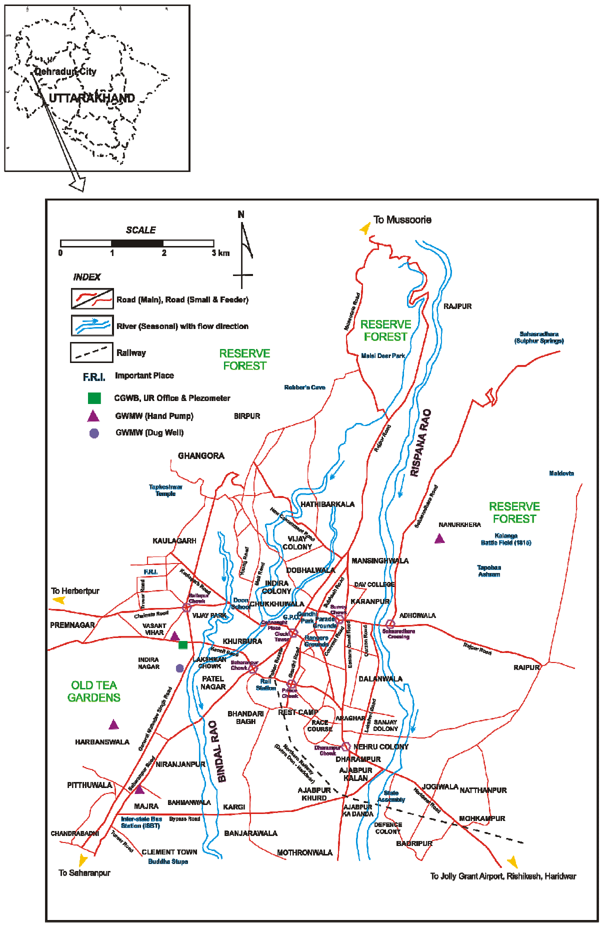
CGWB has so far drilled eight Exploratory Wells in Dehradun District (as on February 2011). Apart from this, four deposit wells were also constructed in and around Dehradun City, which were subsequently handed over to the state government for water supply.

GENERAL FEATURES

Dehradun, the capital of Uttaranchal State is also the headquarter of Raipur Block and has both strategic and political importance. The administrative map of Dehradun city is given in Fig-1.

The average elevation of the city is 450 m (1480 ft) above Mean Sea Level. The population of Dehradun City (excluding the cantonment area) is 447808 (Census 2001). The male: female sex ratio is 1000:893. The density of population as per Census 2001 in Dehradun City was 329 person per km^2. The decadal growth rate of population in Dehradun (Period: 1991 to 2001) is 39.73%.

Generally the climate of Dehradun City is temperate. The temperature during summer ranges from 16.7 to 36.0ºC while winter temperature varies from 5.2 to 23.4ºC. The summer starts by March and lasts up to mid of June when the monsoon sets in. The City experiences moderate to heavy showers during late June to mid August. The maximum temperature recorded in Dehradun City was 43.9ºC on 4th June 1902 while the lowest minimum daily temperature in Dehradun was –1.1ºC recorded on 1st February 1905 and 11th January 1945.



Administrative Map of Dehra Dun City showing locations of Ground Water Monitoring Wells

Fig-1. Administrative Map of Dehradun City

Dehradun City is a part of Intermontane Doon Valley formed by the piedmont alluvial fan deposits and exhibits a general fall in gradient towards south located between the Lesser and Sub-Himalayan ranges. Seasonal streams like Bindal Rao, Rispana Rao, Baldi Nadi, Nalota Nala etc. drain the city.

Due to wide variation in topography, drainage, geomorphology, intensity of erosion, host rock etc., the soils of Dehradun City show wide variation in texture, colour, stoniness, moisture and organic matter. However, as per the classification of NBSSLUB, the main soils of Dehradun City are Udifluventic Ustochrepts, Udic Ustochrepts, Udic Haplustolls and Typic Ustipsamments. The forest cover is scattered across the City and comprises parts of Forest Research Institute, Garhi Cantonment and Chandrabani areas. Soils in the forested areas consist of Inceptisol, Mollisol and Alfisol.

STATUS OF WATER SUPPLY AND DEMAND

The major problems of water supply in Dehradun City are unequal distribution of water, old dilapidated pipe lines, uncontrolled zoning and unsatisfactory operation and maintenance (City Development Plan, Jawaharlal Nehru National Urban Renewal Mission, May 2007). Urban water supply of Dehradun is operated and maintained by Uttarakhand Jal Sansthan (UJS) whereas large capital works and overall planning is done by Uttarakhand Pey Jal Sansadhan Vikas Evam Nirman Nigam, popularly known as Uttarakhand Pey Jal Nigam (UPJN). Although the natural topography of the City helps in gravity drainage, pockets of water logging are present due to local urbanization.

In Dehradun City the duration of water supply is mostly for short hours. Hand Pumps, which were installed and maintained by the UJS, cater to the needs of a limited number of residents. Water supply of Dehradun is based on surface water and groundwater sources. The total water supply from surface water sources is 35.33 million litres per day (MLD), the details of which is given below:

a) Bandal intake works (Gravity Main): 6.75 MLD
b) Massi Fall (Gravity Main): 8.00 MLD
c) Kaligad (Gravity Main): 0.58 MLD
d) Galogi Power House (Gravity Main): 8.00 MLD
e) Bijapur Canal (Pumping): 12.00 MLD

At present, total 92 tube wells are operational for water supply in the City, which is producing 140 MLD. The total demand of water is 117.73 MLD, which is less than the total supply of 175.33 MLD from surface and groundwater sources (Source: Uttarakhand Jal Sansthan). Recently, the SCADA Automatic Water Supply System was installed in some of the tube wells by UPJN, which automatically switch on and off the pumping stations. Similarly, the UJS has also installed automatic water supply and distribution system in many areas of the City like Indra Nagar, Parade Ground, Maharani Bagh, Vasant Vihar, Race Course, Dilaram Bazar etc. The water supply tube wells include many mini tube wells (with limited discharge and much lower construction cost than a regular deep tube well) being maintained by the UJS. Monitoring of the tube wells is being done through the Master Control Station of the UJS located in Nehru Colony.

WATER PROFILE

Surface water sources (rivers, streams etc.) were traditionally used in Dehradun City for water supply but groundwater sources have started playing an important role in supplementing the surface water sources in recent times. The total water supply to the City is 127.05 million litre per day (MLD) out of which surface water sources contributes only 24.54 MLD (19.32%). Contribution of groundwater in total water supply is 102.51 MLD (80.68%), which means that groundwater plays a pivotal role in urban water supply (Source: National Institute of Urban Affairs, 2007). The average per capita water supply in Dehradun is 124 litre per capita per day (lpcd) while the average duration of supply is 4 hours (twice a day). The total water loss in supply is estimated to be a staggering 30%, which demands a thorough review of the water supply position and effective management of the water resource in the City. A socio-economic survey of 1160 households in the

City has revealed that 71% of the population has access to piped water supply (National Institute of Urban Affairs, 2007).

Two water treatment plants are operational in the City with a total capacity of 34 MLD. Water supply in the northern part of Dehradun City is through gravity, in the central part through gravity and pumping while in the southern part, supply is through pumping only (*op. cit.*). One of the biggest problems of water supply in Dehradun is the unequal intra-city distribution, due to which some localities are facing acute water shortage.

GROUND WATER SCENARIO

Potential Aquifers

The hydrogeology of Dehradun City (a part of Raipur block) is related to the geology and geomorphology of the area. Dehradun City comes under two hydrogeological units namely Dun Gravels and Siwalik Group. These units are briefly described below.

Doon Gravels: The intermontane valley comprises alluvial fans and sediments which descend from the Lesser Himalaya to the north (facing slopes of the Siwalik Hills or Sub Himalaya). Geologically the formation is known as Doon Gravels, which is characterized by very coarse boulders embedded in sandy and silty matrix. The clasts are mainly composed of quartzite, limestone, sandstone and phyllite, which are derived mainly from the Krol Group. Conglomerate pebbles of Siwalik Group are also present in Doon Gravels. The Doon Gravels are subdivided into three chronological sub-units namely Older, Younger and Youngest Doon Gravels. The older Doon Gravels are characterized by clasts eroded from the Upper Siwalik conglomerate. These conglomerates are massive, supported by red matrix and represent debris flow deposits. The Younger Doon Gravels are characterized by rounded clasts of quartzite, limestone, sandstone, phyllite and shale derived from the Lesser Himalaya and Sub Himalaya (Siwalik Hills). Calcification is pronounced due to carbonate minerals, whose provenance is Krol Group. The Youngest Doon Gravels comprises very large boulders representing both debris flow and braided river systems. Recent and alluvial deposits formed by rivers overlie this unit.

Groundwater generally occurs in unconfined, confined and perched conditions. The perched water table condition is generally met due to the semi permeable nature of the clay beds owing to their gritty nature, and the limited thickness and wedge or lens shaped tapering of the beds unsuitable for creating confined pressure heads.

Confined groundwater conditions in the area under study are largely attributed to the underground disposition of aquifers and elevation difference between the point of intake or recharge of the aquifer at any point, in the down gradient where the tubewell has been bored. The depth to water in the Doon Valley varies from 6.0 to >100.0 m bgl and the terrain being proximal to Siwalik foothills, the depth of water table is largely dependent on the slope of the country.

Siwalik Group**:** Groundwater occurs in confined conditions and the depth to water levels is comparatively higher than in Doon Gravels. In spite of the boulder-conglomerate bed of Upper Siwalik Formation being highly porous and permeable, much of the water goes as run off due to steep slopes and the sediments forming piedmont fans dipping into the intermontane valley. About 70 gravitational springs have been reported which have a varying discharge ranging from less than 1 liter per second (lps) to 113 lps. The fresh water bearing zones are present in the Upper Siwalik due to the presence of pebble–gravel–conglomerate–boulder beds and act as good groundwater reservoirs when underlain by the Bhabar or Doon Gravel. Groundwater exploration has revealed that the pebble–boulder and gravel–sand beds of Siwalik Group are capable of yielding copious quantities of water for irrigational purpose.

Ground Water Level

A total of five Ground Water Monitoring Wells are monitored regularly in Dehradun City four times in a year viz. January, May, August and November. These include one Dug Well at Kanwali and four Hand Pumps at Harbanswala, Nanurkhera, Tarla Nagal and Balliwala. Apart from these, a Piezometer constructed in the office building of CGWB, UR, Dehradun is also being monitored weekly since 5th February 2010.

Among the different GWMWs periodically being monitored in Dehradun City, the long-term well hydrograph is available for the wells at Majra and Kanwali (Fg-2&3). High frequency depth to water level data (on weekly basis) is being collected and analyzed for a Piezometer, which was being monitored in the office building of CGWB, UR since February 2010. The well hydrograph of the CGWB Piezometer is shown in Fig. 4.

The hydrograph at Majra (Fig. 2) shows that during the post-monsoon period the water level lies between 2 to 4 m bgl while it lies between 4 to 8 m bgl in pre-monsoon period. The depth to water level data has revealed that there was a slight rise in pre-monsoon during the initial years followed by a substantial decline from 2002 onwards. The post-monsoon data is available during the period 1994-2003, which has revealed a slight rise in groundwater level.

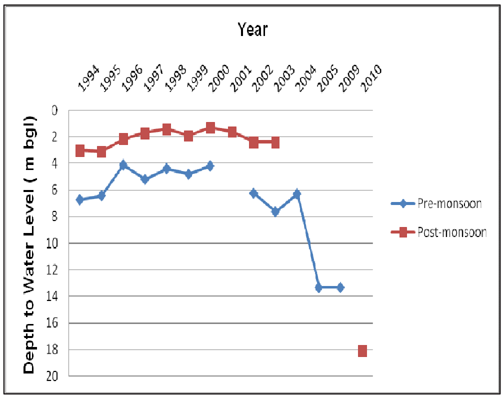


Fig. 2. Well Hydrograph at Majra

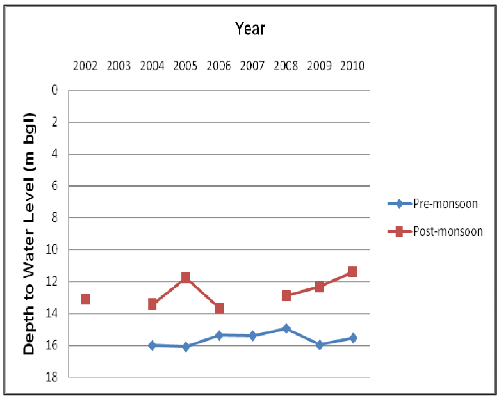


Fig. 3. Well Hydrograph at Kanwali

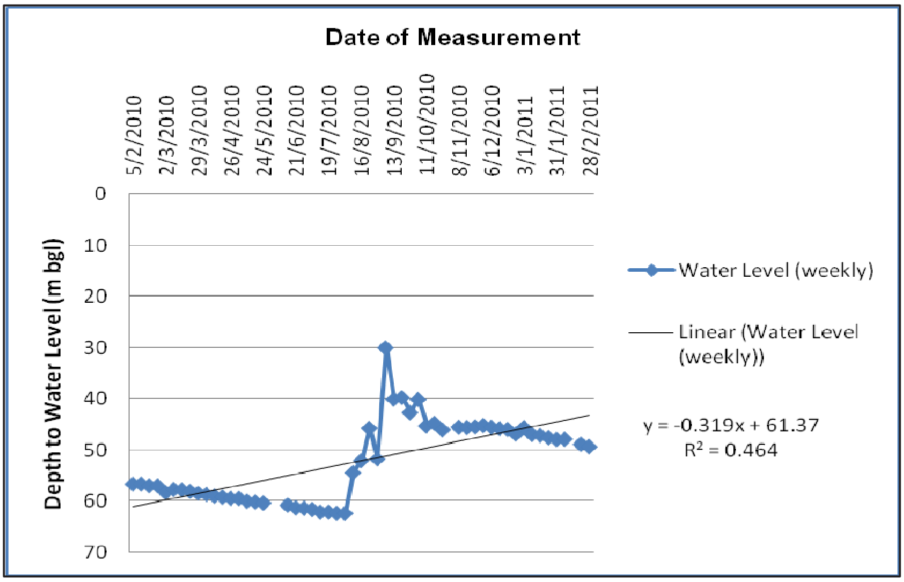


Fig. 4. Hydrograph of Piezometer at CGWB Office

Ground Water Resources and Status of Development

Estimation of Dynamic Groundwater Resources was available for Raipur block, whose headquarter is the Dehradun City itself. Water Table Fluctuation (WTF) method was utilized for calculation of groundwater resource potential of Raipur block. The available figures (as on March 2004) have revealed that the total annual groundwater recharge (both for command and non-command areas) of Raipur Block was 30693.85 ham and the natural discharge during the non-monsoon period was 3069.38 ham. The net annual groundwater availability was calculated as 27624.47 ham.

During the course of Groundwater Management Studies in Dehradun District (AAP:2007-08), an attempt was made to evaluate the available groundwater resources in Raipur Block based on the norms laid down by the Groundwater Estimation Committee (GEC, 1997) and the ad hoc norms followed by the ground water department of Uttar Pradesh. Groundwater resources were calculated both for command and non-command areas (including forest area), leaving the areas where the slope exceeds 20% (hilly area).

The gross groundwater draft (both for command and non-command area) in Raipur Block was calculated as 9139.59 ham and the allocation for domestic and industrial water supply (up to next 25 years from the period 2007-08) was found to be 2992.68 ham. The stage of groundwater development in the command area was found to be 61.71% and for non-command area it was only 28.0%. The overall stage of groundwater development of Raipur Block was 33.08%, which falls in "Safe" Category.

Hydrochemistry

Water samples for complete chemical analysis were collected from Ground Water Monitoring Wells located within the municipal limits of Dehradun City viz. Majra, Kanwali, Balliwala, Harbanswala (Vasant Vihar Phase-II) and Nanurkhera during pre-monsoon monitoring. The analysis results are available for 12 parameters viz. Electrical Conductivity (µS/cm at 25°C), pH, bicarbonate (HCO_3), chloride (Cl), nitrate (NO_3), sulphate (SO_4), fluoride (F), calcium (Ca), magnesium (Mg), total hardness (TH) as $CaCO_3$, sodium (Na) and potassium (K).

The distribution of nine hydrochemical parameters viz. HCO_3, Cl, NO_3, SO_4, F, Ca, Mg, Na and K are represented as bar diagrams (histograms). Due to long-term hydrochemical data availability for Kanwali (period 2004-2009), a separate histogram is given (vide Fig. 5). The intervariability of hydrochemical parameters for the rest of the monitoring stations is shown in Fig. 6.

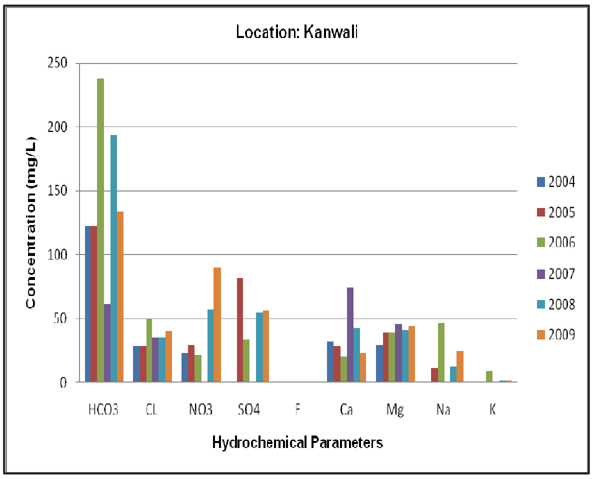


Fig. 5. Variation of Hydrochemical Parameters at Kanwali

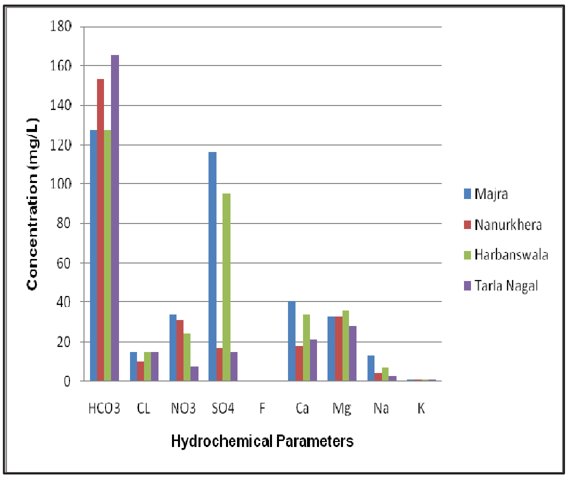


Fig. 6. Intervariability between four Monitoring Stations during 2009

A perusal of Fig. 5 and Fig. 6 has revealed that the various parameters are well within the acceptable limit as per the Revised Guidelines on Drinking Water of the Bureau of Indian Standards (BIS, IS: 10500, 2nd Revision, 2003). However, high nitrate was observed at Kanwali dug well in 2008 and 2009, which may be attributed due to anthropogenic source.

Major Ground Water Related Problems

The study of hydrographs of shallow aquifers tapping perched water bodies has revealed a slightly declining trend. After creating of Uttarakhand State, parts of the Dehradun City and nearby areas like Selakui Industrial Area, Lal Tappar Industrial Area etc. have become a hub of industrial activities. The population of Dehradun has increased at a very high rate over the last few years. This has created tremendous stress on groundwater resource of Doon Valley. As a consequence, the urban water supply deep tube wells and mini tube wells are being forced to operate for longer hours due to increase in demand for groundwater.

During the peak summer season, there has been scarcity of drinking water and some of the mini tube wells have failed. Quality of groundwater in Dehradun City has been found acceptable. However, some slum dwellers have reported contaminated water in the piped water supply schemes. Decline of groundwater level in Hand Pumps was observed in fringe areas of Dehradun City (along Dharmawala-Kunja-Judli-Matak Majri and also along Dalippur–Dakrani–Dakpatthar area) in the post monsoon periods during Groundwater Management Studies in Dehradun District. This may be attributed to seasonal fluctuation in the Yamuna flood plain where the aquifers are recharged by Yamuna River.

Due to rapid urbanization in the last decade (essentially after the formation of Uttarakhand State in the year 2000), the stream flow has reduced substantially except during monsoon. Moreover, encroachment on the banks of Bindal Rao and Rispana Rao has worsened the surface water quality of the streams (Fig-7).

Fig. 7. Illegal Encroachment along Bindal Rao, Dehradun City

Feasibility of Rain Water Harvesting and Artificial Recharge

Due to urbanization and industrialization, there is an ever-increasing stress on groundwater resources. Runoff is quite high in the City. Construction of roads and increase in paved areas during recent years has lead to increased run off and reduced natural recharge to the aquifers. Only very limited channel bed infiltration takes place along some of braided rivers.

Artificial recharge of the aquifer system is not in pace when compared to that of groundwater withdrawal in Dehradun City. The water levels in some parts of the City have declined considerably over the last decade. The Government of Uttarakhand has given instructions for compulsory installation and execution of roof top rain water harvesting system in all government buildings, schools and hospitals in Uttarakhand State vide Official Orders during May 2004 and July 2008. It has been suggested by the Central Ground Water Board, Uttaranchal Region to implement roof top rain water harvesting system in buildings having a roof top area of ≥ 200 m^2.

Central Ground Water Board, Uttaranchal Region has implemented a demonstrative artificial recharge scheme in Thano, Raipur Block under the Central Sector Scheme. A series of four check dams were constructed in a Nala and the success of the scheme was evidenced after a span of five years (in 2008) by increased vegetation cover. Substantial recharge to the shallow aquifers in the area was indicated by absence of surface flow in the downstream side of the check dams.

Roof top rain water harvesting and groundwater recharge schemes have been installed in the buildings by the state government departments in Dehradun City. Besides this, technical assistance to various agencies, NGOs and self help groups are being provided by CGWB, UR.

GROUNDWATER DEVELOPMENT STRATEGY

The overall utilization of groundwater resources in Dehradun City is moderate and exploration activities have been carried out in different locations viz. Tarla Nagal in the north eastern part and Vasant Vihar in the southern part by the Central Ground Water Board, Uttaranchal Region. The various components of a holistic groundwater development strategy of Dehradun City are mentioned hereunder:

Utilization of Existing Groundwater Resources

- Groundwater supply in the City is principally through the deep tube wells, mini tube wells and India Mark-II hand pumps. It has been observed through exploration activities carried out by the CGWB, that potential aquifers exist in parts of Dehradun City where Doon Gravels constitute promising aquifers.
- It has been suggested that sites for groundwater exploration in the City be selected scientifically with an emphasis to generate subsurface hydrogeological data. Surface resistivity surveys should be carried out in virgin areas rather than areas which have good groundwater potential.
- Water supply tube wells can be used both for drinking and irrigation purposes (in the fringe areas of Dehradun City). Existing data from state government departments have revealed that a total of 331 tube wells created groundwater draft of 9139.59 ham for Raipur Block, whose headquarter is Dehradun City.
- Analysis of data of government and private tube wells has revealed that there is a potential of constructing about 1000 tube wells in Raipur Block to fully utilize the available groundwater resources. However, the production wells should be constructed where hydraulic troughs were formed.
- It has been suggested that the optimum spacing between two tube wells should be between 150 and 200 m in Dehradun City.
- It has been observed in the past that failure of mini tube wells in some areas has posed problem in sustainable development of groundwater in and around the City. To overcome the problem, it is suggested to carry out detailed hydrogeological investigation followed by surface resistivity surveys (VES and Profiling depending on the site condition) to locate feasible sites for construction of the mini tube wells.
- Occasional drying up of India Mark-II Hand Pumps is attributed to the shallow depth of penetration and tapping of shallow, perched water bodies. It is suggested to extend the drilling depth by 20-30 m below the static water level in the Hand Pumps for a sustainable supply of groundwater, especially in the slum areas of the City.
- Instead of constructing tube wells haphazardly in different pockets of Dehradun City, battery of tube wells should be constructed along the banks of Song River, located to the east of Dehradun City. Similarly, battery of tube wells should be constructed along the bank of Asan River located to the west of the City. Systematic groundwater exploration has to be carried out along the banks of Song and Asan Rivers for a sustainable water supply through the potential multi aquifer system developed in Doon Gravel.
- River Bank Filtration technology has been proved quite successful in Uttarakhand. Uttaranchal Koops have been installed in the past by Uttarakhand Jal Sansthan along river banks, which have proved to be quite successful in augmenting the water supply position. Pilot studies in Song and Asan Rivers are required so that the technology may be adopted in many areas of Raipur Block.

- There is a scope of augmenting the spring-based irrigation system in the peripheral parts of Dehradun City by adopting spring rejuvenation. Also instead of the existing open channel flow scheme (Guhl system), piped water supply should be practiced for irrigation as it involves minimum distribution loss and lesser maintenance cost than the Guhl system.

Water Conservation Methods

- Water conservation methods like construction of contour bunds, check dams, gully plugs, gabion structures etc. may be adopted on small streams and Nalas in the fringe areas of the City depending on the local geological and hydrogeological conditions.
- Gully plugs having width of 1.5-2.0 m and height of 0.7-1.0 m may be constructed on first and second order streams. Contour bunds may be constructed where land slope is <6%. The dimension of contour bunds will depend on the slope and the type of soil.
- Bushwood Check Dams may be constructed for conservation of water and soil in small Nalas with locally available vegetation. This is a bio engineering structure with long life span and involves very less expenditure of only few thousand rupees.
- Similarly, Gabion Structures can also be constructed in small seasonal streams like Nalota Nala, Baldi Nadi etc. The height of this bio engineering structure may vary from 0.5 to 1.0 m and it requires a good quality steel wire mesh to bind the locally available stones for sustainable water conservation.

Artificial Recharge and Rain Water Harvesting

- There is immense scope for implementing roof top rain water harvesting system in the City .The rain water may be conserved as surface storage or may be utilized for recharging the shallow aquifers.
- Surface storage of rain water may involve construction of a Syntex tank, RCC tank or Masonry tank. The cost component is variable depending on the engineering design and may range between Rs. 10000/- to Rs. 25000/-. The system may be adopted in Group Housing Societies being constructed in Dhoran Khas area by infrastructural firms.

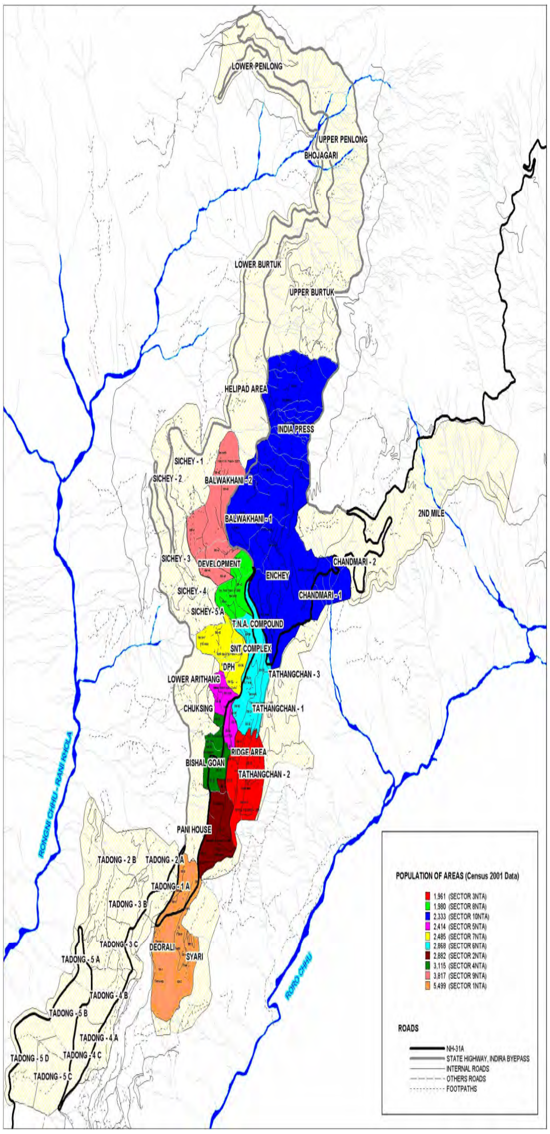
Roof top rain water harvesting and artificial recharge scheme through recharge trench has been implemented in the various state govt offices in Dehradun city. However Artificial Recharge to the aquifers in Doon Gravel, which is applicable for Dehradun City, requires detailed site specific studies.

GANGTOK CITY, SIKKIM

Indranil Roy, CGWB, Kolkata

INTRODUCTION

Gangtok, the capital of Sikkim is located in the East District, along the historical trade route connecting the Great Indian Plains with Chumbi Valley of Tibet. Gangtok rose to prominence as a popular Buddhist pilgrimage site after the construction of the Enchey Monastery in 1840. In 1894, the ruling Sikkimese Chogyal, Thutob Namgyal, shifted the capital to Gangtok. In the early 20th century, Gangtok became a major stopover on the trade route between Lhasa in Tibet and cities such as Kolkata (then Calcutta) in British India. After India won its independence in 1947, Sikkim chose to remain an independent monarchy, with Gangtok as its capital. In 1975, after the integration with the union of India, Gangtok was made India's 22nd state capital. The city lies between 27°20’ to 27°16’ N latitude and 88°37’ to 88°39’ E longitude. Altitude varies from 914 m to 1829 m amsl. Gangtok is connected by National Highway 31A with Darjeeling, Kalimpong and Siliguri.



Courtesy: Town Planning Cell, UD&HD

Fig. 1. Map of Gangtok Census Town

GENERAL FEATURES

Gangtok city has been developed atop a ridge along the NH-31A. The length of the city is about 25km. The physical growth pattern of the city is dictated by topography and accessibility.

Administrative Division

Gangtok urban area covers about 26.4 sq.km., is looked after by Urban Development and Housing Department (UDHD) in collaboration with Water Security & Public Health Engineering Department (WS&PHED). These departments look after the civic functions such as garbage disposal, water supply, tax collection, license allotments, and civic infrastructure. An administrator appointed by the state government heads the UDHD. A map of Gangtok census town is given in Figure 1. The Sikkim Municipal Act, 2007 has approved the formation of Gangtok Municipal Corporation to be made up of 12 wards and which shall take over the administration from the UDHD. However, it has been further planned to form Greater Gangtok Planning Area (GGPA) covering an area of 76.95 sq km. The existing land use pattern of Gangtok is given in Table 1.

Table 1. Land-Use Pattern in Gangtok

Residential	43%
Commercial	4%
Public and Semipublic	15%
Roads	19%

(Source: NERUDP, Final Report, ADB Report, 2006)

Demography

According to the 2001 Census of India, the population of Gangtok "Notified Town Area" was 29354. Males constituted 54% of the population and females 46%. The Gangtok subdivision of the East Sikkim district had a population of 179376 of which 43711 reside in urban areas of Gangtok and Tadong. Of total urban population of Sikkim, Gangtok Notified Town Area has a share of 55.5%. Historical population growth of the area is given in Table 2. It is also to be noted that Government of Sikkim reclassified the city limits of Gangtok in 1991, causing the population and the city area to shrink by 60%.

Table 2. Growth of Population in Gangtok Subdivision and Gangtok Notified Town Area

Year	Population	Decadal Growth Rate	Remarks
1951	2744		
1961	6848	149.56	
1971	13308	94.33	
1981	36747	176.13	
1991	25024	-31.9*	The negative growth rate was due to the reduction in the size of the urban area.
2001	29354	17.3	

Source: Census of India, 2001

Hydrometeorology

Climate of Gangtok remains pleasant throughout the year with an average summer temperature ranging from 17°C to 25°C (from April to September) and average winter temperature ranging from 9°C to 18°C (March to October). The weather of Gangtok is alpine type. Humidity is fairly high throughout the year with an annual average of about 85%. The region receives an annual normal rainfall of 3800 mm over 165 rainy days per year. A major portion of the rainfall is from the south-west monsoon between June to September. Snowfall is rare, and in recent times Gangtok has received snow only in 1990, 2004 and 2005. The annual mean wind speed ranges between 1.8 and 4.1 kmph. Normal rainfall, average rainfall and average rainy days of the area are compiled in Table 3.

Table 3. Rainfall Pattern in Gangtok (in mm)

Month	Normal Rainfall (mm)	Average No of Rainy Days (1941-90)
January	43.8	3.3
February	58.6	5.1
March	132.5	8.1
April	280.9	13.8
May	578.8	22.4
June	684.1	24.7
July	700.8	27
August	616.4	26.4
September	477	21
October	205.3	8.8
November	35.6	3.2
December	20.3	2
Total	**3842.1**	**165.8**

Source: NHPC (2005)

Physiography & Drainage

Gangtok ridgeline divides the city into two parts viz. eastern and western. The general slope of the western side of the ridge vary from 30° to 42° but in certain stretches around Adampool below Amdo Golai and Rani Khola areas of Sichey, slopes are gentler and varies from 10° to 15°. On eastern side the slopes varies from 20° to 40°. In the areas with more than 60% slope (i.e., 30° from horizontal), the rocks are incompetent and structurally disturbed and susceptible to slope failures. The city is located in Seismic Zone IV. Terrain model of the area is given in Figure 2 (a) and FCC of Gangtok area using IRS-1D LISS III data is given in Figure 2 (b).

The area occupies the central portion of the leaf shaped Rongni Chu catchment, surrounded by two streams, namely Rani Khola in the west and the Roro Chu in the east. These two rivers divide the natural drainage into two parts, the eastern and western parts. Both the streams meet the Ranipool and flow towards south as the main Rani khola before it joins the Teesta at Singtam. Numerous small and large natural springs and rivulets locally known as "Jhoras" dissect the entire area. There are 95 major jhoras (30 in South-Eastern region and 65 in North Western region) draining into Roro Chu and Rani Khola Rivers. Average spring discharge is given in Table 4.

Table 4. Average Spring Discharge

Sub Division	No. of Springs measured	Average lean period discharge (lpm)
Gangtok	46	13.28

Source: RM&DD (2004)

Soil Type

Soils in the region are excessively drained, coarse to fine loamy with slight surface stoniness. The soils are acidic in nature with pH < 5 and shows contrasting morphologies under varying topographic settings. Soils in north and eastern part of the Gangtok planning area are thin and highly sandy when compared to the western part. The western part of the ridge towards the River Rani Khola possesses fertile agricultural land where as the eastern part towards the River Roro Chu possesses steep terrain and is not suitable for agriculture.

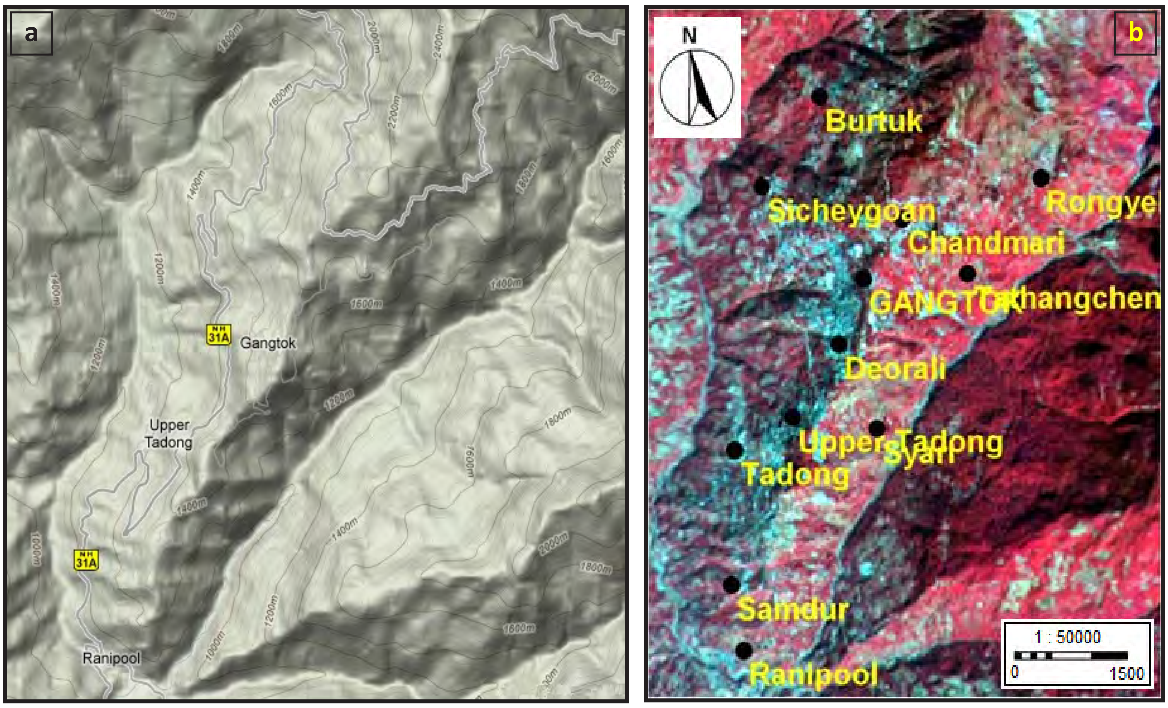


Fig. 2. a) Topographic model of Gangtok Area (source: Google Earth) **b**) FCC of Gangtok area using IRS-1D LISS III data.

STATUS OF WATER SUPPLY AND DEMAND

Water is supplied in Gangtok by the WS&PHED, RM&DD and spring sources. While one pays for water supplied by the WS&PHED, water supplied from RM&DD sources is free. The three major sources of water supply in Gangtok are,

1. Treated and piped water supply by the PHED (access coverage range 70-85%)
2. Treated and piped water supply by the RM&DD (~ 21%)
3. Private piped water supply from spring sources

(Source: Community Engagement, GWSSP)

RM&DD supplies treated water mainly to Burtuk, Sixth mile, Chandmari, 2nd mile, Sichay, Lower Arithang and Lower Syari. WS&PHED supplies treated water to various areas of Gangtok such as the Town area, Arithang, Syari, TNHS and Tadong. Considering reliability of service, although about 83% of the population of Greater Gangtok Planning Area (GGPA) have access to PHED's piped water supplies, only about 50% have an individual water tap. There are a substantial number of shared connections. About 25% of households having PHED water taps receive water 24 hours a day, and almost all get water for a few hours every day. People also collect water from small springs and small streams called jhoras through private connections.

The main source of drinking water for the entire area is the Ratey Chu River located 16 km from the main water treatment plant at Selep. Mainly three treatment plants of 4.5 mld, 9.14 mld and 22.68 mld capacities have been installed under various phases since 1973. A fourth small treatment plant of one mld capacity was also installed some time back, to serve a locality at an elevation higher than Selep. However, the most recent 22.68 mld plant has not become fully operational till date. The river Ratey Chu is snow fed and has perennial streams with alpine characteristics. The discharge of the stream is about 20 cusecs (48.5 mld) during the dry season and 40 cusecs (97 mld) during the monsoon. Like other hill cities Gangtok too has the gravity flow based 'bunched pipelines' system for distribution.

The population of GGPA as per 2001 census was 86,832. Present (2010) estimated population is about 1,10,000. Going by a demand of 140 lpcd and service coverage of 80%, the requirement for water at the consumer end is 12.3 mld. Against this demand, production from all sources is 13.50 mld and is now adequate. However, considering future demands based on projected population, an immediate increase in capacity is needed and work has been planned in phased manner (Table 5). This is also to be noted that a high amount of unaccounted water loss is present in the system, primarily due to distribution losses, pipe leakages, illegal tapping, mechanical damages etc (UD&HD, 2001).

WATER PROFILE

The River Rani Khola flowing southerly is fed by numerous streams from the western side of the Gangtok ridge. The River Roro Chu follows a southwesterly course with numerous easterly and westerly flowing feeder streams. Unlike Rani Khola, Roro Chu is of younger origin and follows more or less along a straight course. Apart from these streams, about 95 jhoras are present in the area. However the area being on the ridge top, surface water bodies like ponds are absent in the area. Moreover, being hilly terrain with slopes commonly > 20%, scope of groundwater storage is also limited. Most of the rainwater flows out as surface run off. Depending upon secondary porosity and structural control of the underlying aquifers, groundwater emanates in the form of springs.

Table 5. Projected Population, Water Requirement and Designed Capacities

Sl. No.	Year	Population	Water demand at 200 lpcd at consumer end (mld)	Gross Demand required at source (mld)	Designed Capacity (mld)	Remarks
1	2011	112005	—	—	13.50	New plant work partly completed
2	2013	116613	23.32	27.32	36.32	Phase-I design population. The population of years 2013 has been arrived on linear interpolation method
3	2021	135046	—	—	—	—
4	2026	147477	29.49	33.86	36.32	Phase-II design population
5	2031	159908	—	—	—	—

Source: WS&PHED, Govt. of Sikkim

GROUND WATER SCENARIO

Ground water occurs in the area in the form of localised disconnected bodies and circulates under favourable geological conditions mainly in secondary porosity i.e. through joints, fractures, fissures etc. of across various lithological units, along contact zones and also in weathered mantle and thin veneers of soil present over various lithological formations. Direct infiltration from rainfall through secondary porosities is the principal mode of recharge of ground water. Due to rugged relief and steep gradient of the area, sub-surface flows are frequently intercepted, and manifested as seepages and springs.

Potential Aquifers

Geologically the region forms part of inner belt of lesser Himalayas and consists of three main lithological units**.** The regional strike of all these lithological units is NW-SE with a dip of 15° – 60° towards NE. Two sets of planar structures are most conspicuous, Bedding plane (S_1) and the Schistosity (S_2) mostly occurring in sub parallel arrangement. Due to different phases of structural disturbances, numerous fractures, small scale faults and joints have been developed. Fracture cleavage occurs in the schistose rock. 3 sets of joints are found in all the rock types. Table 6 provides a description of the geology in Gangtok area. Hydrogeological map of the city is given in Figure 3.

Table 6. Local geology of Gangtok Area

Group	Subgroup/Formation	Lithology	Locations
Daling Group	Quaternary	Alluvial deposit	Patchy valley fills
	– Unconformity –		
	Garubathan Subgroup	Phyllite	Ranipool-Samdur-Linding areas
	– Thrust contact –		
	Lingtse Granite Gneiss	Granite Gneiss	Upper Syari
	– Thrust contact –		
Sikkim Group	Chungthang Subgroup (Rongli Schist)	Biotite gneiss, quatrzite, impure marble, graphitic schist	Major portions of the Gangtok town area
	Darjeeling Gneiss	Migmatitic gneiss with calc-silicate lenses	Burtuk, Rongye

(Simplified after ADB,2009; GSI, 2000)

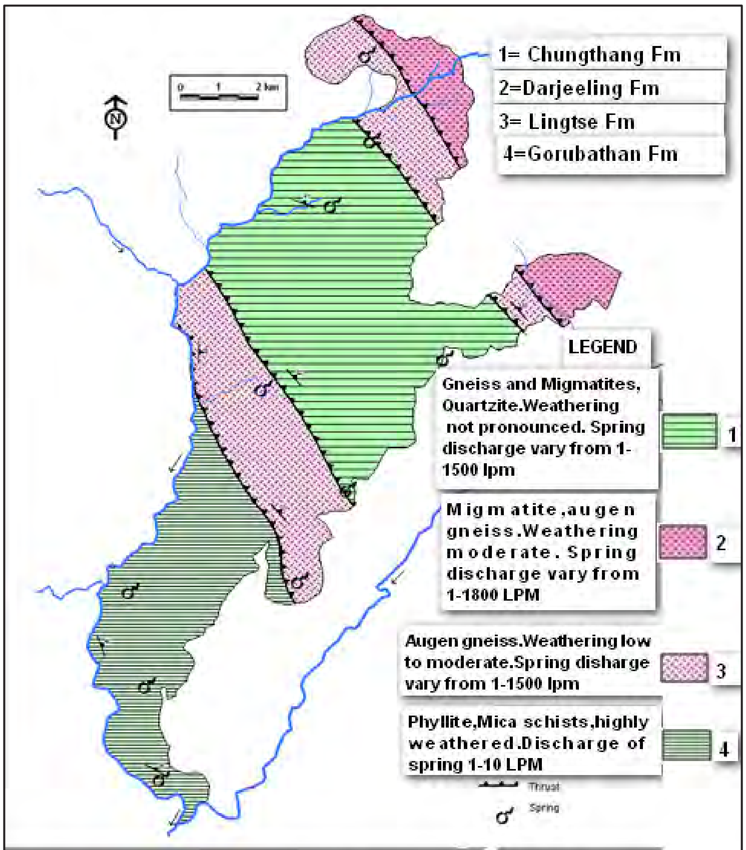


Fig-3 Hydrogeological Map of Gangtok Town

Lineament study by Central Ground Water Board (CGWB) in nearby areas (namely Rumtek and Pakyong) in East district, indicates presence of prominent lineaments trending along N-S, E-W, NE-SW, ENE-WSW and NW-SE directions with lineament intersection density of 10 to 14 intersections per 12.5 x 12.5 km2 area. This may be indicative of presence of deep-seated regionally extensive fractures in the area. The ground water exploration done in the district through exploratory boreholes along with geophysical surveys indicates that fractures generally start from a depth of about 10 m and continue down to about 70 m bgl. While fractures, down to 45 m bgl are not very persistent and appear to be of local pattern, fractures occurring below 50 m bgl are rather persistent and probably of regional extension.

Spring Characteristics

Due to steep gradient groundwater comes out as seepages and springs, whenever the surface intersects ground water table. Steeper hill slopes dominantly form the areas of spring discharge. The movement of ground water in the area is mainly controlled by the structural set up and physiography. Study by CGWB indicates that mainly two types gravity springs are prevalent in the area, namely a) Depression Spring; and b) Fracture Spring. It has been observed that spring discharge decreases during December to April and increases during May to September. Monsoon rainfall results into 2 to 6 times increase in discharge of the springs. In Daling phyllites, spring discharges range from 1 to 60 lpm, while in Darjeeling granite gneiss discharge range from 3 to 30 lpm. Comparison of TDS values indicate very-short to short flow path of springs of Gangtok area.

Ground Water Resources and Status of Development

Ground water resource estimation has not been carried out for Gangtok area specially. District-wise resource estimation results for East District in which Gangtok belongs is summarised in Table 8. However, as mentioned earlier, 83% population of Gangtok town has access to piped water supply of WS&PHED. Hence stage of ground water development is much less in Gangtok area in comparison to entire district.

Table 8. Summary of Ground water Resource Estimation (2008)

Assessment Unit/ District	East Sikkim
Net Annual Ground Water Availability	805
Existing Gross Ground Water Draft for Irrigation	129.77
Existing Gross Ground Water Draft for Domestic and Industrial need	307
Existing Gross Ground Water Draft for All uses	437
Provision for domestic and Industrial supply by year 2025	553
Net Ground Water Availability for future Irrigation development	122
Stage of Ground Water Development (%)	54.3
Estimated Average Individual Spring Catchment area (ha)	30
Estimated Total Spring Catchment area (ha)	41520
Annual Replenishable Ground Water Resources (m)	0.019

Hydrochemistry

Quality of spring water is very good when away from major urban area and commonly potable for drinking purposes. It depends mainly on (i) intake or recharge area, (ii) annual rainfall percolation, and (iii) continuous flow of the spring.

Quality of water of few springs near Gangtok is given Table 9. Spring water temperature varies from 10° C to 23° C in the area. In general water quality is potable except pH is quite low in all the samples and iron is high in Goskan jhora. This low pH may be indicative of presence of carbonic acid at the forested recharge zone as supported by higher DCO_2 values in the sample. This situation may be treated by boiling and using lime. On the other hand, when quality of stream water (Table 10) is considered, anthropogenic bacteriological contamination is prominent. This is result of city sewerage release in rivers.

Table 9. Water Quality of Springs in and around Gangtok

Sl. No.	Parameters	Goskan Jhora	Hospital Jhora	Paljor Stadium Jhora	Fisheries Jhora	Diesel Power House Jhora
1	Source Type	Spring	Spring	Spring	Spring	Spring
2	Temp	13.5 °C	10.5 °C	17 °C	15 °C	-
3	Odor	Toxic	Toxic	Toxic	Toxic	-
4	Colour	Blakkish	Muddy	Yellowish	Darkish	-
5	pH	5.3	5.8	5.5	5.4	-
6	Conductivity (μ mhos/cm)	650	300	200	200	-
7	Salinity	0.50%	-	-	-	-
8	Dissolved Oxygen (mg/l)	5.33	8,53	8.13	8.47	7.87

9	Dissolved CO_2 (mg/l)	89.34	20.66	27.34	7.34	11.34
10	Chlorides (mg/l)	4.50	2.60	1.66	1.42	8.91
11	Alkalinity (mg/l)	201.8	118.67	84.67	72.33	58.67
12	Acidity (mg/l)	49.67	15.17	11.33	4.33	6.83
13	Hardness (mg/l)	199.46	93.48	68.26	75.44	63.84
14	Ca (mg/l)	38.61	28.32	22.71	27.12	24.71
15	Mg (mg/l)	-ND-	-ND-	-ND-	-ND-	-ND-
16	Fe (mg/l)	2.12	0.01	0.18	0.02	0.2
17	Na (mg/l)	51.16	35.48	41.75	37.05	28.98
18	K (mg/l)	92.9	57.32	33.6	37.56	37.56
19	Phosphates (mg/l)	67.1	4.11	7.92	6.54	4.19
20	Nitrates (mg/l)	0.01	0.02	0.011	0.01	0.01
21	Silicates (mg/l)	25.25	18.5	11.6	10.99	12.95
22	TS (mg/l)	428.0	455.2	240.2	104.4	230.1
23	TDS (mg/l)	332.6	384.2	202.0	83.7	226.3
24	TSS (mg/l)	95.4	71.0	38.2	20.7	3.8

Source: SPCB (2007)

Table 10. Water Quality of Streams in and around Gangtok

Sl. No.	Parameters	Sampling Locations		
		Adampool (Rani Khola)	Ranipool (Rani Khola)	Jalipool (Roro Chu)
1	Turbidity (NTU)	2.5	2.5	2.5
2	pH	7.2	7.5	7
3	Conductivity (µmho/cm)	280	280	270
4	Total Alkalinity (mg/l)	200	210	210
5	Total Hardness (mg/l)	132	130	138
6	Sulphate (mg/l)	28	27	28
7	Phosphates (mg/l)	0.02	NT	NT
8	Nitrate as NO3 (mg/l)	2.5	2.2	2.4
9	Fluoride (mg/l)	NT	NT	NT
10	BOD (mg/l)	12	11	10
11	DO (mg/l)	8	6	5
12	Total Coliforms	220000	170000	130000
13	Faecal Coliform	170000	110000	90000

Source: WS&PHED (2008)

Major Ground Water Related Problems

As such major problem related to ground water of the city is absent. However, springs are very much vulnerable to surface pollution and sometimes it is contaminated due to turbidity in it and presence of organic filths and harmful bacteria. Gangtok city generates about 45 tons of garbage per day. It is estimated that 57% of domestic solid waste is dumped in jhoras. Study (JNNURM, 2008) has revealed that around 66% of the households dispose their wastes into jhoras and drains polluting the jhoras and posing serious threat to the groundwater quality. Moreover, with 83% of the drains being unlined, coupled with porous and permeable soil formations act as groundwater pollution source.

Feasibility of Rainwater Harvesting and Artificial Recharge

Although the area gets more than 3800 mm of rain fall annually but most of the rainfall goes as surface run off. In lean periods discharges of the springs become meager and people suffer a lot. As the terrain is moderate to very steep, landslide prone and within seismic Zone IV, hence artificial recharge to groundwater is generally not possible in the area as it may increase susceptibility to landslide. Moreover, construction of tube well structure is also a costly affair in hilly terrain of Sikkim due to limited site suitability for placement and transportation of drilling rig, availability of potential fractures etc.

Roof top rainwater harvesting (RWH) may be encouraged to overcome the water crisis problem. Suitable big reservoirs (made of the RCC, fiber glass etc.), storage tanks would be highly useful to collect roof water from the building during monsoon period. In this respect, Ministry of Water Resources, Govt. Of India has funded various schemes on Rain water harvesting at Sikkim. Pilot project on roof-top rain water harvesting structure at Governor's House at Gangtok has been implemented by WS&PHED, Govt. of Sikkim under the technical guidance of CGWB under Central Sector Scheme and 5 nos. of RWH structures for have been constructed in Govt. Rural Schools of Sikkim for drinking and use in girl's toilets. Salient features of pilot RWH project at Governor's house is given in Table 11. Structural design of the scheme is given in Figure 4. Estimated cost break-up for construction of a RWH Unit of 50000 litres capacity in mountainous area of Sikkim is given in Table 12. It is also to be noted that being hilly area, while on one hand most of the houses have sloping roofs of galvanized cast iron (GCI) making rooftop water harvesting feasible, on the other hand scattered houses make it difficult to have a collective approach which is cost effective.

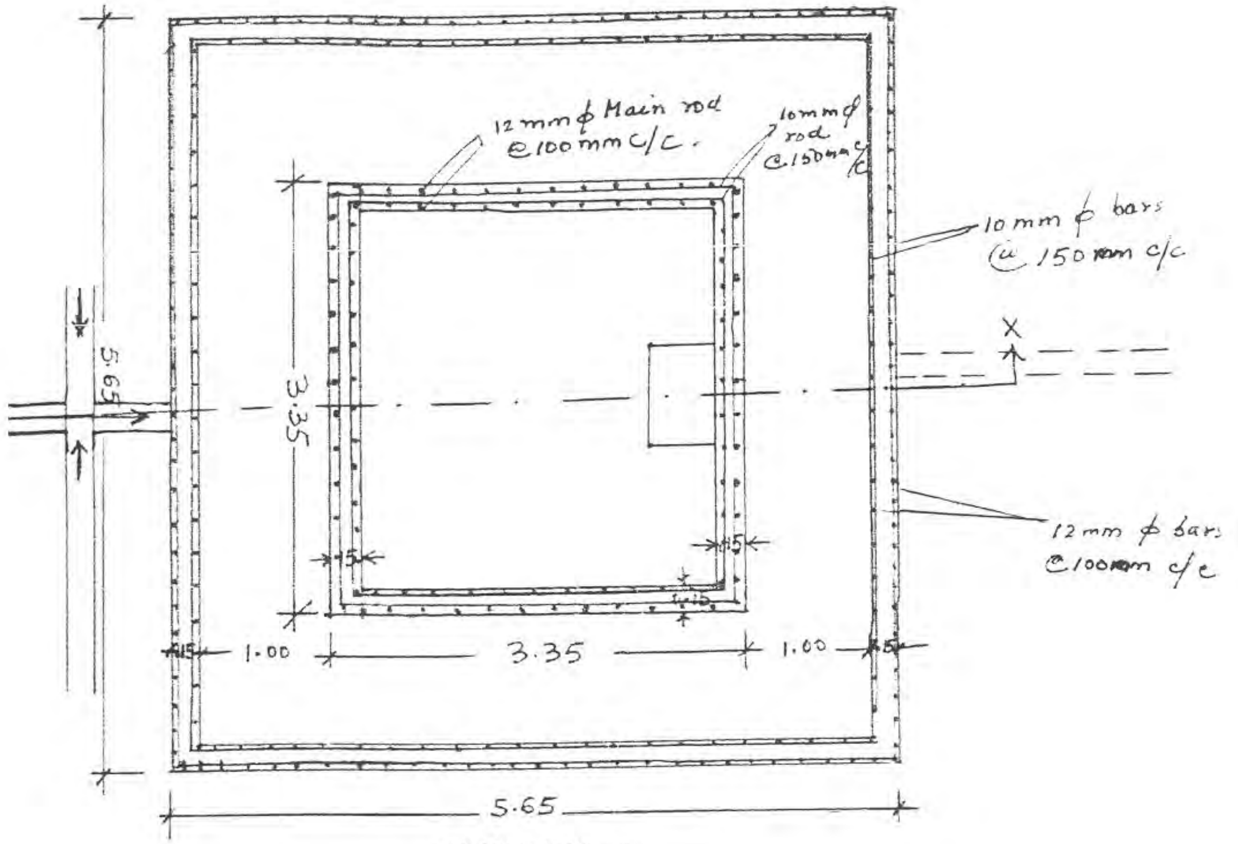
Selective artificial recharge of rain water in the areas of spring recharge zone may also be taken into consideration. With high degree of caution, considering physiography and geological conditions, some structures like contour trenching, gabion structures etc. of small extent may be constructed along with aforestation within spring catchment area to increase recharge.

Table 11. Salient features of Pilot Rainwater harvesting Project at Governor's House

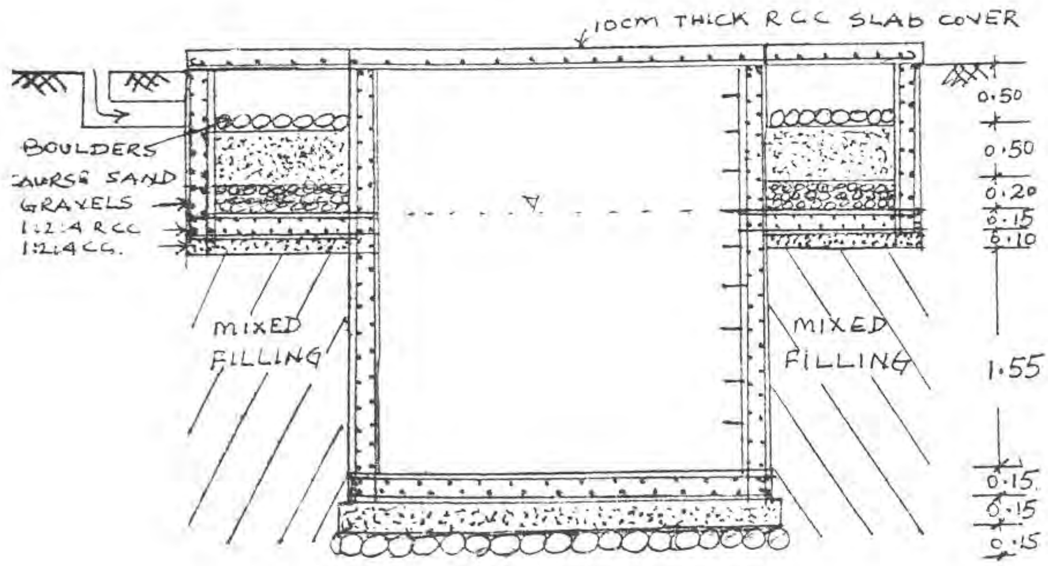
Structure Details	One Storage Tank with Filtration chamber of 20000 lts capacity
Annual Rainfall	3800 mm with an average of 150mm in single spell
Roof Utilized	Rooftop of Banquet Hall, Rajbhaban
Roof Area	600 m^2
Date of completion	30th September, 2004
Implementing Agency	WS&PHED, Govt. of Sikkim
Funding Agency	MOWR, Govt. of India
Cost	Rs. 2.30 lacs

Table 12. Estimated cost break-up of RWH Unit construction

Sl. No.	Item/Head	Cost
	Capacity: 50000 litre	
1)	Material	Rs. 125000
	Stones	-
	Cement	-
	Iron bars	-
	Hand pump	-
	Manhole Lids	-
	Ventilators	-
	Connecting Pipes	-
2)	Labour	Rs. 75000
3)	Transport	Rs. 30000
4)	Designing & Documentation	Rs. 10000
5)	Others	Rs. 10000
	Total	**Rs. 2,50,000**



PLAN TANK - 1



SECTION OF STAORAGE TANK AND FILTER PLANT

SCALE : 1 m = 2 cm

Fig.4. Design of Rain Water Harvesting Structure

GROUND WATER DEVELOPMENT STRATEGY

In Sikkim, mountain springs, have been traditionally playing a vital role in providing water security to rural households, hence they have utmost significance in water resource management. With increasing population and developing activities, maintaining Quality and Quantity (Q & Q) of spring water is of prime importance.

Spring sources should be cleaned periodically and storage tanks of adequate capacity may be built and water needs to undergo treatment (both chemical and bacteriological) before put into the network of distribution. Number of spring waters can be collected in tanks (depending on the demand) in a particular altitude and can be supplied through pipe lines by gravity drainage after necessary treatment for drinking & domestic uses. Protection of spring recharge catchment area is another aspect to look into. Sikkim governments initiative in this direction through "Dhara Vikas" project is worth mentioning. This resulted in increase in discharge as well sustainability of the springs under this project.

Effort should be made for provision of roof top rain water harvesting particularly in the Govt. buildings, Schools, Colleges etc. On the basis of its usefulness the local people should be educated to implement RWH schemes in their own buildings. Local panchayats should take initiative to make local people to understand the technique & significance of RWH and provide financial assistance wherever possible.

To achieve the above mentioned targets, proper scientific study is needed to understand the underlying earth system processes and interactions between various components at wide range of nested temporal and spatial scales. Development with the aim of sustainability should be the aim for further work where people's participation plays pivotal role.

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GUWAHATI CITY, ASSAM

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INTRODUCTION

Guwahati is Assam's largest commercial and industrial city. It is also known as the Gateway of North-East India. During the Mahabharata era Guwahati was known as **Pragjyotishpur** meaning the City of Eastern Light. The name Guwahati has been derived from the Assamese words, *guwa* meaning areca nut, and *haat* meaning weekly market.

Guwahati's myths and history go back several thousands of years. Its references in the epics, puranas, and other traditional histories, lead many people to assume that it is one of the ancient cities of Asia. Guwahati was the capital of many ancient kingdoms. According to the Mahabharata it was the capital of the 'mythological' kings Naraka and Bhagadatta . It was also the capital under the Varman and the Pala dynasties of the Kamarupa kingdom.

With each dynasty the city had a new name but retained its status as a Capital, and did so till the 11th century. Between the 12th to the 15th century, when it came under the Mughal rule, it lost some of its importance and glory. It is said that Assam was attacked 17 times by the Mughals. The most famous battle was the Battle of Saraighat, where the Mughals were actually defeated sometime in the late 16thcentury.

The city also has an ancient tradition of *tantric* worship. The ancient sakti temple of Goddess Kamakhya located in Nilachal hill remained the important seat of Tantric and Vajrayana Buddhism.

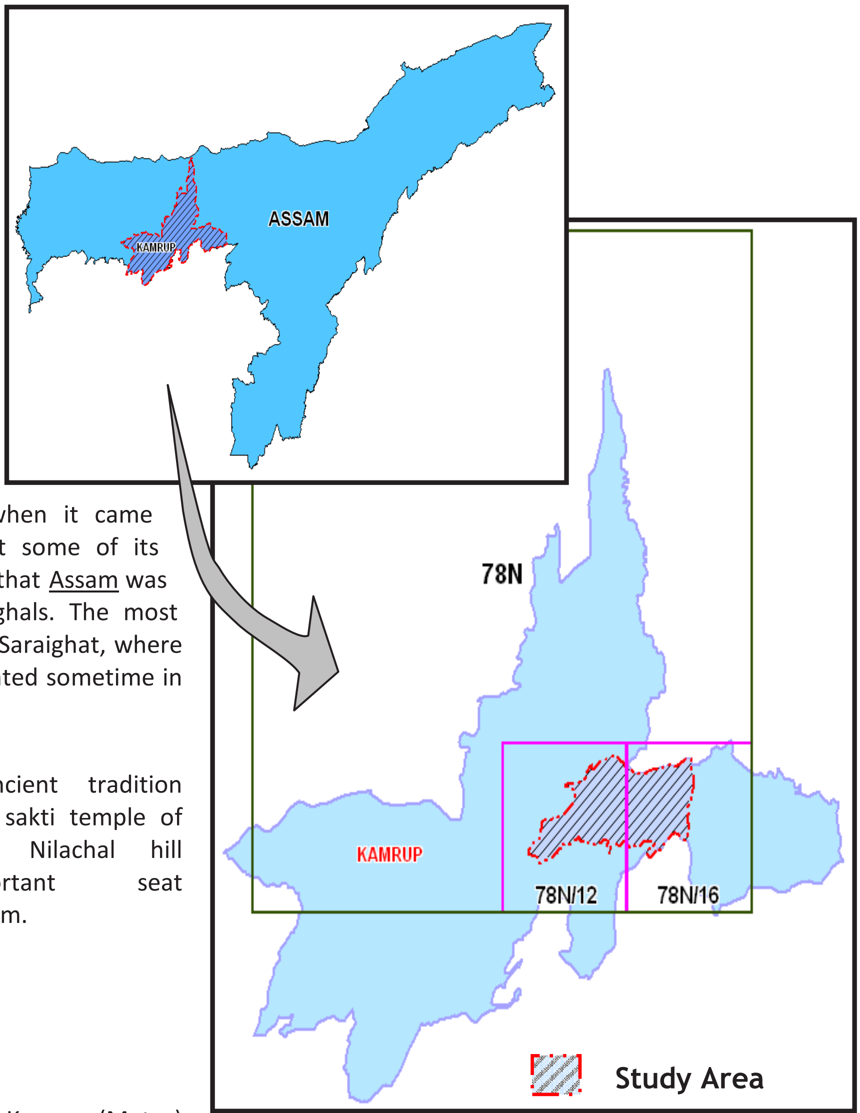


Fig. 1 Location map of Greater Guwahati Area

GENERAL FEATURES

Area / Administrative Division

Guwahati City is headquarters of Kamrup (Metro) district of Assam. Official capital of the state of Assam is Dispur which is a part of Guwahati city. It is located on the bank of the river Bramhaputra, covering an area of 315.72 sq.km (excluding Bramhaputra river). with the municipality area of 216.79 sq.km. The area is bounded by 91^0 34' & 91^0 51' E. longitudes. and 26^0 04' 27'' & 26^0 14' 51'' N latitudes.. Guwahati Municipal Corporation covers an area of 216 km² under its jurisdiction and it is divided into 60 municipal wards. Location map of the urban area is given in **Fig. 1**

Demography

Guwahati is one of the most rapidly growing cities in India. It witnessed major increase in population during 1950s and during 1970-90s. As per 2001 census, the population of the city is 8,14,575 with a population density of 3757persons/sq.km. The population has been projected as 1.19 million by 2011.

Hydrometeorology

The city experiences sub-tropical humid climate with an average annual rainfall of 1715.7 mm in the average normal 94 rainy days, with the average annual temperatures 6^0C minimum to 38^0C maximum. Monsoon season receives about 70% and pre-monsoon receives about 20% of annual rainfall.

Physiography & Drainage

Physiographically the area can be broadly sub-divided into three units i.e. hills, plains and marshy lands. Altitude varies between 50m and 600m above msl with an average elevation of 55m. The area is surrounded by hills in eastern and southern margins. Northern and western margin is open and continues as alluvial tract. The area drained by the river Bhramhaputra and its tributaries Bahralu and Bahini.

Soil Type

The major soil type of the city can be classified as 1) Newer alluvial soils, 2) Older alluvial soils, 3) Red loams, and 4) Laterites.

STATUS OF WATER SUPPLY AND DEMAND

The existing water supply is supported by Guwahati Municipal Corporation (GMC), Public Health Engineering Department (PHED) and Assam Urban Water Supply and Sewerage Board (AUWSSB), which partially meets the demand of the city. The existing infrastructure is unable to keep pace with the present population pressure. The present requirement of water for the city is estimated to be 243 million litres /day (MLPD). The existing water supply by GMC, PHED, and AUWS&SB is unable to cope up with the demand and they together could cover only 30.85% of population of GMC area @ 73.40 MLPD.

WATER PROFILE

Water supply of Guwahati city is dependent on both Surface and Ground Water. Major part of the water supply (72000 m^3 per day) by GMC within municipality area comes from the river Brahmaputra. AUWS&SB also supplies ~ 9000 m^3/day of river water daily. Apart from the above mentioned public water supply systems, N. F. Railway and Indian Oil Corp., has its own water supply system, supplying 6000 and 11000 m^3/day respectively, from the river Brahmaputra.

However, major part of the population is dependent on ground water through individual Dug wells, Shallow tube wells and Deep tube wells. PHED provides water supply to a considerable number of population through deep tubewell and spring sources.

GROUND WATER SCENARIO

Potential Aquifers

Hydrogeologically the area is underlain by two distinct types of formations belonging to Quaternary and Precambrian age. The Quaternary formations constitute the plain area adjoining to river Brahmaputra and its tributaries comprising different grades of sand, gravel, clay and silt. This plain is widened in the western part of the city. Fence diagram of the area is shown in **Fig. 2**

The Precambrian formations are exposed in the hilly terrain and comprise of granite gneiss, schist, granite, amphibolite, pegmatite, aplite and quartz veins etc as litho units. These hard rocks from the hillocks and has undergone weathering up to considerable depths. The thickness of weathered formation varies from less than a meter to more than 30m. The hard massive formations are fractured and fissured due to tectonic activities over the geological period.

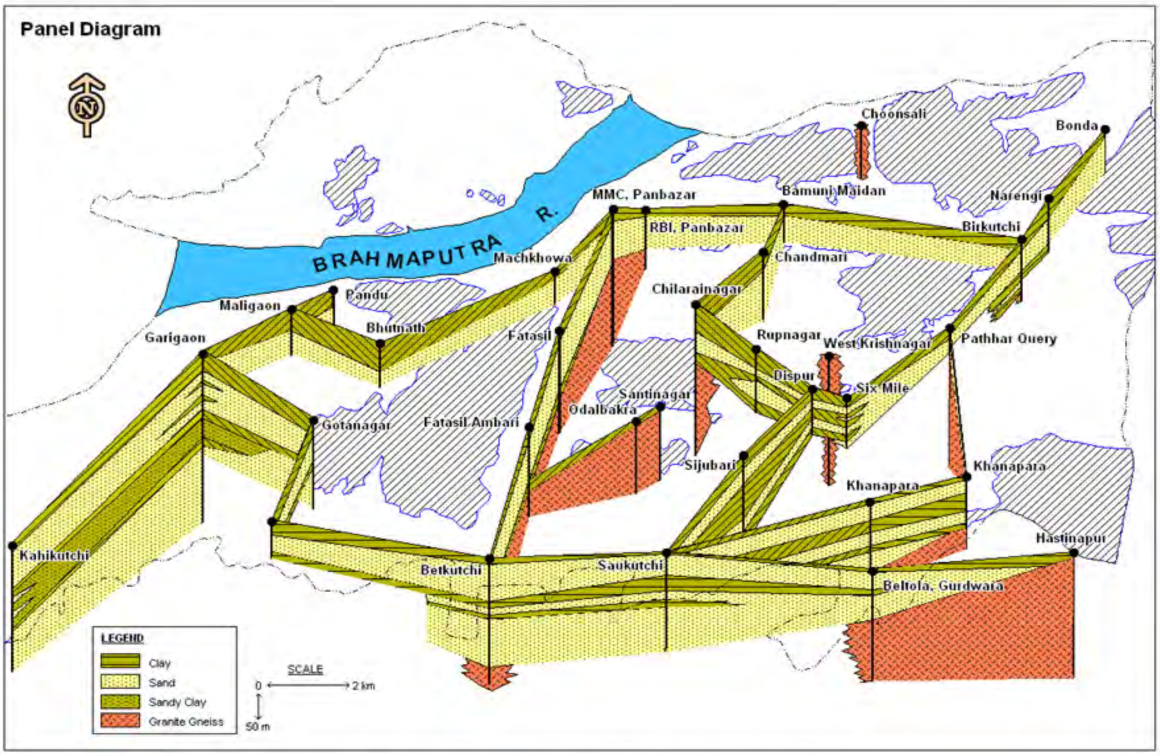


Fig. 2 Fence diagram of Greater Guwahati area

Based on the hydrogeological properties and relative ground water potentialities, the subsurface lithology can be broadly grouped into two major hydrogeological units *i.e.* a) Fractured formation and b) Granular formation.

Fractured formations are comprised of granite gneiss, biotite gneiss, amphibolites etc. These are predominant at shallow depth mostly in eastern and southern parts with sporadically at central and northern parts of the study area. They are characterised by a weathered lateritic layer at top, followed by a semi-weathered layer containing fragmented rocks of basement and massive rock with fractures. Ground water occurs in the weathered zone under water table conditions. On the other hand, ground water occurs under semi-confined to confined conditions in the hard fissured and fractured formations at various depths.

The Granular formations constitute deposits comprising of several grades of gravel, sand, clay, silt etc. The Quaternary deposits cover the plains in the western part of the city and valleys within the central part. In these formations, ground water occurs under water table to semi-confined conditions. Average thickness of granular zone is given in **Table 1**. Hydrogeological map of Guwahati is given in **Fig. 3**

Table 1 Average Granular zone thickness

Area	**Sub-area**	**Aquifer thickness range (m)**	**Average thickness (m)**
Northern Bank	-	10 - >200	>50
Southern Bank	Eastern part	20 - >150	40
	Western part	20 – 40	20
	Northern part	30 - >150	50
	Southern part	5 - 15	10
	Central part	50 - 60	55

Ground Water Level

In general, the water level close to the undulating inselbergs/residual hills, is deeper and in areas situated in relatively flat alluvial plains and valley-fill areas, the water level is generally shallower. In valley-fill areas depth to water level is variable depending on thickness of the weathered residuum. Overall depth to water level gradually reduces from elevated eastern and south-eastern areas towards the flat lying alluvial planes in the west.

In the dugwell zone the water level, in general, varies from less than 1.00 mbgl to 5 mbgl, except in the foot hill area where it varies from 8 to 10.00 mbgl.

In the deeper aquifer of foot-hill area, the piezometric level varies from 14 to 36.12 mbgl. However in certain localities in the eastern foothills area of the city water level varies from 0.07 mbgl to auto flow conditions indicating confined to semi-confined conditions. In the valley-fill/alluvial area the piezometric level of deeper aquifer varies from less than 1.00 mbgl to about 15.00 mbgl.

Long term water level trend analysis of the water level in monitoring wells in Greater Guwahati area shows that there is no significant rise or fall in water level.

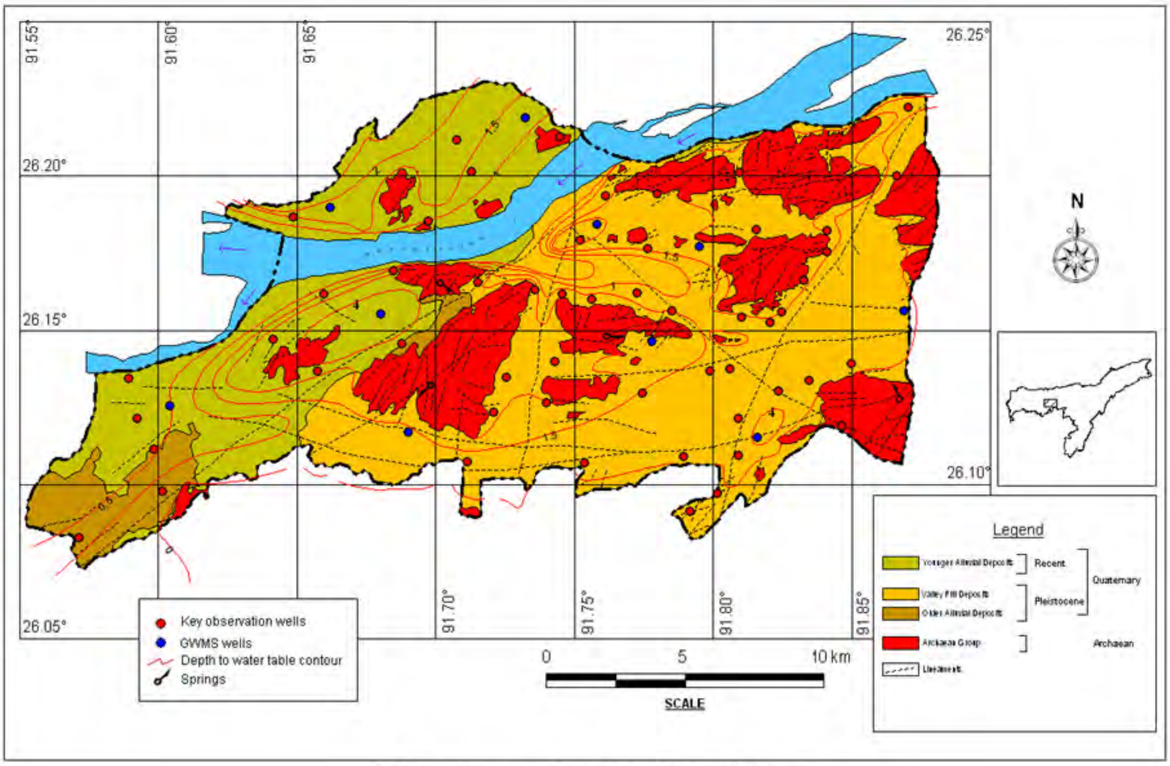


Fig. 3. Hydrogeological map of Greater Guwahati area

Ground Water Resources and Status of Development

Guwahati city is surrounded by hiils. Out of the total area the ground water recharge worthy area is about 22945 ham and remaining area is covered hill with more than 20% slope. As per GEC 1997, the Dynamic ground water resources of Guwahati city is estimated to be 11045 ham. The stages of ground water development in the city is 25% only. Hence there is sufficient scope of future development.

Hydrochemistry

Ground water in general is alkaline with pH value ranging from 6.7 to 8.1 with an average of 7.4. Various chemical constituents indicate that ground water quality is generally suitable for irrigation and domestic purposes except where iron content which is high. Total hardness (as $CaCO_3$) of ground water in the area varies from 30 and 390 mg/l with an average of 154, which shows moderately hard nature of ground water. Electrical Conductivity, which is a function of amount of total dissolved solids in ground water, ranges between 115 and 1650 µ mhos/cm (laboratory values) in ground water of the area.

Major chemical constituents of ground water of the area can be broadly classified as:

Cations: Calcium (Ca^{+2}), Magnesium (Mg^{+2}), Sodium (Na^{+}), and Potassium (K^{+}) are major cations present in ground water of the area. Calcium and Magnesium contents range from 6 to 92 mg/l and 1.2 to 52 mg/l, respectively. Iron ($Fe^{+2/+3}$) content of ground water of the area is commonly higher than the permissible limit of 1 ppm. The concentration of Fe ranges from 0.02 to 24.8 ppm.

Anions: Chloride (Cl^{-}), Sulphate (SO_4^{-2}), Nitrate (NO_3^{-}), and Bicarbonates (HCO_3^{-}) are major anions in ground water. Analysis results show that Chloride content varies between 7 and 213 mg/l, Bicarbonates between 12 and 390 mg/l, Sulphate between 1 and 72 mg/l, and Nitrates between 15 and 56 mg/l in the study area. Another important anion species is Fluoride (F^{-}), which ranges between 0.02 and 4.8 mg/l .

Summarises results of overall range and average values of common chemical constituents of ground water in the area is given Table 2. The distribution of Fluoride and Iron concentration are shown in Fig 4 and pH in shown in Fig. 5

Table 2 Range and average values of chemical constituents of ground water

Parameters	Unit	Max	Min	Average
pH (lab)	-	8.09	6.7	7.37
EC	µ mhos/cm	1650	115	524.5
TH	as CaCO3	390	30	153.7
Ca	mg/l	92	6	38.6
Mg	mg/l	52	1.2	13.4
HCO_3	mg/l	390	12	169.1
Cl	mg/l	213	7	55.7
SO_4	mg/l	72	1	18.2
NO_3	mg/l	56	15	47.6
F	mg/l	4.8	0.02	0.89
Fe	mg/l	24.8	0.02	1.73

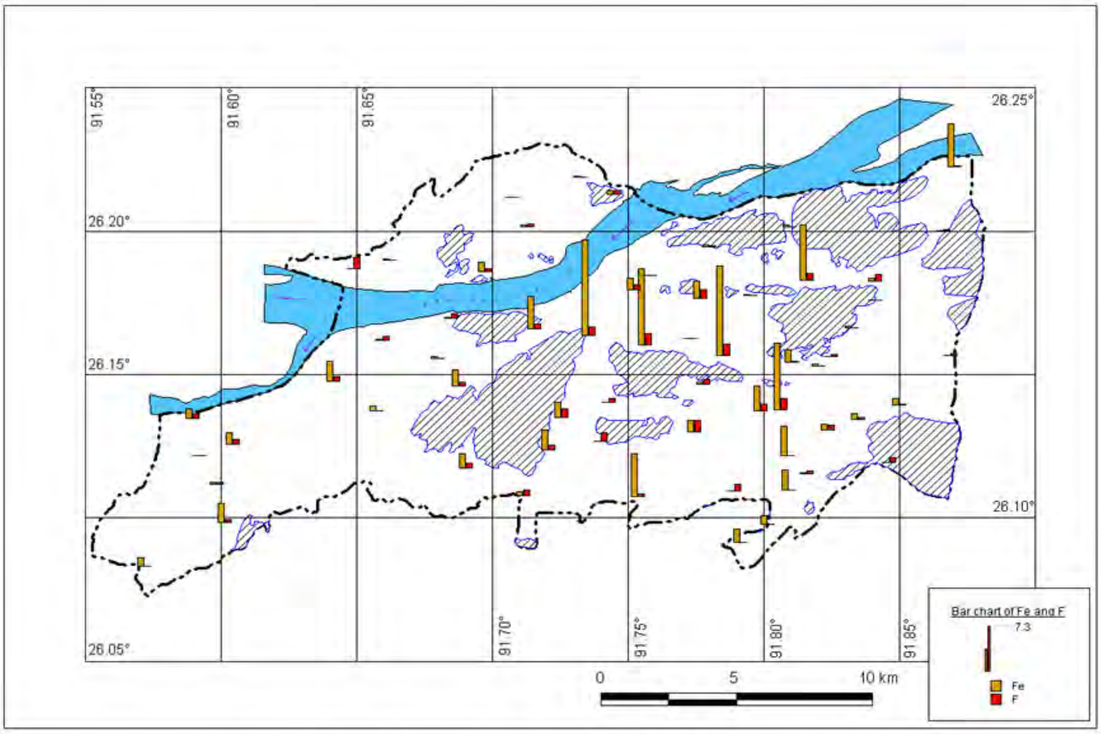


Fig. 4 Spatial distribution of Fe and F in Greater Guwahati area

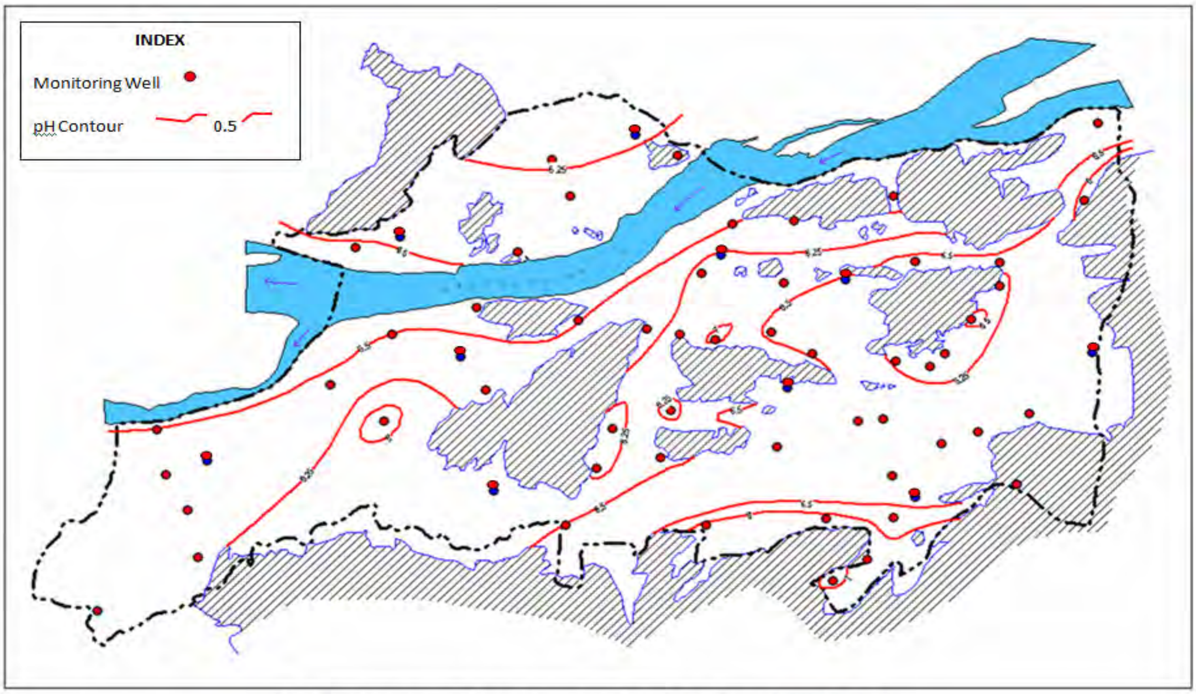


Fig. 5 Distribution of pH in shallow aquifer zone in Greater Guwahati area

Shallow Aquifer Zone: Ground water quality in shallow aquifer zone of granular formation is generally slightly *acidic* with pH value ranging from 5.5-7.8 with an average of 6.6. Electrical Conductivity ranges from 80 to 1440 µmhos/cm in ground water of the area. Except iron (Fe), other constituents are within permissible limit.

Deeper Aquifer (Granular formation): Ground water of deeper aquifer zone in granular formation is generally slightly alkaline with pH value ranging from 6.8 to 7.8 with an average of 7.26, in contrast to acidic nature of shallow aquifer zone. Electrical Conductivity ranges from 268 to 800 µmhos/cm in the area. Total hardness varies from 90 and 140, which shows moderately hard nature of ground water. Other parameters namely Ca^{+2}, Mg^{+2}, Cl^{-}, HCO_3^{-}, and SO_4^{-2} shows values within maximum permissible limit. However, fluoride value of Betkutchi area is very high and above maximum permissible limit. In other areas, the fluoride value is below maximum permissible limit but shows an overall higher trend.

Deeper Aquifer (Crystalline formation): Ground Water of this zone is generally slightly alkaline with pH value ranging from 7 to 8 with an average of 7.47 in contrast to overall alkaline nature. Electrical Conductivity ranges from 392 to 1370 µmhos/cm in ground water of the zone. Total hardness varies from 105 and 320, which shows moderately hard to hard nature of ground water. Major ionic species, namely Ca^{+2}, Mg^{+2}, Cl^{-}, HCO_3^{-}, and SO_4^{-2} shows values within permissible limit. However, iron ($Fe^{+2/+3}$), fluoride (F^{-}), and nitrate (NO_3^{-2}) values are not always within highest desirable or maximum permissible limit of BIS standard. In deeper zones of crystalline formation Fe values are generally above maximum permissible limit. In one case (Beltola, Gurdwara) Fluoride value is found above maximum permissible limit and in another case (Chilarai Nagar) Fluoride value has been found above highest desirable limit but below maximum permissible limit of BIS standard. In other areas, the fluoride values are below highest desirable limit but shows comparatively high values in comparison with shallow aquifer. At Chilarai Nagar, NO_3 has also been found to be above highest desirable limit.

The major ground water related problem in the city are 1) Water logging; 2) Pollution from sewerage and garbage dumping; 3) Unplanned ground water abstraction; 4) High iron content in ground water; and 5) Sporadic high fluoride content in deeper aquifer. All the problems, except the high Fe and F

Major Ground Water Related Problems

The ever increasing population growth and related developmental activities has changed the landuse pattern. The momentum of present developmental activity is far exceeding the sustainable growth rate of the city. During last decade, the area experienced an unprecedented population growth of 154%. To accommodate the population growth, resulting developmental activity for residential / commercial purpose has lead to filling up of marshy lands and conversion of agricultural low lands to residential / commercial plots as well as cutting of hill slopes. By disturbing the natural flow pattern, reduction of recharge area, sewerage and garbage disposal have also became burning problems posing threat to the ground water resources.

The major ground water related problem in the city are 1) Water logging; 2) Pollution from sewerage and garbage dumping; 3) Unplanned ground water abstraction; 4) High iron content in ground water; and 5) Sporadic high fluoride content in deeper aquifer. All the problems, except the high Fe and F content of ground water are anthropogenic and can be related with rapid urbanization process. On the other hand, problems of high Fe and F are geogenic.

Feasibility of Rainwater Harvesting and Artificial Recharge

The area, having mostly shallow water table and low ground water development, at present artificial recharge to ground water may not be suitable. However, rainwater harvesting and artificial recharge in selective areas may reduce water scarcity as well as reduce the pollution threat.
In urban areas, artificial recharge through roof-top rainwater harvesting may be carried out to reduce water scarcity as well as reduce the pollution threat. As the incidence of rainfall is high in the area, Roof-top Rain Water Harvesting may be considered as most viable means to augment the water supply for domestic water needs. The design and storage of such structure are decided based on the water to be harvested from the rainfall.

In hilly parts, artificial recharge may be done to augment the natural infiltration process. Like many cities in India, Roof-top Rainwater Harvesting should be made mandatory for every house. At suitable locations sub-surface dyke may be constructed to arrest the natural discharge.

GROUND WATER DEVELOPMENT STRATEGY

The development of ground water in the city is in the tune of 25% only. With the replenishable ground water resource of 11 MCM, there is ample scope for ground water development. Both shallow and deeper ground water abstraction structures may be constructed for development of ground water.

Design of Wells

Designing of wells should be done based on the aquifer characteristics, hydrogeological setup, and water requirement. Three types of wells are feasible in survey area, namely a) Dug wells; b) Shallow tube wells; and c) Deep tube wells.

A) Dug wells: In the study area, dug wells are most prevalent. It is conventional source to draw potable water. Dug wells of the area occur both as lined and unlined condition. Ideally they should be lined and constructed with 5-15.00 m deep, and 0.75 to 1.50 m diameter. Considering an average depth to water level of 4.00m and depth of well as 15.00 m, the well can store 7 to 28 m^3 of water.

Dug cum bore wells may be more effective in the hilly part of the area, where aquifer zone is deep seated. Boring may be done down to 30.00 m. Site specifically, multiple directional bores may also be useful. A statistical study by Duba (1974) showed that in granites and gneisses, inflow rate is higher for rectangular wells than circular wells. Hence for hard rock part of the area, rectangular wells may provide better results.

B) Shallow tube wells: The northern bank of river Brahmaputra is represented by mono alluvial aquifer system and southern bank is represented by perched – lensoid multiple alluvial aquifer system. With this background, within the study area, in North Guwahati – Amingaon area, gravel packed shallow tube wells are feasible. The tube well should be constructed down to a depth of 50.00 m. By tapping 10 to 15.00 m of aquifer thickness, a discharge of 30 to 45 m^3/hr may be expected from these wells for a drawdown of 1 to 5 m. Borehole diameter of 102mm and 152mm are suggested for 30 m^3/hr and 45 m^3/hr discharges respectively.

c) Deep tube wells: The optimum well design criteria is computed from the data generated from exploratory tube wells drilled by Central Ground Water Board, taking into account for average hydraulic conductivity, aquifer thickness to be tapped, optimum screen entrance velocity, and well efficiency for the area. The alluvial/ valley-fill area the tube wells may be constructed down to a depth of 80 to 150.00 m bgl with 30 to 40 m housing and tapping 15 – 20 m aquifer materials. The expected yield of these wells are about 100 to 200 m^3/hr. The design should be site specific and in tune with the local sub-surface geology to get maximum yield, as clay lenses of various thickness is present in the area.

However, for efficient working of neighbouring wells without causing mutual interference during pumping, some control on ground water development should be employed. The spacing between two adjacent tube wells should be kept at two times the radius of influence, as estimated, on the basis of field pumping tests. The recommended parameters for various abstraction structures are given in **Table 3**.

Table 3. Recommended parameters for various abstraction structures

Abstraction structure	Yield (lpm)	Recommendations		
		Optimum Depth	Expected Coverage	Suggested Spacing
Dug well	< 30	5 - 15 m	1 - 3 household	10 – 20 m
Handpump (tapping dugwell zone)	< 50	10 - 20 m	2 - 5 household	20 - 30 m
Shallow tube well (Granular Formation)	150 – 500 Avg. 200 Running hours 6-8 hours/day	20 -40 m	20 – 30 household	150 - 200 m
Deep tube well (Granular Formation)	100 – 3000 Avg. 1000 Running hours 8-10 hours/day	80 - 90 m	300 - 400 household	1500 - 2000 m
Deep bore well (Crystalline Formation)	180-300 Running hours 4-5 hours/day	75 – 85 m, 105 - 130 m 195 - 215 m	120 - 150 household	Site specific

Selection of pump: Determination of the capacity of pump is essential for optimum utilisation of discharge and the lift from the tube well. Results of field tests indicate that pump capacity in the range of 3 to 5 H.P for the shallow tube wells and 12.5 to 45 H.P for deep tube wells are suitable in the area, considering 75% pump efficiency. The same for crystalline formation will be 2 HP

Selection of well screens: Well screen is a vital part of a well assembly. It controls the water intake capacity of the well as well as prevents the formation material from coming in. As aquifers of the area are commonly composed of fine to medium sand, The slot size should be 1.5 mm and the well should be shrouded with pea gravel. Where ever the aquifer material is finer in nature, Johnson Screen having slot size of 1 mm should be used to ensure the stoppage of incoming of fine sand.

The general water level in Guwahati city is shallow. In such terrain artificial recharge to ground water may not be suitable. However, in the valley area Roof-top rainwater harvesting structures may adopted to supplement the individual water supply and in the foot-hill area, water conservation structures and spring development can be a suitable means for augmentation of domestic water supply system.

Spring Development: Several springs are identified in the area. Typically these springs are perennial with average monsoon discharge of 0.84 lps. However, average daily discharge is 70 m^3, which if stored properly can serve about 150 households with 100 lpcd. Benefits of spring development for the area can be summarized as follows:

1. Good quality, potable water available from springs sources.
2. Availability of fresh water round the year.

3. Low vulnerability to contamination due to human activity as it is situated at higher altitude.
4. Water directly available for consumption with minimum treatment cost.
5. Low cost structures required for harvesting the spring resources.
6. Distribution under gravity would eliminate cost of pumping.

The catchment area of the spring should be protected from interference of human being and animals by erecting fencing. Small spring can developed by constructing concrete sump fitted with proper cover and over flow-cum-delivery pipe. It is estimated that the cost of development of a spring is about 3 to 5 lacs..

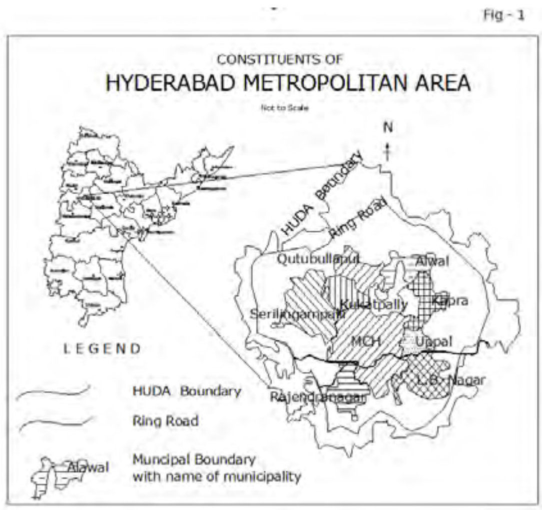
Roof-Top Rainwater Harvesting Structure: The city is bestowed with good rainfall. The annual average rainfall in the city is more than 1700 mm. This rainfall can be harnessed and stored in surface / sub-surface storage tank. Individual houses, School buildings, offices may be used for Roof-top rainwater harvesting. On an average a house with 100 sq.mtr. roof and 1.7 m rainfall it can harvest about 1,36,000 lit. of water per annum. The average cost of a roof-top rain water harvesting structure is about 2 to 3 lacs. Including storage tank.

HYDERABAD CITY, ANDHRA PRADESH

Ravi Kumar Gumma, P.N.Rao, N.Varadaraj, G.Praveen Kumar, CGWB, Hyderabad

INTRODUCTION

Hyderabad, the capital of Andhra Pradesh, founded in the year 1591 by Mohammed Quli Qutub Shah, offers a fascinating panorama of the past with richly mixed cultural and historical tradition spanning over 400 years. Soon after India gained independence, Hyderabad State merged with the Union of India in the year 1948. On November 1, 1956 the map of India was redrawn into linguistic states and Hyderabad became the capital of Andhra Pradesh. Hyderabad, centrally located on the top of the Deccan Plateau, presently is one of the fastest growing cities of India and has emerged as a strong industrial, commercial, technology centre and occupies prime position in India and as a regional hub in this part of the world.



GENERAL FEATURES

Area/ Administrative Divisions

Hyderabad city is situated at 17°22' N Latitude and 78°27' E Longitude with an elevation of 525 m amsl. The Hyderabad Urban Agglomeration (HUA) is the sixth largest in India and is spread over an area of 778 sq.kms comprising Municipal Corporation Hyderabad (MCH), ten peripheral municipalities, Secunderabad Cantonment and Osmania University (Fig.1). The details of the MCH and surrounding Municipality areas are provided in Table-1. The Hyderabad Metropolitan area covers an area of 1905 sq. km under the jurisdiction of Hyderabad Urban Development Authority (HUDA) covering toposheet nos. 56 K/6, 7, 10, 11 and 12.

Table 1: Administrative Divisions

Name of the Municipality	Area (Sq.kms)
Municipal Corporation of Hyderabad (MCH)	172.60
Kapra	43.81
Uppal	21.97
Malkajgiri	16.75
Alwal	26.32
Rajendra Nagar	50.87
Serilingampalli	96.99
Kukatapally	43.12
Qutubullapur	43.12
LB Nagar	66.73
Gaddi Annaram	19.87

(Source: City Development Plan: JNNURM/GHMC, Hyderabad)

Demography

Hyderabad is one of the fastest growing metropolitan cities with a decadal growth rate of 32%. The Population of HUA increased from 4.3 million in 1991 to 5.7 million in 2001. The growth of population was more than 50% during 1981-91 and 27% during 1991-2001. The details of the present population and future projections of HUA and other constituents of Hyderabad Metropolitan Area are given in Table-2.

Table-2: Population Trends in Hyderabad Metropolitan Area

Component	Area (Sq. Kms)	Population (Lakhs)			Density (2001)	Projected Population (Lakhs)	Projected Density	Projected Population (Lakhs)	Projected Density
		1981	1991	2001	(P/Sq.kms)	**2011**	**(P/Sq.kms)**	**2021**	**(P/Sq.kms)**
MCH	172	21.0	30.5	36.3	21048	43.3	25116	51.7	29977
Surrounding Municipalities	419	3.8	9.9	17	4102	28.9	6926	50.9	12151
Others	187	2.3	3.2	4	2147	5	2692	6.3	3391
HUA	778	27.1	43.6	57.5	7393	77.2	9923	108.9	13997
HUDA	1905	29.9	46.7	63.8	3351	90.5	4753	136.4	7162

(Source: City Development Plan: JNNURM/GHMC, Hyderabad)

Physiography

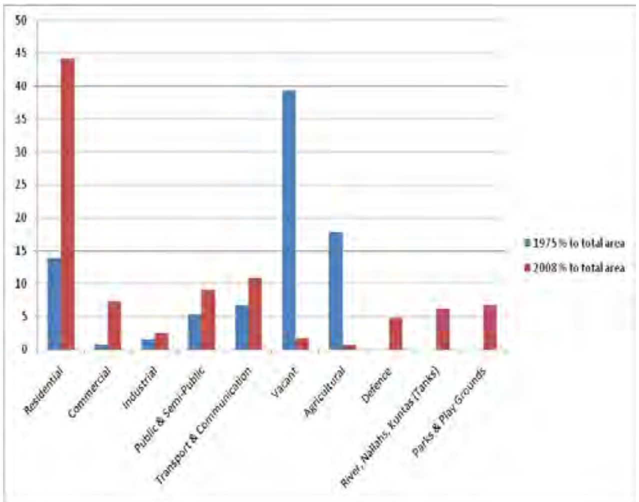
The area has undulating topography with elevation ranging from 460 to 560 m amsl. The main geomorphic units are residual Hills, pediment inselbergs, pediplains and valley fills. The River Musi, with a gradient of 2 m per km flows from west to east and most of the streams are ephemeral in nature.

Soil Type

The soils are mostly of red lateritic, yellow sandy-clay loams and alluvial black soils. The thickness of the soil cover ranges from 0.5 m to 2.0 m. The land use pattern indicates the changing pattern of land use over the years. It shows increase in residential and commercial at the expense of vacant and agricultural land (Fig.2).

Hydrometerology

Hyderabad experiences the semi arid tropical climatic conditions. The average annual rainfall is 810 mm. The south west monsoon contributes 74% of annual rainfall and north east monsoon contributes 14%. The temperatures touches 45º C during the summer season and with the onset of monsoons during June, the temperature drops and varies between 26º C to 38º C.



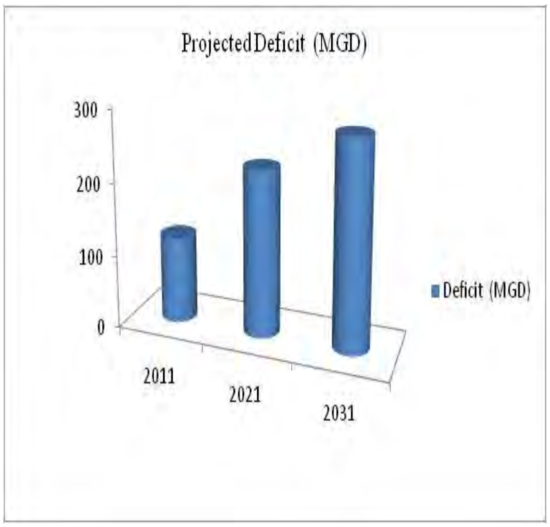


Fig-2: Trends in Land Use pattern from 1975-2008

Fig-3: Projected Water deficit.

STATUS OF WATER SUPPLY & DEMAND

The Hyderabad Metro Water Supply and Sewerage Board (HMWS & SB) is providing 340 mgd of piped water supply from surface water resource covering MCH, ten adjoining municipalities, Osmania University, Secunderabad Cantonement and ten enroute villages along NH-9 upto Sanga Reddy (793 sq.kms). This includes 180 mgd from Krishna river source, located about 145 km from city. Apart from the 340 mgd piped water supply from surface water resource, about 25 mgd is being supplied from ground water resource. The indicators of water supply positions are as follows.

Indicators	MCH	Surrounding Municipalities
Total Population	36.33 lakhs	17.18 lakhs
Slum Population	14.1 lakhs	6.98 lakhs
Network Coverage	90%	65%
% Access to piped water supply	70%	43%
Average Per capita Supply	162 lpcd	91 lpcd
Duration of supply	2 hours alternate day	1 hrs alternate day

Source: HMWS & SW

Hyderabad has average sewerage network access of only 58% with a network access of 70% on MCH area and only 20% in surrounding municipalities. At present, only 23% of the collected sewage is treated of which only 3% is recycled and reused. The Capacity of treatment plants under construction (2008) is 591 MLD and the Capacity of Proposed STPs is 865 MLD. The Projected water deficit has given in Fig.3.

Geology

Hyderabad forms part of the Pre-Cambrian peninsular shield and is underlain by the Archaean crystalline complex, comprising of granites intruded by dolerite dykes. A thin veneer of alluvium of Recent age occurs along the Musi River. Granites exhibit structural features such as fractures, joints, faults and fissures. WNW - ESE and ENE-WSW, NE-SW trending structures are tensional in nature while NW-SW& NW-SE structures are shears in type. Innumerable dolerite dykes mostly in East-West, ESE-WNW & NE-SW directions occur in the area.

WATER PROFILE

Surface Water: The River Musi originates from Anantagiri hills in Vikarabad area of Ranga Reddy district and flows 70 kilometers before entering into the reservoirs of Osman Sagar and Himayat Sagar in Hyderabad. Apart from the River Musi, Hyderabad was endowed with a number of natural and artificial lakes which includes Hussain Sagar, Mir Alam tank, Afzal Sagar, Jalpalli, Ma-Sehaba Tank, Talab Katta, Osmansagar and Himayatsagar, Saroor Nagar Lake.

Ground Water: Ground water occurs under phreatic conditions in weathered zone and under semi-confined to confined conditions in the fractured zones. The piezometric elevations in northern part vary from 500 to 563 m amsl with steep gradient in NE direction. In southern part, the piezometric elevation is between 470 and 520 m amsl with gentle gradient towards Musi River (Fig-4). Ground water was exploited through shallow, large diameter dug wells until 1970 to meet domestic and irrigation requirements. Presently ground water is being exploited through shallow and deep bore wells with depth ranging from 100-300 m.

Fig - 4 : Hydrogeology

Aquifer Systems

More than 97% of the area is underlain by the Archaean group of rocks consisting of mostly pink and grey granites and the remaining 3% of the area is underlain by the Alluvium. Accordingly two aquifer systems exist in the area, i.e Aquifers of the granites and Aquifers of Alluvium, though alluvial aquifers are insignificant.

Aquifers of the granites: The aquifers are of anisotropic and non-homogenous type resulting in different hydrogeological conditions within shorter distances depending upon degree and intensity of fracture and recharge conditions. The thickness of the weathered zone varies from 5-25 m and discharges generally vary from negligible to 5 lps. High density of fractures are observed in the eastern, western and northern parts of the area while moderate to low density fractures are observed in central part in the main city area. In general, the shallow fractures are more productive than the deeper ones. But, in some of the western parts, the deeper fractures (127 m & 172 m) are more productive (6 lps at Film Nagar and 10 lps at Borabanda) than the shallow fractures indicating the structural disturbances in some of the western parts. Central Ground Water Board (CGWB), under its exploration programme constructed 10 bore wells down to different depths ranging from 132 to 203. The water level ranges from 3.30 m (Manikeswarinagar) to 56.3 m in (Film nagar).The discharges of these wells vary from 0.21 to 6.9 lps with drawdowns of 6 to 20.6 m. The specific capacities of the bore wells range between 10 lpm/m (New Boiguda) to 72 lpm/m (Borabanda) and the Transmissivity of the aquifers ranges between 0.48 and 202 sq.m/day.

Aquifers of Alluvium: The alluvial formations, though negligible both in areal and vertical extension, occurs as isolated patches along the Musi River. It consists of medium to fine grained sand, silt with thickness varies from few meters to about 5 meters. Ground Water occurs under phreatic conditions. The ground water used to be developed through large diameter dug wells, but presently not in practice due to the contamination of the pollutants from the Musi effluents.

Ground Water Levels

It is observed that in general the depth to water levels ranged between 5 and 20 m but on an average it is around 12 m. The general depth to water level during pre-monsoon period varies from 5 m to 20 m bgl, whereas during post monsoon periods, it varies from 2 m to 15 m bgl. In the core area of Hyderabad, the general pre-monsoon water level ranges from 6.10m bgl (Erra Manzil) to 17.33 m bgl (Nampalli) and the post monsoon water level ranges from 1.40 m bgl (Alwal) to 9.42 m bgl (West Maredpalli) and from 8.65m bgl (Tarnaka) to 18 m bgl (Kothapaet). In Secunderabad area, pre-monsoon water levels range from 7.26 m bgl (Bolarum) to 23.40 m bgl (West Maredpalli) and post- monsoon water level ranges from 2.40 m bgl (Bolarum) to 9.5 m bgl(West Maredpalli). In the peripheral areas of Hyderabad, the pre-monsoon water level ranges from 1.98b bgl (Ahmedguda) to 7.7 m bgl (Patancheru) and post monsoon water level ranges from 2.90m bgl (Kokapet) to 6.7m bgl (Suraram).

A study of the hydrographs indicate that the water table is depleted over the years at many places like Boinpalli, Aghapura, Erragadda, Bashherbagh, Langar house, Jubilee hills, Begumpet, Koti, West Maredpalli, Gudimalkapur, Mushherabad, Sanath nagar, Picket, Madhapur etc., (Fig-5). However, there is a substantial rise of ground water levels in most of the localities of Hyderabad due to the high precipitation received after 2008.

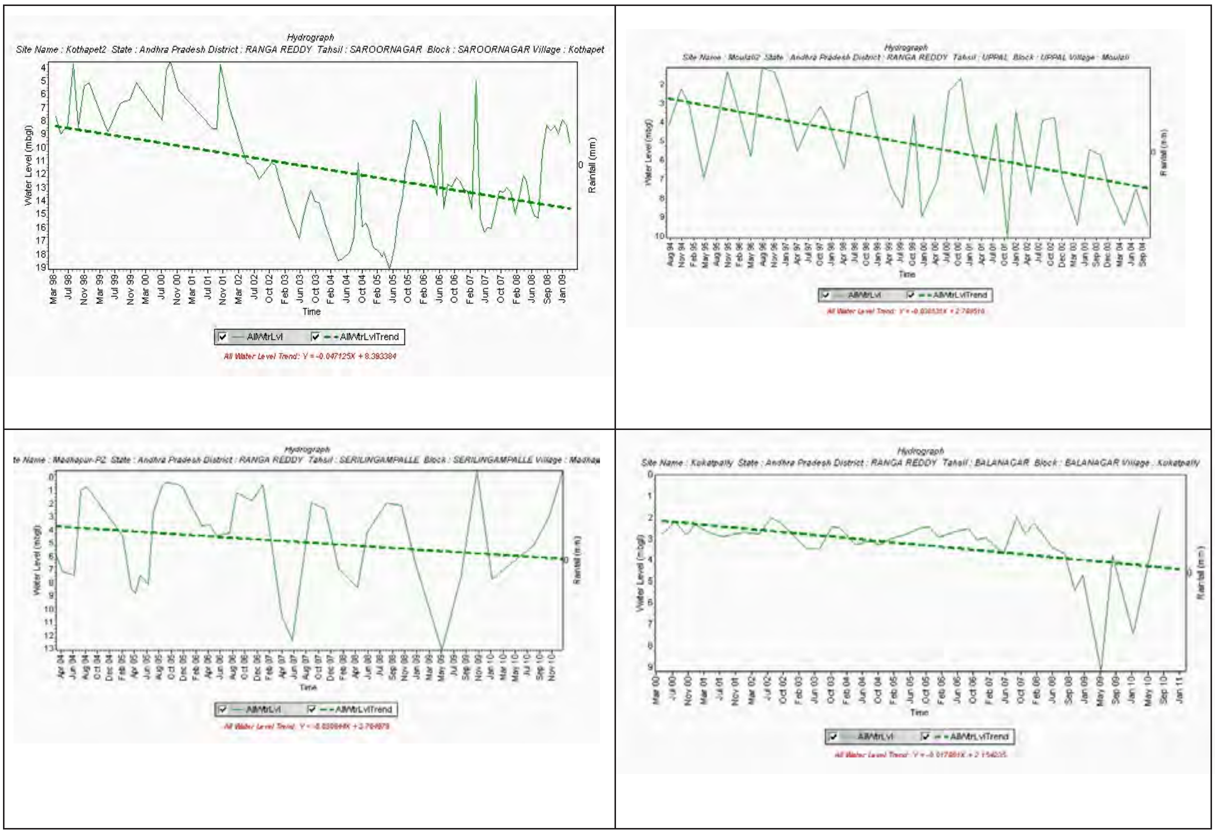


Fig-5: Hydrographs of select monitoring wells in City Core area

Ground Water Resources: The dynamic ground Water Resources (2004) estimates for the mandals under the jurisdiction of Hyderabad Metropolitan Development Authority (HMDA) falling in Ranga Reddy district are given in Table-4.

Table-4: Ground Water Resources in Ranga Reddy falling under HMDA

S.No	Mandal	Ground Water Availability ha.m	Ground Water Utilization ha.m	Ground Water Balance ha.m	Stage of Development (%)	Category
1	BalaNagar	969	86	883	9	Safe
2	Ghatkesar	1647	862	786	52	Safe
3	Hayaat Nagar	2283	1609	674	70	SC
4	Keesara	1513	1649	-136	109	OE
5	Malkajgiri	626	291	335	47	Safe
6	Medchal	2275	3752	-1478	165	OE
7	Qutubullapur	1782	1109	673	62	Safe
8	Rajendra Nagar	1896	808	1088	43	Safe
9	Saroor Nagar	1101	856	245	78	SC
10	Serilingampalli	1463	301	1163	21	Safe
11	Shamirpet	3252	6093	-2841	187	OE
12	Shamshabad	2371	2724	-353	115	OE
13	Uppal	437	130	307	30	Safe
14	Hyderabad	1400	12099	-10699	864	OE

Ground Water Quality

The effects of urbanization and industrialization in Hyderabad led to the contamination of ground water. Due to inadequate sewerage system and treatment capacities, the domestic sewerage and industrial effluents are letting directly into the nalas and streams, causing severe ground water contamination. The concentration of Nitrate far exceeded the permissible limits in many parts of the city. The excessive concentrations of sulphates, trace elements like copper, cadmium, zinc, manganese and lead are found in and around industrial areas.

The analytical results of chemical analysis of ground water samples (1998) from shallow bore wells (40-60 m) indicates the alkaline nature. The total hardness ranges from 95 to 711 mg/l and the ground water is moderately soft to very hard type. The electrical conductivity (EC) range from 200-7500 µS/cm, while the general range is 750-3000 µS/cm. (Table-5) The areas with EC values beyond permissible limits (more than 3000 µS/cm) are located mostly around industrial localities like Bollarum, Suraram, Jeedimetla, Sanath Nagar, Kukatpalli and Saroornagar etc. Nitrate (NO_3) is observed to be high in more than permissible limits of drinking water standards in 72 % of samples at locations like Moosapet, Alwal, Kutubshahi tombs, Tarnaka, Amberpet, Moosarambagh, Lalapet, Nallakunta, Secunderabad, Kavadiguda, Ranigunj, Gosha Mahal, Golconda fort, Langar house, Tolichowki, Sanath Nagar, Tadbund, Chandrayangutta. Higher concentrations of Sulphates (more than 400 mg/l) is noticed in areas like Uppal, Sanath Nagar, Saroor Nagar and also near Musi river, attributed to the industrial pollution in these areas.

Table-5: Ranges of Chemical constituents in shallow aquifers

Sl. No	Constituents	Range		General Range	Percent of samples exceeding permissible limits
		Min	Max		
1	PH	6.5	8.57	6.9-7.7	
2	EC (µs/cm)	200	7500	700-3000	2 %
3	TH (mg/l)	70	2780	150-1000	29 %
4	NO_3 (mg/l)	1.2	760	10-300	72 %
5	SO4 (mg/l)	4.8	1392	25-450	2 %
6	F (mg/l)	0.17	3.3	0.5-1.7	7 %

(Source: CGWB, SR)

The ground water in deep seated fractures is also alkaline in nature (p^H from 7.0 to 7.9) and the ground water is hard to very hard type. The Electrical conductivity of ground water in deeper aquifers ranges from 850 to

2000 µS/cm. The concentration of fluoride in deeper ground water ranging from 0.50-2.57 mg/l and at certain places, the concentration of fluoride is beyond permissible limits (New Boiguda, BJR Nagar, Borabanda areas).

There are about nine the Industrial Development Areas (IDAs) spread throughout the city intermingling with large residential colonies. Almost all the IDAs have few industries which are potential sources of heavy metal wastes into the environment. Chemical analysis of Ground water samples from these areas in 2003-04 has revealed the presence of Fe and Mn with concentration in some wells exceeding the BIS maximum permissible limit (MPL). Lead, Nickel, Zinc and Cadmium were detected in the IDAs of Balanagar, Sanatnagar & Jeedimetla. Lead and Cadmium were beyond the MPL in some of the wells in these areas (Table-6).

Table - 6 Industrial Agglomerations and Metals detected in Ground Water

Sl No	Industrial Area	Nature of Industry	Metals detected beyond permissible	Remarks
1	Kadedam	Metallurgical, food processing, plastic food processing	Fe, Cd, Mn, Ni	Notified by CPCB
2	Nacharam	Foundries, fabrication	Ni, Cd, Fe, Mn	
3	Jeedimetla-Balanagar	Metallurgical, food processing, pharmaceutical, paints	Fe, Zn, Cd, Pb, Cr	
4	Patancheru	-do-	Fe, Pb, Cd, Cu, Co, Mn	Notified by CPCB

Major Ground Water Related Problems

Extinct/Shrinkage of tanks: The existing surface water bodies are diminishing because of inconsiderate development of the city and its surroundings. Initially, the city had 25 tanks and with the progressive urbanization, some of the tanks within the city and surroundings were disappeared (Masab tank, Nallakunta) or their sizes got reduced due to unabated human encroachments (Saroor Nagar tank) or the inflows into the tanks got reduced due to inconsiderate management of Catchment areas (Osman sagar, Himayat sagar) or affected by pollution (Kukatpalli Nala, Hussain sagar, Miralam tank etc). Many water channels that used to carry floodwaters from one lake to the next in a catchment area, have also been encroached by private and government agencies. This has resulted in substantial decrease in natural ground water recharge and deterioration in its quality. As per the one study by JNTU, there is a continuous decrease in inflows in water supply reservoirs of Himayat Sagar and Osman Sagar for the past 36 years due to urbanization though there is no change in normal rainfall pattern in these years.

Vast open areas within the widely scattered buildings have now been converted into dwelling units due to heavy influx of people migrating from all corners of the state and the country. During the last 4 decades there was an increase of residential area (10-44 %) and reduction of vacant land (38 to 2 %) and open spaces, parks and play grounds together account 6.81% only. There was, increase in area from 6.67% to 10.87 % under transport and communication also. This drastic changes in land use pattern resulted in altercations in hydrological cycle and had greatly reduced the scope of natural recharge to ground water body. Water conservation is practiced in very few buildings and areas.

Discharge of untreated industrial and domestic effluents has led to the total degradation of the water quality in surface and sub-surface water bodies. The sewerage network coverage is low and the treatment facilities are highly inadequate. Most of the untreated sewage finds its way into water bodies resulting in poor water quality, high pollution, loss of habitat and environmental degradation. Due to this, ground water quality is deteriorated in not only industrial areas but also in residential areas. River Musi, the main source of water, gets an estimated untreated sewage of 500 ML per day. Hussain Sagar Lake, once used to supply water for the city until 1930 is getting untreated domestic sewage leading to high pollution levels. The fact that about 72%

of samples contain excess nitrate, confirm the vulnerability of shallow aquifers to domestic pollution in the city.

Solid waste: The inadequate disposable practices of municipal soild waste is one of other major sources for pollution. The HUA generates around 3379 tons of solid waste every day out of which MCH contributes to 2040 tons and surrounding municipalities contribute towards 1139 tons at a per capita generation rate of 600 gms/cap/day. According to a recent study conducted by Center for Environmental Studies of Jawaharlal Nehru Technological University (JNTU), Hyderabad, the combustible matter in Solid Waste of Hyderabad ranges from 37 % to 28 %. The sources and quantity of solid waste generated in Hyderabad Urban Agglomeration (HUA). There is no engineered landfill site in Hyderabad Urban Agglomeration. Presently, waste disposal facility is located at Jawaharnagar landfill in Shamirpet Mandal of Ranga Reddy district only, located at a distance of 45 km from the city.

Waste Water Generation & Reuse: The estimated sewerage generation is 1162 MLD and the treatment capacity is 133 MLD leaving a deficit of 920 MLD as on 2011. At present, only 23% of the collected sewerage is treated of which only 3% is recycled, whereas fresh water withdrawal is very high at 51% compared to countries such as UK or Australia where withdrawals are as low as 5%, which shows minimal water recycling and reuse in the HUA. However, part of treated water is being used for irrigation in the lower reaches of Musi river.

It has been opined that 80% of waste water in developing countries may be used for irrigation. Mccartney et.al (2008) estimated waste water for irrigation use for 10,000 ha of irrigated land in the lower reaches of Musi river in 2004 to be 193 M $m^{3.}$ They also estimated that the total annual salt load of water from the city is to tune of 497000 tones and the average annual salt content in waste water irrigation is approximately 256000 tones and also observed soil salinity in irrigated land. Considering the potential of waste water generation, it is suggested that the waste water be used for irrigation after proper treatment.

GROUND WATER DEVELOPMENT & MANAGEMENT STRATEGIES

Future Ground Water Development: There is already stress on ground water and as per one estimate, about 25-30% of total water requirement is being met through ground water. Considering the limited potential of hard rock aquifers, reduced recharge and that the resource is being tapped from deeper depths any large scale development of ground water resources is not advisable without adopting proper augmentation practices and strict implementation strategies.

Management Strategies

Roof Top Rain Water Harvesting and Artificial Recharge: In view of huge availability of larger roof areas adoption of various water conservation measures is the need of hour and any delay in large scale adaptation of various conservation methods will lead to a further depletion and contamination of ground water. Hence, the Rain Water Harvesting of Roof Top collection is required to be implemented on mandatory basis in urban areas.

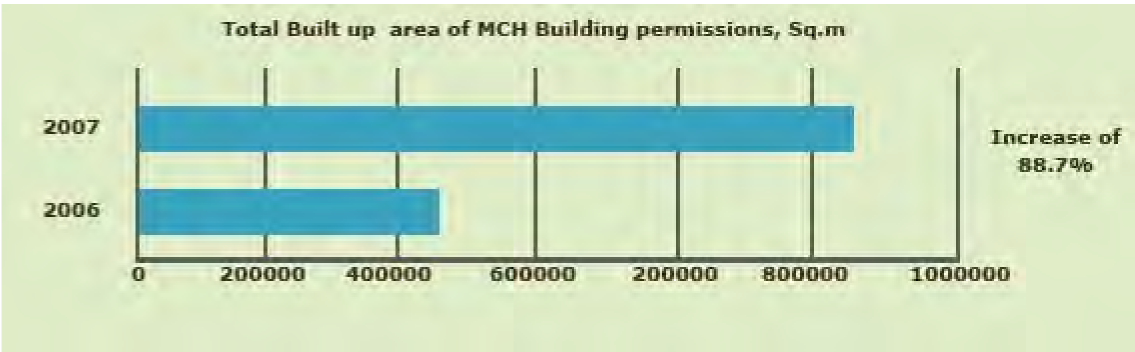


Fig-6: Graph showing increase in Built up area in MCH

There was about 9, 00,000 sq.mts built up area (2007) under the MCH which accounts for an increase of 88.7% in built up area where permissions given by MCH during 2006 to 2007 (Fig-6). There is likely to be a 133% increase in residential area in next 15 years and also Commercial area. More than 60 lakh sq.feet areas (new apartments) were ready for occupants for the year 2010. According to the 2001 Census the city had 6.52 Lakh households in Hyderabad. At present the approximate total households in the MCH and surrounding 12 municipalities and Secunderabad area is 13.02lakh (GHMC website).

It is observed that mainly 3 sets of fracture systems (shallow zone: 20-40, intermediate: 40-60 m and deeper >60 m) exist in the area. Of these though shallow fractures are more prevalent, intermediate fractures, often connected to shallow fractures are more productive, which need to be harnessed through rooftop rain water harvesting. Considering that each apartment complex/household has one functioning/abandoned bore well, it is recommended that each house/apartment complex should have recharge unit/ fast filtration unit, above or below ground (preferably above ground) which is dug and filled with coarse gravel (bottom 2/3 portion) and keeping the remaining part open. The rooftop water be allowed to pass through recharge unit/filtration unit and recharge existing well/abandoned well. There should be proper maintenance of the structure and surveillance. The cost involved for execution of this structure is about Rs 15000/- for each house. This equals to an estimated amount of about 1000 crores for 50 % of total estimated households for implementing Roof Top Rain water harvesting in the MCH and surrounding municipalities and Secunderabad. Besides this, in twin cities, Defence establishments (Secunderabad area), Universities, Central and State Institutions, Public Parks, Play grounds etc have large open areas. These areas are suitable for taking up artificial recharge structures such as recharge shafts and recharge pits.

Storm runoff collection and recharge: Hyderabad often faces serious floods during monsoons. This water can be recharged with proper infrastructure in place. The storm runoff generated within an area can be utilized for groundwater recharging by diverting it into suitably designed structures near pavements, parking lots, municipal parks, play grounds, stadiums, airports etc., and by earmarking some open spaces exclusively for the purpose. As per the land use pattern, a total of 66% including Residential areas (44.24%), Parks and play grounds (6.81%), Defence establishments (4.83 %), Public and semi-public (9.01%) and Vacant open lands (1.58%) can be brought under the ambit of Artificial recharge. The design of recharge structures should involve construction of sufficient number of recharge pits and trenches filled with gravel. Pavements can be utilized for collecting road run off and for recharging groundwater. Permeable pavement is an alternative to conventional paving in which water permeates through the paved structure rather than draining off it.

Waste water Recycling and Re-use : Wastewater recycling and reuse at source can save up to 45% of water demand in individual residential buildings and can save up to 60% of water demand in apartment complexes, residential layouts, townships, institutional buildings and other large neighbourhoods. Introduction of dual plumbing systems to segregate wastewater (grey & black) will enable the separation of grey and black water at the source of generation. The grey water (sullage) constitutes about 70% of the wastewater generated, which can be treated by using simple and cost effective systems and thereby can be reused for landscaping, external washing in all treatment options and also be used for WC flushing by using some secondary treatment options. Once the grey water is separated, the remaining black water (sewage) can then be treated by decentralized wastewater treatment systems. These parameters will enable the architects/ contractors/ developers and users in assessing upon type of treatment option that should be adopted for different types of buildings.

Solid waste collection & treatment: As mentioned earlier, the HUA generates around 3379 tons of solid waste every day at a per capita generation rate of 600 gms/cap/day. There is no engineered landfill site in Hyderabad Urban Agglomeration. Presently, waste disposal facility is located at Jawaharnagar in Shamirpet Mandal of Ranga Reddy district only, where contamination of ground water is observed. Efforts should be made to identify the sites based on scientific surveys and wastes be collected and treated properly before disposal.

Water Use Auditing: Water use audits are an important initiative toward understanding a building's water use and how it can be reduced. It reviews water use from its point of entry into the building through its discharge into the sewer. It identifies each point of water use within and around the building and estimates the quantity of water used at each of these areas.

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JAIPUR CITY, RAJASTHAN

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INTRODUCTION

Jaipur city was founded by Sawai Jai Singh in the year 1723. The areal extension of Jaipur Urban area is between North latitudes 26°47'-27°02' and East longitudes 75°36' – 75°55' (Fig. 1) located almost in the centre of the district and covers an area of about 470 sq. km. The Jaipur agglomerate has parts of Sanganer (45.5%), Jhotwara (42.5%) and Amer (12%) blocks.

Fig. 1 Administrative setup

GENERAL FEATURES

Demography

Jhotwara block which constitutes the major part of the urban city has a population density of 2745 persons/sq. km. With the increase in the rate of urbanization the population of the city also increased many fold during the last 6 decades. The decadal growth rate of population is highest during 1941 – 51 as 65.59 % followed by 62.77 % during 1991– 2001. The population growth since 1931 is given below and shown in Fig. 2. The present population as per projection is 35.60 lacs (Table 1).

Physiography & Drainage

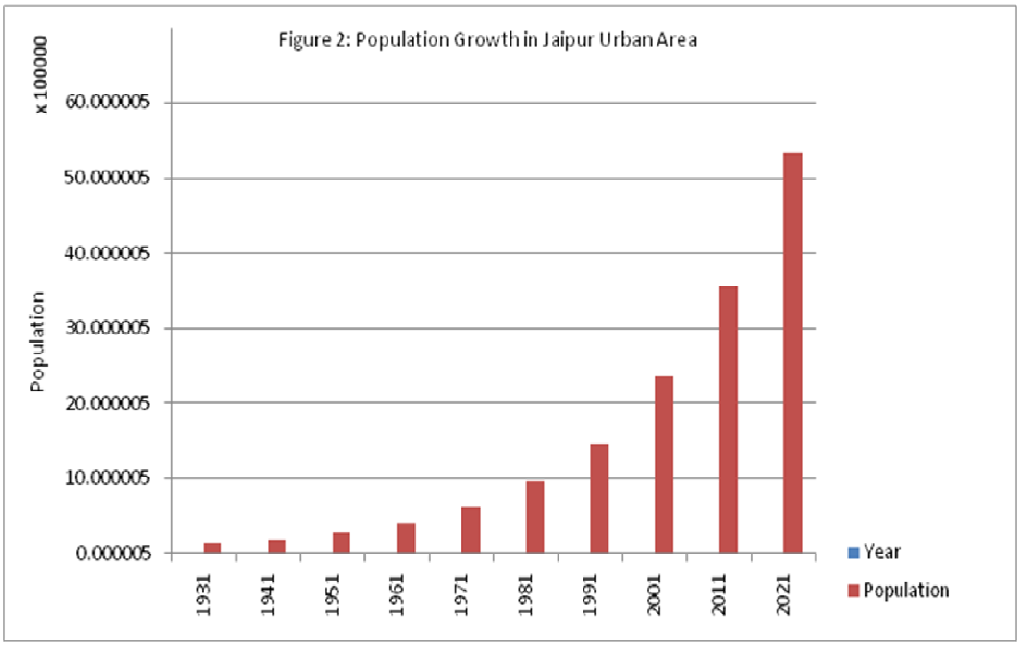
Physiography

Physiographically the city area is characterized by sandy-plains, hills, intermountain-valleys, pediments etc. Major part of the city is covered by the alluvial sandy plains which are dissected at places. In the northern and eastern parts, the Aravalli Hill Ranges, trending north east-south west alternating with intermountain-valleys, constitute significant signatures of physiography. The ridges are generally made-up of resistant quartzite rocks. Important among these are the Nahargarh, Amer, Puranaghat and Jhalana Hills. The highest peak of these hills is about 648 meter above mean sea level (m amsl). Hills are often marked by escarpments and uplands have slopes at 15-20%, and are characterized by sheet and gully erosion. Pediment landscapes are observed in the south western part of the city. The latitude of the peneplained area ranges from about 350 in the southern part to 480 m amsl in the northern part of the urban area.

Table 1 Population and decadal growth rate of Jaipur Urban Area

Year	Population	Decadal Growth %
1931	150000	-
1941	175810	17.21
1951	291130	65.59
1961	403444	38.58
1971	615258	52.50
1981	977165	58.82
1991	1458483	49.26
2001	2374000	62.77
Projected Population		
2011	3560000	49.95
2021	5340000	50.00

Source : Public Health and Engineering Department, Govt. of Rajasthan



Drainage

There is no major river drainage system in the Jaipur Urban Area. One streamlet originating from Nahargarh Hill namely Amanishah Nalla flows southerly up to Sanganer area where it takes easterly flow direction due to structural control. The Amanishah nalla and associated streamlets are ephemeral in nature and merge with the Dhund River, a tributary of Morel River (out of urban area). Surface runoff in extreme western part flows in westerly direction and discharged through Bandi (locally called Mashi) river. In major part, drainage density ranges between 0.30 and 0.50 km/sq. km whereas in extreme western and southern part it is of the order of 0.20 to 0.30 km/sq. km. Studies reveal the existence of palaeochannels in the area also.

Hydrometeorology

It enjoys semi-arid climatic condition. The mean annual rainfall at Sanganer, Amer and Jaipur raingauge stations have been 534.3, 622.78 and 546.03 mm respectively during the period 1980-2009. The average mean annual rainfall for these three stations works out to 567.70 mm.

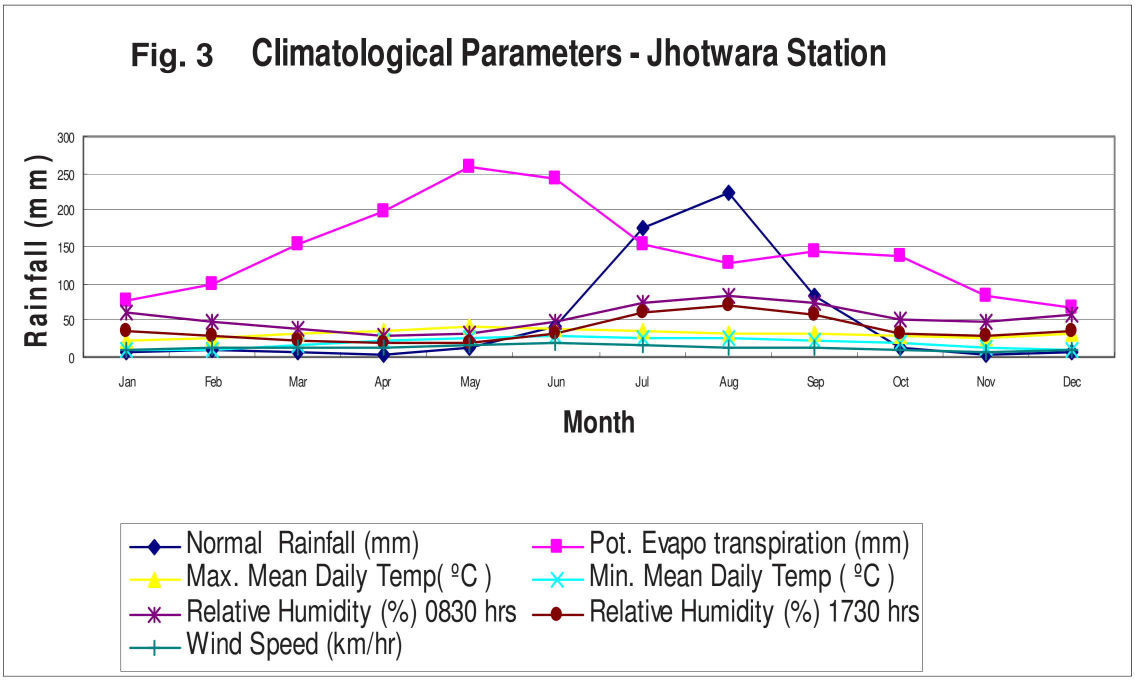
The highest rainfall has been recorded as 1101.90 mm at Sanganer (1981), 1008 mm at Amer (1995) and 887 mm at Jaipur (1996), where as lowest rainfall has been recorded at Sanganer as 206 mm (1980), at Amer as 235.00 mm (2002) and at Jaipur as 222.40 mm (2002) Table 2. The standard deviation of annual rainfall from mean annual rainfall has been worked out as 206.47.

Table 2 Analysis of rainfall data

S. No.	Rain Gauge Station	Mean Annual Rainfall (mm)	Highest Annual Rainfall (mm)	Year	Lowest Annual Rainfall (mm)	Year	Standard Deviation (mm)
1	Sanganer	534.30	1101.90	1981	206.00	1980	206.43
2	Amer	622.78	1008.00	1995	235.00	2002	223.43
3	Jaipur	546.03	887.00	1996	222.40	2002	189.54

The monsoon rainfall, which contributes about 90% of the total annual rainfall extends from June end till September, July and August being the wettest months. Based on Chegodev's empirical relation, probability of exceedance of average annual rainfall is about 25% and normal drought 19.4% whereas probability of severe and most severe drought is almost negligible. Summer season starts in the month of March and continues till mid June. The mean daily maximum temperature is highest (40.6°C) in May, whereas mean daily minimum temperature is highest (27.3°C) in June. The on-set of monsoon in June end/July brings down the temperature.

Winter season starts in November and the temperature continues to fall till January which is the coldest month of the year. The mean daily minimum temperature is lowest in January (8.3°C). Climatological parameters of Jhotwara Station are shown in fig 3.



The air is generally dry during the major part of the year. However, during monsoon period (July-September) the relative humidity is generally over 60% and during summer months it is as low as 20%. As characteristic of semi-arid climate, the rate of potential evapotranspiration is high in the city area. It is highest in the month of May (average 257 mm) and is lowest during December (average 167 mm). The city by and large experience light to moderate winds during major part of the year. However, winds become relatively stronger in summers as well as during the monsoon period. The wind speed is highest (17.8 km/hr) in June and is lowest (7.6 km/hr) in November.

Soil Type

Sandy alluvial soil is the main soil type in the city area. Agricultural activity is restricted to cash crops and horticultural. The land is largely utilized for domestic housing, office complexes, industrial set-up, gardening etc.

STATUS OF WATER SUPPLY AND DEMAND

At the time of foundation of Jaipur city in 1727, water supply scheme started by construction of Jhalaras (a big public well) in each of the nine Chowkaris (squares). In the beginning of the 18th century the citizens used to draw water from 100 open wells and baoris located in the city. The first water supply scheme for City Palace where water from open wells was drawn with oxen and was supplied through a small canal. In the mid of 18th century the walled city was supplied water from Amanishah Nala through canals up to Chhoti Chopar and Bari Chopar from where people used to take water. Piped-water supply to Jaipur for public began in 1874 with the construction of a Reservoir of 4.5 MLD capacity across Amanisha Nala. Open wells were constructed in the Nala to meet the drinking water demand. In 1915, water supply for the city was about 23.7 litres per capita per day. This was followed by the development of alternative sources for water supply in the city in view of the growing population.

The Ramgarh dam was constructed in the year 1906. Due to increased population a scheme was taken up to augment water supply from the lake. The foundation stone of the scheme was laid on 13th March 1931 by the

Lord Irvin to develop capacity of supplying 9 MLD of water to a population of 1.5 lacs. In 1953, capacity of pumpage from the Ramgarh Lake was increased from 9 MLD to 27 MLD by installation of necessary pumping stations, carrier main filter plants, distribution mains etc. In 1963, capacity of the Lake was further increased from 27 MLD to 54 MLD and filter plants were installed at Laxman Dungri. Because of the increasing population the augmentation scheme was sanctioned during 1971-72 taking ground water as source with 63 MLD capacity. During 1973-74, capacity of ground water withdrawal was increased from 63 to 99 MLD by constructing additional tubewells in the outskirt areas. This scheme was sanctioned during 1976-77 to enhance the supplies from the ground water to the tune of 126 MLD. IDA assisted augmentation scheme was implemented during 1980-85 to further increase the water supply capacity by 72 MLD. About 18 MLD of water was increased from Ramgarh lake whereas 54 MLD ground water from 120 wells. Thus the total capacity of Jaipur water supply scheme was raised to 234 MLD.

Present Status

The present status of water supply scheme to cater about 27.98 lacs population of Jaipur Urban area is as under.

i.	Water Sources :	a.	Ramgarh Lake		
		b.	Tubewells	:	1897
		c.	Hand Pumps	:	1983
		d.	Tubewells (125mm)	:	176
		e.	Bisalpur Dam	:	
ii.	Water supply (352.5 MLD)				
		a.	Ramgarh Lake	:	Nil
		b.	Tubewells	:	300 MLD
		c.	Hand Pumps	:	1 MLD
		d.	Tubewells (125mm)	:	1.5 MLD
		e.	Bisalpur Dam	:	50 MLD
iii	Service Level			:	125 lpcd
iv	Water Requirement			:	349.75 MLD

The present population of Jaipur Urban Area as per projection is estimated to be 35.60 lacs for which water requirement is about 445 MLD. There are about 5000 private tube wells with average 2 hrs pumping per day. This leads to ground water abstraction of about 30 MLD considering 15 m3/hr average discharge of a well.

WATER PROFILE (SURFACE AND GROUND WATER)

State water supplying department (PHED) has formulated Bisalpur Water Supply Project to meet a target of 950 MLD of water to JUA. The project has been commissioned in 2010, and present supply from Bisalpur is only 50 MLD despite good rainfall during the year 2010. The present surface water supply to JUA from Ramgarh Lake (dry) is nil, which was used to be 54 MLD since 1963. The ground water abstraction in JUA is about 302.5 MLD from Govt tube wells and about 30 MLD from private tube wells. The ground water contributes 92.12 % of total water utilization. The status of water supply from surface and ground water is given in Table 3.

Table 3 Status of water supply in Jaipur urban area (in MLD)

Year	Surface water	Ground water	Total water supply
1980	27.00 (Ramgarh lake)	108.00	135.00
1985	29.50 (Ramgarh lake)	136.35	165.60
1990	11.60 (Ramgarh lake)	152.90	174.60
1995	11.25 (Ramgarh lake)	209.25	220.50
2000	32.00 (Ramgarh lake)	300.00	332.00
2005	Nil	328.00	328.00
2010	50.00 (Bisalpur Dam)	300.00	350.00

GROUND WATER SCENARIO

Geological Set-up

Bhilwara Supergroup of rocks are the oldest rocks followed by Delhi Supergroup of rocks. These consolidated rocks are covered by Quaternary deposits in the major part of the area. The rocks of Bhilwara Supergroup comprise mainly gneisses and schist of Archaean age and are overlain by quartzites with inter-bedded phyllites and schists sequence of Alwar Group (Delhi Supergroup). These predominantly arenaceous rocks are exposed as high ridges near Harmada, Amber, Jhalana etc. Quartzites are generally grey coloured and are medium to coarse grained.

Major part of the city area is covered by a thick mass of quaternary deposits. These unconsolidated fluvial as well as aeolian sediments are mainly composed of sand, silt, clay with kankar and gravels at places. Geological succession in the Jaipur Urban Area is summarized below in Table 4.

Table 4 Geological succession in Jaipur Urban Area

Era	Period	Lithology
Quaternary	Quaternary	Sand, Silt, Clay, Kankar, Gravel
Proterozoic	Delhi Supergroup (Alwar Group)	Quartzites, Schists, Phyllites
Archaean	Bhilwara Super Group	Schist, Gneiss, Migmatite

Subsurface Geology

With the objective of delineating the vertical and lateral extent of the aquifers, exploratory boreholes have been drilled by the Central Ground Water Board and Ground Water Department, Govt. of Rajasthan in the city area of Jaipur. The depth to basement encountered in these boreholes and also deposit wells are given in Table-5.

Table 5 Depth of Basement in the Jaipur Urban Area

S. No.	Location	Depth to basement (mbgl)
1	Ambabari (EW)	98.00
2	Sanganer(EW)	55.20
3	Mohana (PZ)	49.20
4	Jhotwara (PZ)	84.00
5	Stadium Jaipur (DW)	73.00
6	Murlipura (DW)	65.00
7	Mansarovar (PZ)	80.00
8	Shyamnagar (DW)	63.21
9	Vaishalinagar (DW)	74.00
10	Hathroi-Gopalbari (DW)	38.20
11	Nahru Place (Tonk Road) (DW)	73.00
12	Harmada (EW)	49.12
13	Jaipur (OTS) (PZ)	70.10
14	Vidhyadhar Nagar (PZ)	92.00
15	Surya Nagar (PZ)	75.00
16	Sirsi (PZ)	81.00
17	Durgapura (PZ)	71.00
18	Hirapura (PZ)	60.00
19	Sanchoti (PZ)	50.00
20	Sukhpuria (PZ)	57.00
21	Jhalana (PZ)	50.00
22	Bajaj Nagar (EW)	83.60
23	MES (PZ)	67.80
24	Nangal Jaisanbohran (EW)	66.47
25	Malviya Nagar (DW)	75.00

EW-Exploratory well, PZ-Piezometer, DW-Deposit well (Production well)

The borehole data reveal that thickness of the alluvium is less than 50 m in the area around Harmada and Hathroi, and over 80 m at Vidhyadhar Nagar, Jhotwara, Sirsi, Ambabari and Bajajnagar area of the city. In remaining areas, the alluvium thickness is between 50 to 80 m (Fig. 4). Altitude of the bed rock is from about 325 m amsl in southern part to over 400 m amsl (Fig. 5) in the northern part of the urban agglomerate. Mostly quartzitic rocks have been encountered, except in southern part, where granitic gneisses and schist are the bed rocks.

Fig.4

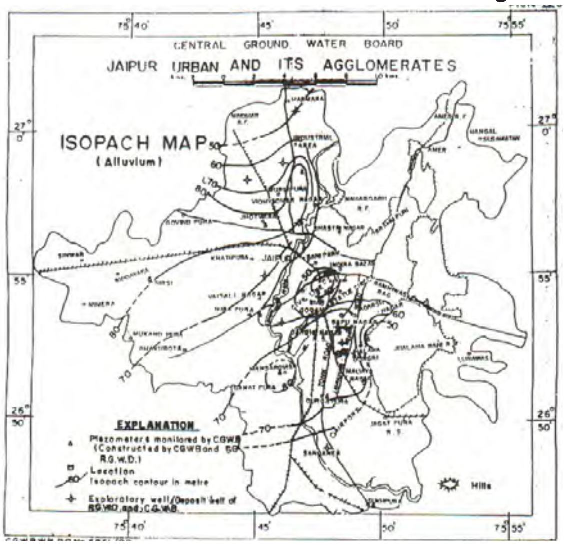
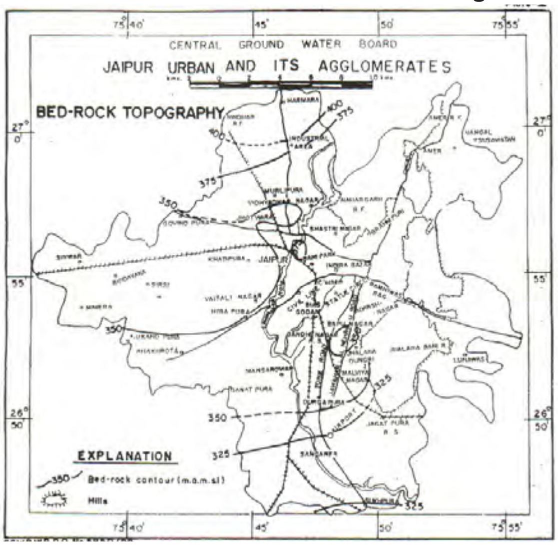


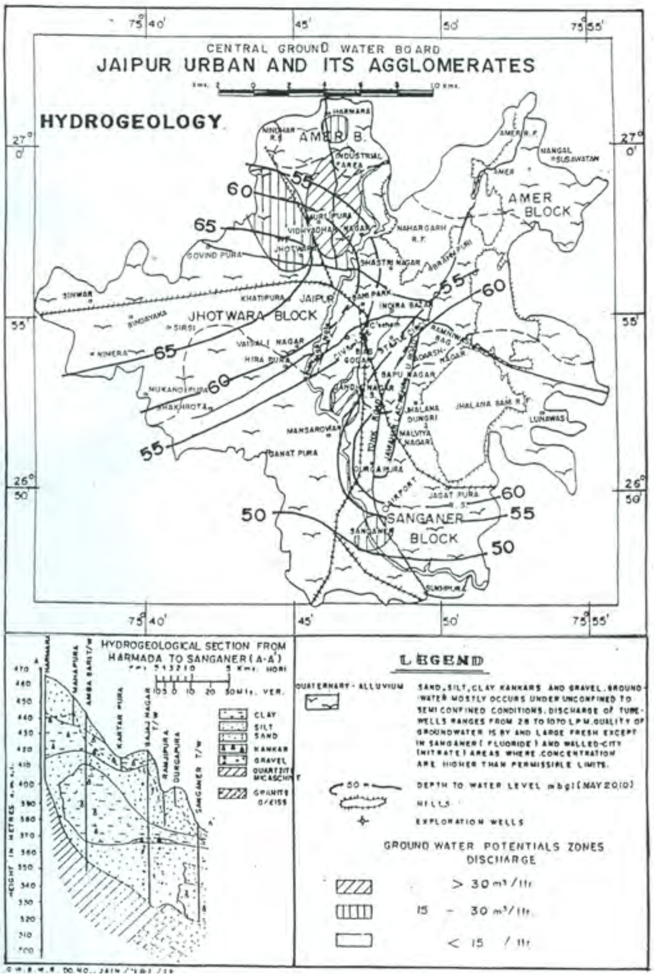
Fig. 5



Potential Aquifers

Ground water conditions are mainly governed by the geological set-up besides the influence of geo-morphological and climatological factors. The movement of ground water takes place through the primary and secondary porosity in the formation. Unconsolidated Quaternary formation forms the principal aquifer in the Jaipur urban area. These sediments are fluvial, fluvio-aeolian and aeolian in origin. Talus and scree near foothills also serve as potential aquifers at places. Hydrogeological set up of the area is given in Fig. 6.

Fig.6



Saturated thickness of the alluvial aquifer varies considerably. Towards southern and western part of the city it ranges from about 15 m to 30 m, along the axis of walled city-Sanganer it is over 20 m, reducing to less than 10 m towards Amanishah Nalla. In the area west of Amanishah Nalla, saturated thickness is again more, varying from 20 m to 35 m.

Ground Water Level

To ascertain the behaviour of water table in the city area 15 National Hydrograph Network stations are monitored four times a year i.e. January, May, August and November. The data from these stations of Nov. 2010 reveals that the depth to water level in the city area varies from 10.75 m to 66.95 m (Fig. 6) and is more in western part of the urban agglomerates and in the area of Officers Training School (OTS), Jawahar Nagar et. Depth to water level within walled city, Amer, Jal Mahal, Puranaghat area etc., is generally shallow i.e. generally less than 15 m bgl. Depth to water table in the range of 40 m to 60 m occurs near Chandpole, C-scheme, Mansarovar, Durgapur, Sanganer and Sukhpuria. Water levels over 65 m have been recorded around Jhotwara, Army Cant and Sirsi.

Water Table Elevation and Slope

The elevation of water level varies from about 430 m above mean sea level (m amsl) in northern part of the area to about 330 mamsl in the southern part. Hydraulic gradient closely follows the physiography and is in the southern and south-westerly directions. The monitoring of National Hydrograph Network Stations in the city area reveals declining trend in water levels. Water level fluctuation data of hydrograph stations for the period of Nov. 1990, 1995, 2000, 2005 and 2010 are given in Table 6.

Table 6 Depth to water level and fluctuation in Jaipur Urban Area

Sl No	Location	Depth to Water Level (mbgl)					Water Level Fluctuation m/year			
		Nov-1990	Nov-1995	Nov-2000	Nov-2005	Nov-2010	1990-2010	1995-2010	2000-2010	2005-2010
1	Amer	11.9	5.73	11.77	9.31	10.75	0.06	-0.33	0.10	-0.29
2	Durgapura		18.98	22.8	33.54	58.4		-2.63	-3.56	-4.97
3	Goner		6.97	11.28	6.79	12.4		-0.36	-0.11	-1.12
4	Gopalpura Bye Pass					43.5				
5	Jhotwara		36.28	46	54.7	66.95		-2.04	-2.10	-2.45
6	Mansarowar			24.62	35.95	51.45			-2.68	-3.10
7	Mansrowar CGWB					47.1				
8	MES Jaipur		35.95	39.14	43.97	57.35		-1.43	-1.82	-2.68
9	Mohana		26.85	37.87	33.73	31.5		-0.31	0.64	0.45
10	Shivdaspura	11.6		19.96	18.2	19.5	-0.40		0.05	-0.26
11	Sirsi		35.45	42.17	55.02	65.1		-1.98	-2.29	-2.02
12	Sukhpura		22	22.09	25.32	45.7		-1.58	-2.36	-4.08
13	Suryanagar			16.82	20.59	42.4			-2.56	-4.36
	Average		23.53	26.77	30.65	42.47	-0.17	-1.33	-1.52	-2.26

The decline in water level has been observed in the area and it has been estimated as 0.17 m/year during 1990 -2010, 1.33 m/year during 1995 -2010, 1.52 m/year during 2000 – 2010 and 2.26 m/year during 2005 – 2010. This shows that rate of decline in water is increasing day by day due to increase in ground water utilization and poor aquifer at deeper levels. The hydrograph of Mansarowar for the period 1996-2010, Durgapura for the period 1995-2010, Jhotwara for the period 1992 – 2010 and Amer for the period 1975 - 1976 stations are plotted and shown in

Fig. 7a Hydrograph of MANSAROVAR (45N-1D20)

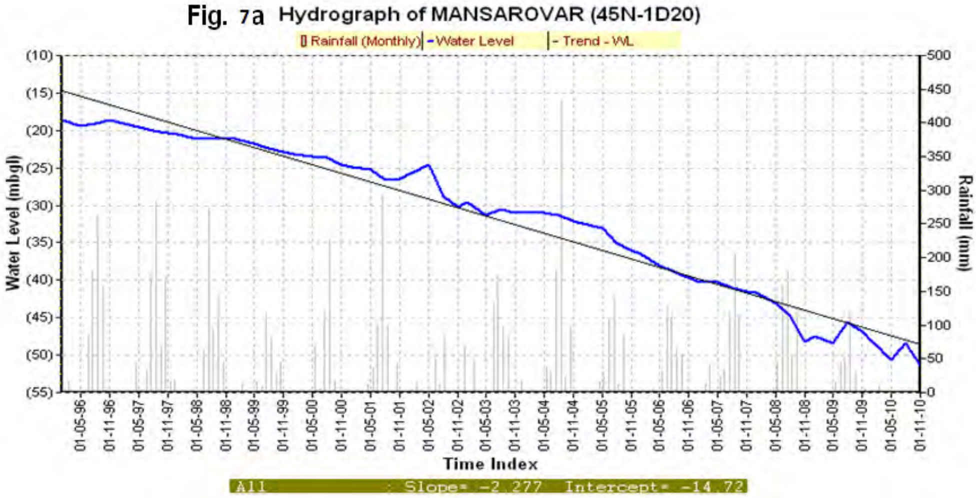


Fig 7a, 7b, 7c, and 7d. The reason for declining trend in ground water table in the area is due to the ever-increasing exploitation of ground water to meet the demands mainly for drinking and industrial purposes. The decline in water level more than 3m/year has been observed in hydrograph station of Durgapura, Mansarowar and Sukhpura during the period from 2005 -2010.

Fig. 7b Hydrograph of DURGAPURA (45N-1D18)

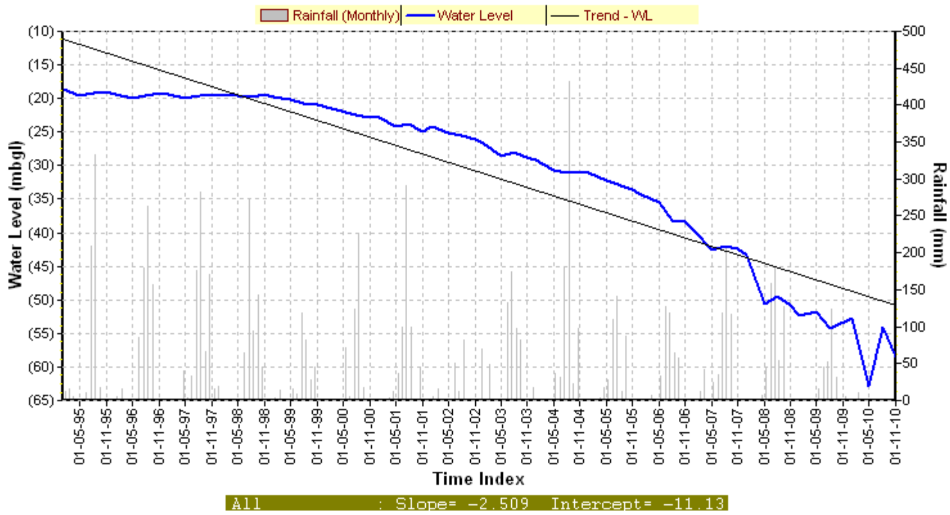


Fig. 7c Hydrograph of JHOTWARA (45N-1D6A)

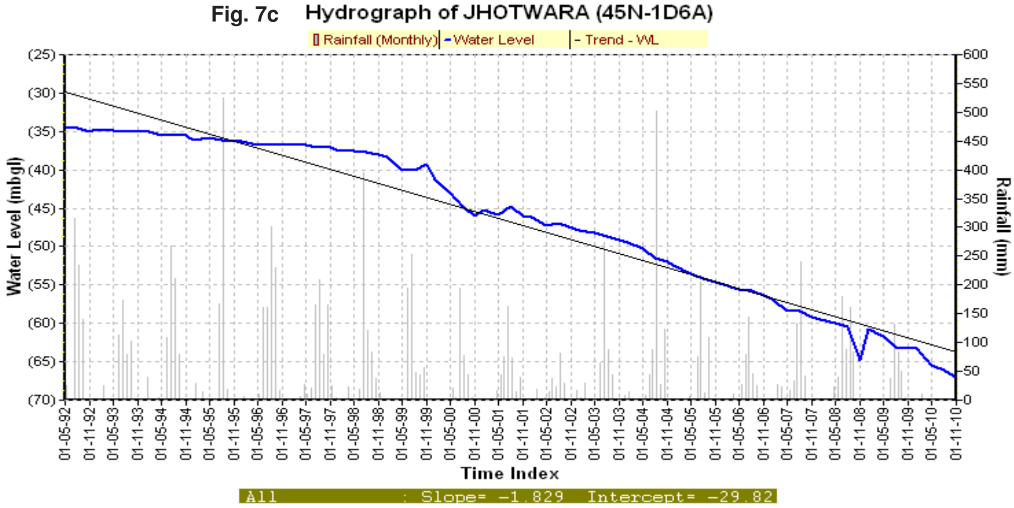
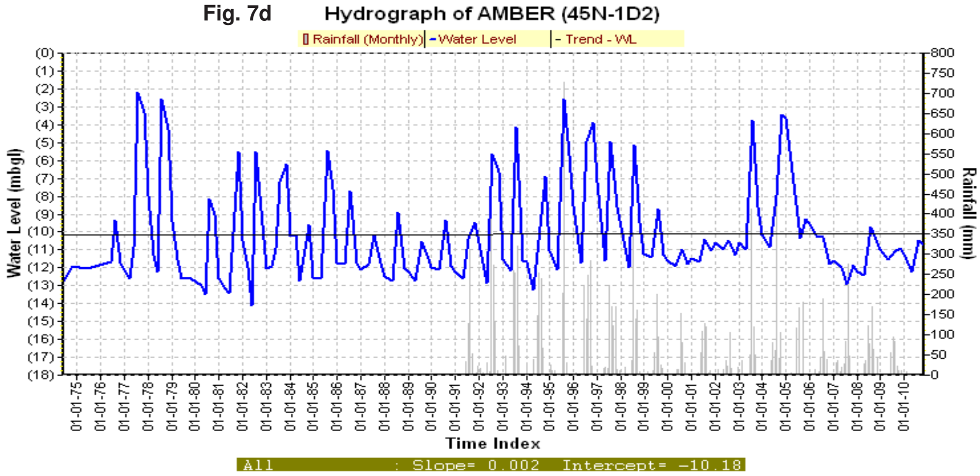


Fig. 7d Hydrograph of AMBER (45N-1D2)



Ground Water Resource & Status of Development

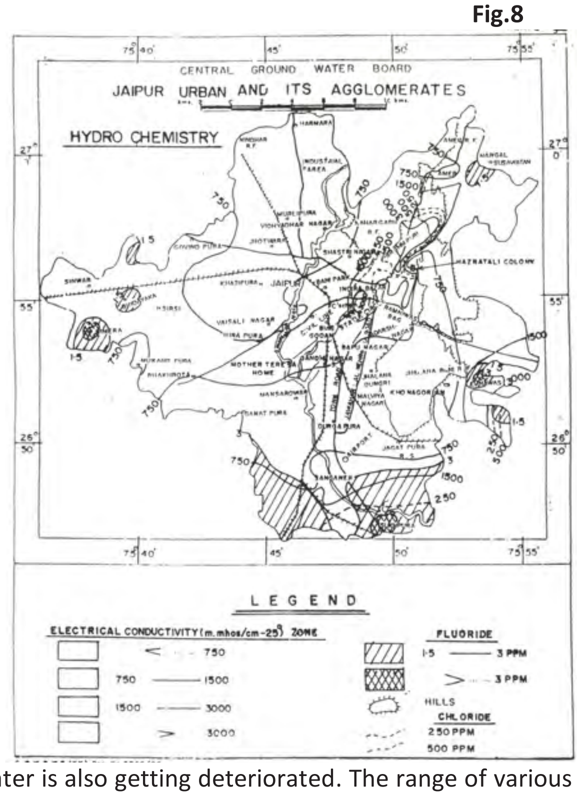
Dynamic ground water resources have been estimated on block wise basis jointly by the Rajasthan Ground Water Department and the Central Ground Water Board as on 31.03.2009. The estimation of resources is provisional till its approval from CGWB, New Delhi. It has been proportionately reduced for the Jaipur Urban Area and are furnished in Table 7.

Table 7 Block wise ground water resource as on 31.03.2009

Block	Area (km2)	Net annual ground water availability (mcm)	Existing gross ground water draft for irrigation (mcm)	Existing gross ground water draft for Dom. & Ind. Use (mcm)	Existing gross ground water draft for all uses (mcm)	Present ground water balance as on 31.03.2009 (mcm)	Stage of ground water developm ent (%)	Category
Amer	56	4.36	8.19	0.85	9.04	-4.67	207.55	OE
Jhotwara	200	21.15	30.78	46.33	77.11	-55.96	364.51	OE
Sanganer	214	15.70	37.65	10.31	47.96	-32.26	305.42	OE
Total	470	41.21	76.62	57.49	134.11	-92.90	325.40	OE

The over-exploitation of ground water to the tune of 92.90 mcm/year is likely to adversely affect the availability of ground water during the next 5 to 8 years if the necessary remedial measures are not initiated immediately.

Fig.8



Hydrochemistry

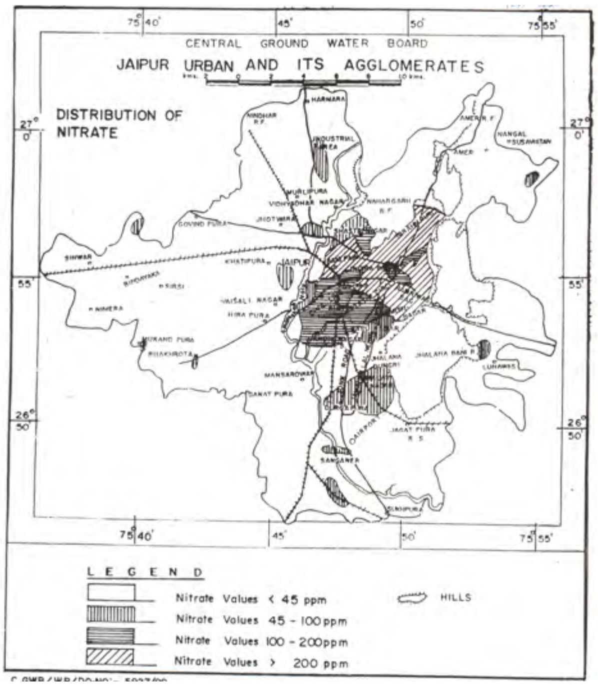
Hydrochemical scenario prevailing in the area reveal that quality of ground water is by and large fresh in the major parts of the city. However poor ground water quality (Electrical conductivity more than 1500 micromhos/cm at 25°C) have been recorded in the Walled City, C-Scheme, Adarsh Nagar, Bani Park, Jyoti Nagar, Civil Lines, south of Sanganer etc. Electrical conductivity (EC) and chloride values in the northern part of the walled city range from 2900 to 4330 micromhos/cm at 25°C and 469 to 995 ppm respectively. Ground water having EC over 3000 m mhos/cm has been found at localities like Mother Teressa Home in C-scheme (3820), Purani Basti (3100), Indira Bazar (3740), Lavan Ka Gher (3440), Gator Bus stand (4200), Hazarat Ali colony (4330), Kala Hanuman Ji Mandir (3950), Ropura (3710), etc. High Nitrate content in walled city and adjoining areas range from 45 to 900 ppm makes the ground water unsafe for drinking purposes. Similarly occurrence of high fluoride in ground water range from 1.5 to 9.95 ppm makes it unsafe for drinking purposes. The studies reveal that with the declining trends in water levels, the quality of water is also getting deteriorated. The range of various chemical constituent in the area is given in Table 8. The variation of electrical conductivity and concentration of fluoride in ground water are shown in Fig 9. The distribution of Nitrate concentration in ground water is shown in Fig. 10.

Table 8 Range of various chemical constituents

Sl. No.	Constituents	Range
1	Specific conductance micromhos/cm at 25°C	210 (Khonagoriyan) to 4330 (Hazrad Ali Colony)
2	Chloride (ppm)	7 (Vidhyadhar Nagar) to 995 (Hazrad Ali Colony)
3	Fluoride (ppm)	Trace (Inspection Bunglow, MES and Govt. Hostel) to 9.95 (Nimera)
4	Nitrate (ppm)	Trace (Mansarovar) to 900 (Mother Teressa Home, C-Scheme)

Ground Water Pollution

Fig. 9



Increasing industrialisation and urbanization have caused not only air, sound and surface water pollution but have also caused ground water pollution in the Jaipur city resulting in adverse effects on the health. Some parts of the urban agglomerate is affected with fluoride pollution (as in Sanganer) while the major parts lying within the walled-city is suffering from nitrate pollution. There is an urgent warning and calls for measures to tackle the quality hazards of ground water.

High Fluoride in Ground Water

The concentration of fluoride in ground water in greater part of the area is with in permissible limit of 1.5 mg/liter. Alarming levels of fluoride in ground water has been recorded in Sanganer block area forming part of Jaipur urban area. Alluvium is the principal aquifer in the Sanganer area having maximum thickness of 76 m. Depth to water level generally ranges from 35 to 45 m.

The town Sanganer is famous for specific cloth print designs for which vegetable dyes were being used during earlier days. However because of considerably lower cost of the organic (chemical) dyes, the same are preferred and are now being used extensively by the dyeing and printing industry. Voluminous liquid wastes are generated by the dyeing and printing industry and are disposed off in carrier channels (canals). In addition, some industrial units are also pouring their effluents into the Amanishah Nala. These liquid wastes are also being used for irrigation purposes. The unused part of effluent water is allowed to accumulate near the bunds in the peripheral areas giving adequate time period to this effluent water to percolate and reach the saturated zone. Thereby degrading and deteriorating ground water quality. The polluted surface water flows as per hydraulic gradient and gets concentrated at favourable geomorphic locations where its flow is sluggish. The organic dyes have been found to contain fluoride content from 0.2 to 1.8 ppm whereas the effluent wastes have fluoride concentration ranging from 1.6 to 7.7 ppm. It is therefore recommended that the liquid effluents should be treated and beneficiated to remove the hazardous constituents before their disposal and also to encourage / motivate to use vegetable dyes. Alternatively, the dyes having higher concentration of fluoride be replaced by alternative dyes.

High Nitrates in Ground Water

Prolonged use of water with nitrate beyond permissible limit of 45 ppm for drinking purposes causes stomach disorder and methemoglobinemia. Presence of high nitrate in aquifer water has been recorded in the Jaipur city, particularly within the walled-city and adjoining areas. Ground water occurs mostly under phreatic conditions except at few locations. The significant findings of the scientific studies is that high level of nitrate contents were found more in thickly populated walled city area where proper sewerage system do not exist and also ground water levels are shallow. Therefore, it is recommended to develop a proper sewerage network system in urban agglomerate areas particularly in the walled city so as to prevent mixing with ground water.

Major Ground Water Related Problems

Depleting ground water resource

The ground water requirement is increasing day by day in the urban area for domestic and industrial purposes due to rapid growth in population and economic developments. The water requirement met by surface water in JUA is only 15 % of total requirement and remaining requirements are met by ground water. The earlier source of surface water was Ramgarh lake, which has been dried up and now surface water is transferred through pipe line from Bisalpur Dam on Banas river located about 110 km. from Jaipur. Large scale ground water development due to urbanization and industrialization has rendered Jaipur urban area ground water system as over exploited with stage of ground water development as 325.40%. Natural recharge to ground water is also diminishing because of the shrinkage in the open areas due to construction of buildings and increase in paved area. The ground water resource estimate reveals that there is overexploitation of 92.8966 MCM / year, resulting into declining trends in water levels there by causing decrease in yield of the wells.

Quality Deterioration

Increasing urbanization and industrialization have caused not only air, sound and surface water pollution but have also caused ground water pollution in the Jaipur city resulting in adverse effect on the health, environment and imbalance in the eco-system:

Urbanisation – Nitrate pollution

Intake of high nitrate water (more than 45 ppm) causes stomach disorder and the disease called methemoglobinemia. The ever-increasing pollution density, lack of properly developed sewerage system and shallow water levels have resulted in high nitrate pollution in ground water particularly in walled city and adjoining areas. The situation is likely to improve if proper development / maintenance of sewerage system is given due attention.

Textile industrialization – Fluoride pollution

High concentration of fluoride in drinking water causes the disease called fluorisis. In Sanganer area, famous the world over for printed fabric, use of chemical dyes in place of vegetable dyes by the expanding cloth printing industry has resulted in qualitative deterioration of ground water by high level of fluoride. The already alarming level of fluoride in ground water in some areas is likely to further expand in time and space due to enhanced use of such fluoride containing dyes (in printing industry) if immediate remedial measures are not taken.

Salinity

High level of salinity in ground water has been found particularly in the walled city. The high salinity in ground water is attributed to contamination by increased pollution, poor sewerage network and shallow water levels. Diminishing natural recharge of ground water due to shrinking of open space and continuous over-exploitation leading to mining of aquifer water have also resulted in the increase in salinity in ground water.

Feasibility of Rainwater Harvesting and Artificial Recharge

The area is receiving rainfall on an average of 567.7 mm/year and thus there is precipitation of 266.82 mcm/year. A part of this source water can be used for artificial recharge of ground water. The subsurface formation in greater part of the area is alluvium. The depth to water level in the area varies from 10.75 to 66.95 m bgl with an average of 42.47 m bgl. The subsurface storage space available for artificial recharge has been estimated as 1317.419 mcm which can be used for rain water harvesting and artificial recharge of ground water. The rain water run off from roof top / paved area / roads and storm water can be used for artificial recharge. The feasible rain water harvesting structures in the area are recharge shafts (with / without boring), trench, recharge tube wells, abandoned dug wells / tube wells / hand pumps and anicuts at suitable locations. The Central Ground Water Board has constructed roof top / paved area rain water harvesting structures in the 14 government buildings in the city as demonstrative projects of rain water harvesting and artificial recharge of ground water. About 25% of rain water i.e. about 66.7 mcm can be planned for artificial recharge of ground water through construction of suitable recharge structures which will result in restricting decline in water levels and lead to increase in yield of wells.

GROUND WATER DEVELOPMENT STRATEGY

Ground Water Resources

The replenishable /dynamic ground water resources are overexploited to the tune of 92.8966 MCM with stage of ground water development as 325.40%. The principal aquifer in the area is alluvium and depth to water level ranges from 10.75 m to 66.95 m with an average of about 42.27 m. Alluvium is underlained by schist, gneisses and quartzite with negligible yield. The depth to basement in the area varies from 49.20 to 98 metres with an average depth of 68 m. There is need for ban on further ground water development in the area. The Central Ground Water Board has notified Jhotwara block as "NOTIFIED" area for regulation of control and development of ground water resources vide Public Notice dated 14.09.2006. The Sanganer block area is in process of notification by CGWA for regulation of control and development of ground water resources.

There is need of transfer of surface water from adjoining basin. Bisalpur Project of Govt. of Rajasthan was planned for transfer of 950 MLD water to Jaipur. But it has been restricted to 50 MLD only. The constraint in less supply to Jaipur from Bisalpur needs to be addressed.

The flow of water leaving the Jaipur Urban Area is waste water of about 91 MCM /year and this flow will only increase as a result of increased sewerage cover and increasing consumption. Treated waste water can be used for watering of green areas in Jaipur city. The waste water leaving the JUA from north through Brahmpuri STP plant and Jalmahal Lake and from south through Delawas STP plant and Amanisha nala. There is need of pumping to bring the treated waster water in urban area as there is elevation difference of more than 100 m. Therefore small STP can be installed and treated waste water should be utilized in nearby areas. This will save fresh ground water.

Conservation Methods

- Ground water exploitation needs to be regulated. In the peripheral areas of the urban agglomerate, utilization of ground water for irrigation purposes should be practiced by employing sprinklers / drip methods only. The quantity of water thus saved may be diverted and utilized for city water supply.
- All ground water based industries must re-use 80% of the water in different operation.
- Use of recycled treated waste industrial waters for agriculture may be made mandatory, so as to conserve ground water for drinking purposes.
- Defunct boreholes with hand pumps should be deepened and repaired immediately. Use of hand pumps should be encouraged.
- Wastage of water from leakage through pipelines is a common and serious phenomenon. Prompt action to check such losses may save the water to a greater extent. Organizations including Public Health Engineering Department / Housing Society etc. should give proper attention to control such leakages. Besides every citizen should also feel the responsibilities to inform such incidences to the concerned organization immediately.
- Re-use of domestic waste water needs to be encouraged. Use of water disposed off from kitchen may be encouraged for gardening which may be a step in this direction. Sale of low capacity flushing system (7 to 10 liters) in the domestic latrines should be promoted.
- Registration of drilling agencies, existing ground water abstraction structures, must be made mandatory. Seeking of permission for further construction of ground water abstraction structures should be also made mandatory so as to control exploitation and protection of ground water from over draft and quality degradation.
- Mass awareness and education to protect and conserve the precious and scarce ground water is the need of the hour.

Artificial Recharge

About 25% of annual rain fall occurring in Jaipur Urban Area i.e. about 66.7 mcm can be planned for artificial recharge of ground water through construction of suitable recharge structures which will result in restricting decline in water levels and increase in yield of wells. The area is feasible for artificial recharge to ground water as mentioned above.

JAMMU CITY, J&K

Priya Kanwar, CGWB, Jammu

INTRODUCTION

The City of Temples, Jammu, is the winter capital of J&K State and is beautifully perched on the hillock at the foothill of which flows river Tawi, often described as 'Sureyputri' in Holy Scriptures and historic books. The city derives its name from the legendry ruler Raja Jambulochan. Historians believe that Raja *Jambulochan* founded the city in the 14th century.

The city took shape by 1962 and its municipal limits extended on both banks of Tawi River. It has expanded on both the banks of river Tawi but the gilded pinnacles of several temples still add to its striking view.

GENERAL FEATURES

Area / Administrative Divisions

Jammu city is located between 74°24' and 75°18' East longitude and 32°50' and 33° 30' North latitude. Area of the city is 112 sq.km. Administratively the city is divided into 71 wards(Fig-1)

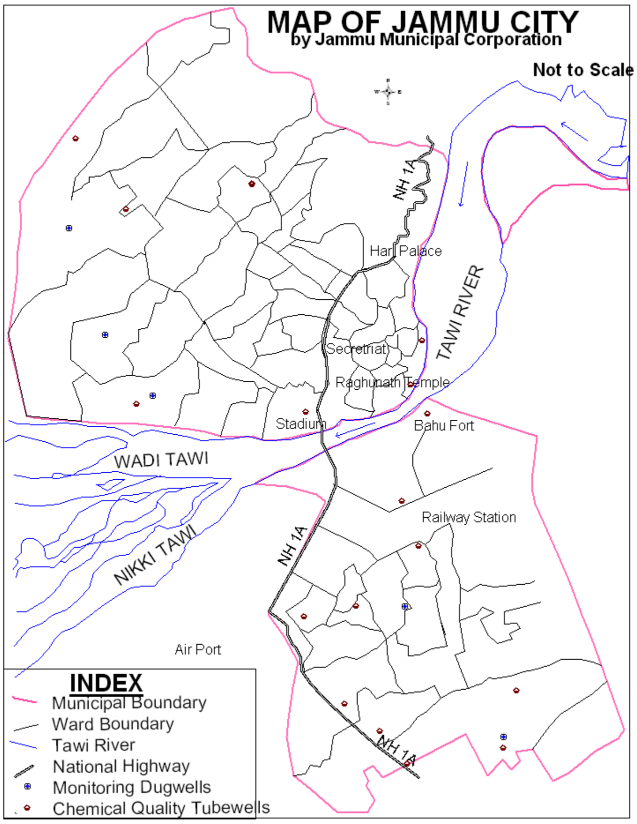


Fig. 1 Map of Jammu Municipal Corporation

Demography

As per the 2001 census, Jammu had a population of 5,71,332. Males constitute 54% of the population and females 46%. Jammu has an average literacy rate of 79%, higher than the national average of 64.5%: male literacy is 82%, and female literacy is 74%. Projected population of Jammu for the year 2011 is 14.62 lac souls and for 2021 17.83 lacs.

Hydrometerology

Jammu, like the rest of north-western India, features a humid subtropical climate, with summer temperatures reaching 41 °C, and in the winter months occasionally falling below freezing. June is the hottest month while January is the coldest month with average lows reaching 7 °C .Average annual precipitation is about 1,100 mm with the bulk of the rainfall in the months from June to October, although the winters can also be rather wet.

Physiography & Drainage

The area consists of mainly two types of geomorphic units – foothills of Siwaliks and piedmont plains. Major physiographic slope is towards the south-western direction i.e towards outer plain/ piedmont plain area. The north-western part is occupied by the hard rocks of Siwalik formation which are followed by the plains of Kandi and Siwalik formations towards south-eastern parts.

The urban area is drained basically by the Tawi River which divides the urban area in two parts. The river flows from north-west to south-east direction. Tawi river bifurcates into two different directions near the main Jammu Tawi bridge to meet again at the Makwal border. Many other seasonal khads dissects the urban area of Jammu that are on most of their parts are now occupied by the human inhabitation.

Soil Type

The soil of the city is mainly of two types a) Boulder Conglomerate mixed with hard clay; and b) alluvial soils.

STATUS OF WATER SUPPLY AND DEMAND

The present source of drinking water supply to Jammu city is partly from river Tawi and partly from ground water. Most of the water supply schemes in the city were implemented during the period from 1950s to 1970s. The water supply in the city is intermittent with 1-2 hours of supply each in the morning and evening.

Against the demand of 45.50 MGD drinking water in Jammu city, the present water supply to the city is 42.5 MGD and there is a shortage of 3 MGD. The problem of water supply has been so acute due to the depletion of surface water resources. The city relies on groundwater more than two thirds of its need.

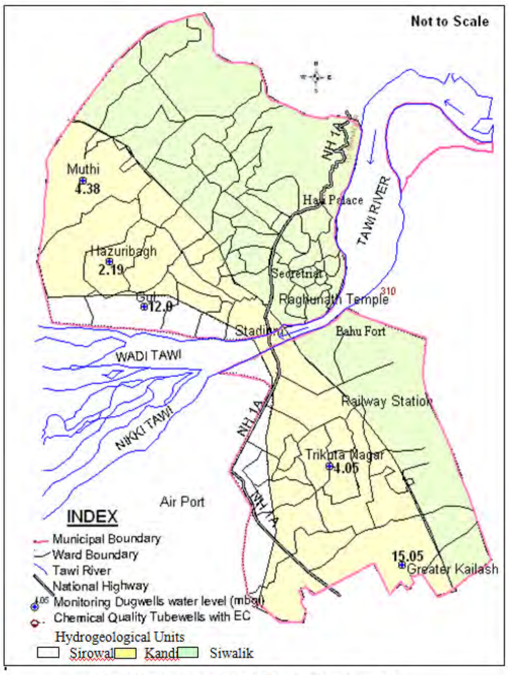


Fig. 2 Hydrogeological Map of Jammu City

WATER PROFILE

Ranbir Canal takes off from left of Chenab River, up-stream Akhnoor Bridge and passes through the Jammu city. This canal was completed in 1905. The main canal is 60 km in length and its distribution system about 400 km. The drawals in Ranbir Canal from River Chenab are restricted under Indus Water Treaty of 1960. The canal was remodeled during 1968-75. Due to loss and seepage, increased irrigated agriculture, over-aging of canal and distributaries the modernization of Ranbir Canal was proposed.

GROUND WATER SCENARIO

Potential Aquifers

Geologically, the urban area is occupied by the hard rocks of Upper Siwalik formations of Lower to Middle Pliestocene age in the north-eastern part and unconsolidated Kandi and Sirowal plains of Quaternary to Recent age in the south-western part.

The hard rock of Siwalik formation are not explored much deeper from the ground water point of view. But it occurs as small isolated bodies and in weathered and fractured portions, cracks, joints and crevices in these rocks. It manifests in the form of springs emerging out along the contacts and other structural features. The water levels in the transition area from Siwaliks to Kandi plains are about 60 m to 75 m bgl. Discharge is generally low and it varies from negligible to 600 lpm. The flow direction of groundwater is broadly form north to south and corresponds roughly with the topographic slope.

In the outer plains, Kandi and Sirowal formations the ground water occur as regional bodies. It occurs under unconfined conditions in Kandi belt and under confined conditions in Sirowal plains. The Kandi formation has steep slopes and deeper water levels ranging between 5 m and 65 m bgl and yield varies from 235 to 2574 lpm. In Sirowal formation the topographic slopes are gentle and water levels are quite shallow in the range of 10 m to 20 m bgl and discharge range between 1050 and 3785 lpm. The Hydrogeological of Jammu city has been depicted in Fig.2.

Depth to Water Level

The water levels in the plain areas of for Jammu city are measured from 5 dugwells for the month of May 2010, which is as follows in **Table-II.** The Map of Ground Water Level has been depicted in Fig.3.

SN	Location	Water Levels in May 2010 mbgl	EC (micromhos/cm)	Cl mg/l
1	Muthi	2.19	755	21
2	Nagbhani	4.38	742	71
3	Hazuribag	12.00	955	39
4	Trikuta Nagar	4.05	840	32
5	Greater Kailash	15.05	730	21

Ground Water Resources and Status of Ground Water Development

Ground water development in the district on moderate scale is restricted along the major streams and rivers. In these areas, all the major irrigation and drinking water supplies depend on the tube well and dug wells in addition to various water supply schemes based on rivers / nallas. Outer plains occupy more than 75 % of the area of the city. Ground water development on moderate scale is seen in the areas particularly in the outer plains.

So far the ground water resources of Jammu city have not been calculated separately (resources have been estimated for whole Jammu District) by CGWB. PHE has constructed about 114 tubewells in the city which has a total area of 132 sq.km.

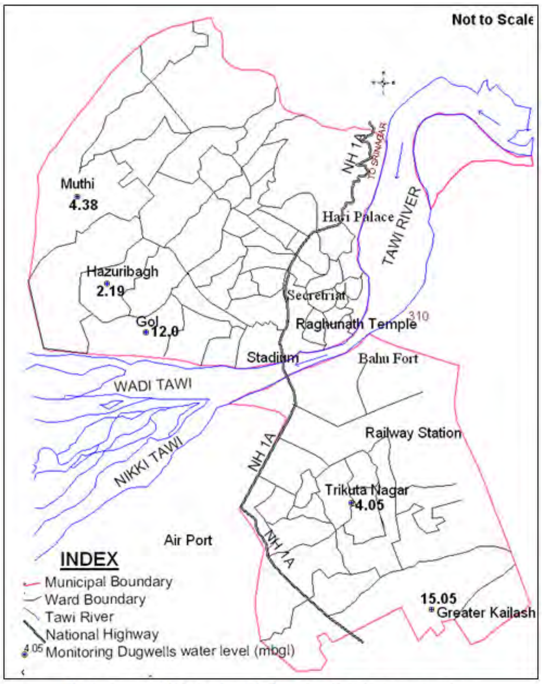


Fig.3 Ground Water Levels (spot value) in Jammu City

Hydrochemistry

The chemical quality in Jammu city is by and large fit for drinking and irrigation purposes as per Indian Standards (IS-10500-1991). Chemical analysis of water samples from sources like Dug wells and Tubewells has been taken in to consideration.

Shallow Aquifers:- Ground water quality of Jammu urban area is potable and fresh (Table-II) . Electrical conductivity ranges from 540 micro mhos /cm to 1297 micro mhos /cm. while Cl varies from 11 to 92 mg/l. pH varies from 7.10 to 7.65, mild alkaline in nature. Bicarbonate concentration ranges from 384 mg/l to 628 mg/l. Sulphate, Nitrate & Fluoride constituents are within the safe limit. Maximum concentration of nitrate, 28 mg/l is reported in water sample collected from Purkhoo. Iron concentration is also well within the maximum permissible limit (1.0mg/l). Alkaline earth metals like Ca & Mg are dominating over alkali metals. As per classification of hardness ground water is very hard.

Deeper Aquifers:- Electrical conductivity ranges from 310 micro mhos/cm to 1220 micro mhos/cm pH varies from 7.7 to 8.45 which shows that ground water is quite alkaline in nature. Chloride varies from 3.6 mg/l to 75 mg/l. Bicarbonate concentration varies from 98 mg/l to 525 mg/l. Sulphate and Nitrate concentration ranges from traces to 100 mg/l and 1.2 mg/l to 92 mg/l respectively. Fluoride concentration is also low. The concentration of Fluoride and Iron are well within the maximum permissible limit set up by BIS. Alkaline earth metals dominate over alkali metals i.e Na & K. Ground water is very hard. EC (Spot Value) of ground water from tubewells has been depicted in Fig.4.

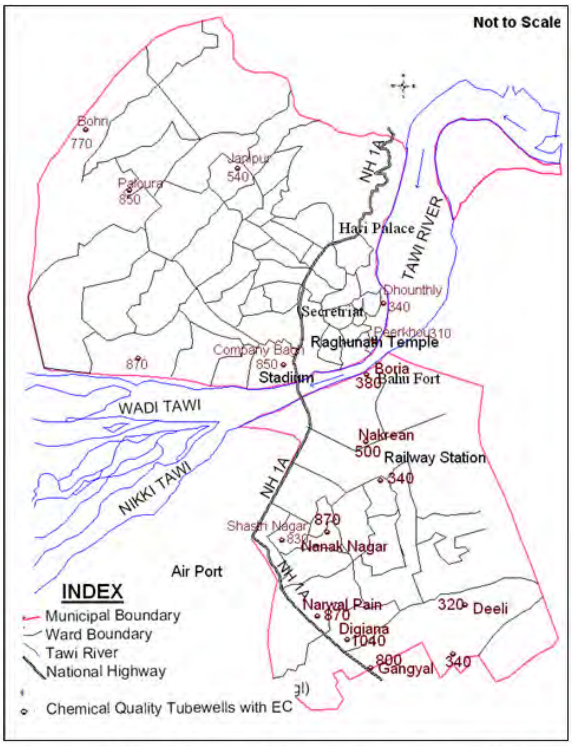


Fig. 4 EC (Spot Value) of Ground Water in Jammu City

Major Ground Water Related Problems

1. Open dugwells which could have served as monitoring wells have either been filled or covered with RCC slabs
2. Tube wells used for water supply in Urban areas are continuously running for more than 21 hrs in a day, which is ultimately putting huge stress on ground water.

3. Acute shortage of water in Kandi region
4. Occurrence of high Nitrate in the water samples from tubewells.

Feasibility of Rain Water Harvesting and Artificial Recharge

Roof top rainwater harvesting need to be adopted in urban and water scarce hilly areas and proper scientific intervention for development of groundwater is required in water scarce areas. Kandi region of the district faces acute shortage of water supply round the year because of deep water level and hard boulders in clayey matrix. To recharge and conserve the groundwater resources, de-silting and revival of *Kandi* ponds appears an effective solution

Central Ground Water Board has taken up a few pilot schemes on Artificial Recharge to groundwater in J&K State. Such schemes are completed in which roof top water is collected and recharged through recharge wells at Government College for Women, Gandhi Nagar, Air port building, Satwari and at Nirman Bhawan in Jammu city.

GROUND WATER DEVELOPMENT STRATEGY

- The Piezometeres may be constructed to monitor the behavior of ground water in multi aquifer system.
- Since there are data gaps in monitoring of depth to water levels, it is recommended to install piezometers to observe behavioral changes of water levels over a long period of time in order to know the trends.
- Rainwater harvesting in general & RTRWH in particular is an ideal solution for augmenting water resources particularly in sloppy hilly & chronic water scarce areas. There is thus need to create awareness for water conservation and augmentation and proper waste disposal for protecting water sources
- Kandi ponds / tanks / talavs must be utilized for conserving and augmenting water resources and for recharging ground water body. These structures can be de-silted, rehabilitated and renovated for harvesting water and utilized for both recharging and meeting the local needs.
- Mining of the riverbeds should be prohibited as it leads to fall in the water levels & it also damages the natural river system.
- In addition, micro level efforts are required for proper implementation of development programme.
- Over pumping of tubewells constructed by the State Government Agencies should be minimized.
- Further development of ground water by the State Government Organizations should be regulated and monitored.
- People should be made aware for proper utilization and conservation of available water resources.
- There is need of creation of ground water department in the State which can take up matters related to ground water management at the micro levels.

KOLKATA CITY, WEST BENGAL

Tarun Mishra, CGWB, Kolkata

INTRODUCTION

Kolkata is the capital of West Bengal. It is located in eastern India on the east bank of the River Hooghly. The city was a colonial city developed by the British East India Company and then the British Empire. The city was the capital of the British Indian empire till 1911. It is labelled as the "Cultural Capital of India", "The City of Processions", "The City of Palaces", and the "City of Joy". Kolkata has also been home to luminaries such as Rabindranath Tagore, Subhash Chandra Bose, Mother Teresa and Satyajit Ray. Problems related to rapid urbanisation started to plague the city from 1930s and still the city is an example of an urban hotbed of the developing nations. The state government changed the city's official name from Calcutta to Kolkata in 2001.

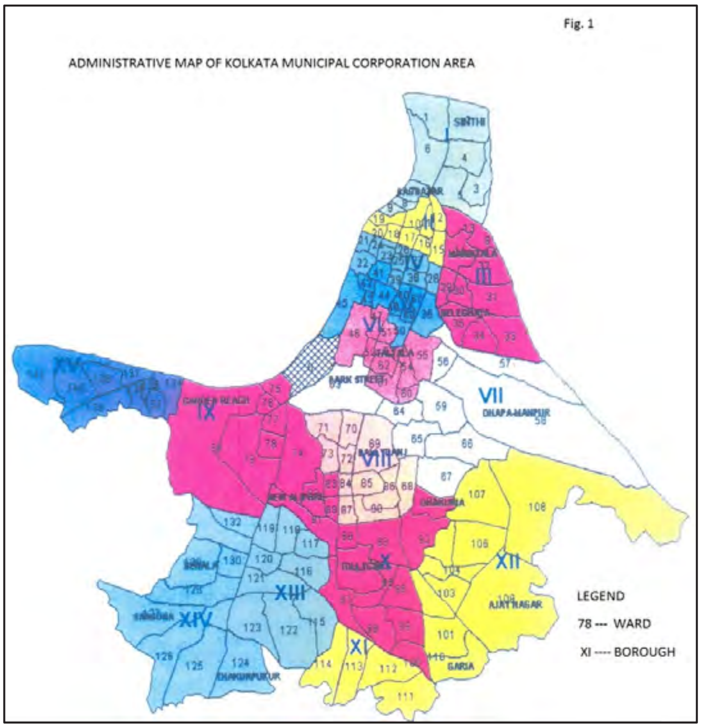


Fig. 1 Administrative map of Kolkata municipal corporation area.

GENERAL FEATURES

Kolkata municipal corporation is bounded by 22˚ 28′ 00″ N to 22˚37′ 30″ N latitudes and 88˚ 17′ 30″ E to 88˚25′ 00″ E longitudes with its Western boundary with river Ganga. The city Kolkata is the capital of the State and is well connected by rail, road & air netwok.

Area/ Administrative Divisions

The Kolkata Municipal Corporation (KMC) having an area of 187.33 sq.km. comprises of 141 wards and 15 nos. of Borough having 21 assemblies and 3 parliamentary constituencies (Fig. 1).

Demography

As per 2001 census, the KMC area has a population of 4572876 of which 54.67% are male and 45.33% are female. The population density of KMC area is 24718 per sq km as per 2001 census. As per 1901 census its population was 933754, and as per 1951 census 2698494 and it became 4572876 in 2001 census. The population density is 24718 per sq km in 2001. The growth rate of Kolkata city is 17305 populations per year. The population growth of the Kolkata city is increasing rapidly which also enhances the demand of ground water in the city and ultimately imposes stress on ground water regime in the area.

Hydrometeorology

Kolkata has a tropical wet-and-dry climate. The annual mean temperature is 26.8 °C, monthly mean temperatures ranges from 19 °C to 30 °C. Often during early summer, dusty squalls followed by spells of thunderstorm or hailstorms and heavy rains with ice sleets lash the city, bringing relief from the humid heat. These thunderstorms are convective in nature, and is locally known as *Kal baisakhi*. Rains brought by the Bay of Bengal branch of South-West monsoon lash the city between June and September and supplies the city with most of its annual rainfall of 1,582 mm. The highest rainfall occurs during the monsoon in August—306 mm (12 in). The city receives 2,528 hours of sunshine per annum, with the maximum sunlight occurring in March. Annual rainfall of KMC area is 1647 mm (2006). Normal monsoon rainfall is 1282 mm and normal non-monsoon rainfall is 365 mm.

Physiography and drainage

Kolkata forms a part of the lower deltaic plains of the Ganga-Bhagirthi river system. The area lies due east of the Hugli distributory, which takes off from the main Ganga channel at the head of the delta near Farakka as Bhagirathi. This Bhagirathi in further down- stream in the tidal stretch is called Hugli. It is a typical deltaic flat land with surface elevation ranging between 3.5 to 6.0 meter above mean sea level (amsl). Several low lying depressions in the form of marshes, shallow lakes or *jhils* occur within the city and most of these represent river scars of the post river channels of Bhagirathi. The master slope of the land is towards south. Younger levee, deltaic plain, interdistributory marsh, paleo channels and younger levee adjacent to river Hugli and older levee on both sides of the old Adi Ganga are the important geomorphological units present in the area. Due to rapid urbanization of the city the major part of the original geomorphologic units has been obscured. Most of the marshy lands have been filled up and covered with buildings. The area is drained by major Hugli river along its Northwestern boundary and by several canals like Bagjola Khal in the north and Beleiaghata and Circular Khal (canal) in the central part and Adi-Ganga (a paleo channel), and Talli nala in the southern part, which flows in the NNW-SSE direction. These khals and nalas cover a large area of the city. At present all the khals and nalas have been silted.

Soil Types

The is covered with younger alluvial soils mainly of silty and clayey loams

STATUS OF WATER SUPPLY AND DEMAND

As per extended population (48 lakhs as on 2011) water demand is 969.00 million litre per day. To overcome the disconsolate predicament multi various activities, in line with the recommendations of the Master Plan (1966-2001), so far been rendered by different Organizations within the limited financial resources have resorted this metropolis from crisis to a more or less stable condition no doubt, but there remains a huge back log requires to be wiped out on urgent basis taking into consideration the changed scenario that have taken place during the intervening period since 1966. KMC has got its twofold water source viz: (a) Surface water from the only source of river Hooghly and (b) Ground water source. Out of these two sources, the water from river Hooghly is being treated and supplied to a very limited areas of KMC through the treatment plants and infrastructures that has so far been constructed leaving the vast majority of remaining KMC to depend on the source (b) i.e. Ground water.

Table - 1 : Status of water supply in KMC area.

Kolkata: Water Supply Statistics at a Glance (As on date)	
Total daily potable water supply(in million litre)	1350
Per capita availability of water per day (in litre)	202
No. of Tube Wells Big daimeter	455
Small Diameter	7875
No. of connections Domestic	2,12,000
Industrial and Commercial	25,000
Public Access Standard Posts (in nos.)	17,019
Unfiltered water through street hydrants (in nos.)	2000
No. of reservoirs Present	7
Under construction	14
Combined capacity(in million gallon)	96

WATER PROFILE (SURFACE AND GROUND WATER)

City water supply is dependent on both surface water source from the river Hugli and ground water sources.

Surface Water Sources

Initially surface water supply was made from Palta pumping station (27mld in 1869). A quantity of 1161mld (2006) of treated surface water from river Hugli is being supplied in KMC area through four pumping stations at Palta, Garden Reach, Jorabagan and Watganj.

Ground Water Sources

As on December 2006 Kolkata Municipal Corporation owned 264 nos large dia (300mm) tube wells fitted with 20 Horse Power submersible pump with a discharge of 0.486 million litres per day and 10,000 nos small dia (40mm) tube wells fitted with hand pump with a discharge of 0.0016 million litres per day, which are operating in Kolkata Municipal Corporation area. Besides Kolkata Municipal Corporation owned tube wells, there are

5840nos of Private owned small dia (40-200mm) tube wells fitted with 1 to 12 Horse Power pump with discharge varying from 0.0189 to 0.27 million litres per day in Kolkata Municipal Corporation area. Withdrawal from Private owned tube wells and hand pump fitted tube wells works out to be 160.9 million litres per day and 16 million litres per day respectively. As per Kolkata Municipal Corporation withdrawal from Kolkata Municipal Corporation owned large dia tube wells is 128.30 million litres per day during 2006. Thus a total of 305.20 million litres per day of ground water is being withdrawn in Kolkata Municipal Corporation area. Withdrawal of ground water in Kolkata Municipal Corporation area by Kolkata Municipal Corporation increased progressively from 121.5 million litres per day in 1986 to 209.7 million litres per day in 1998 and it continued upto 2004. From 2005 Kolkata Municipal Corporation started replacing gradually the ground water supply by surface water supply. As a result there is a reduction in the quantum of ground water withdrawal from 2005. In 2006 ground water withdrawal by Kolkata Municipal Corporation owned tube wells comes down to 144.30 million litre per day million litres per day.

GROUND WATER SCENARIO

Kolkata Municipal Corporation area is occupied by Quaternary alluvial sediments, comprising alternate sequence of clay, silt and sands of various grades, gravel and occasional pebble beds, brought down by Ganga-Bhagirathi river system. Two regionally extensive clay beds are present throughout KMC area within the depth of 400 mbgl. The depth of occurrence of the basal clay varies from place to place but in general it occurs from 300 to 450 m bgl and the top clay bed (10 m to more than 60m thick) overlies the entire alluvium sequences in KMC area. Between these two clay beds occurs granular zones made up of fine to coarse sand, gravel and occasional pebble intervened by clay lenses. Thin lenses of very fine grained sand and silt in a silty clay layer occur above the top clay layer at some places around Ballyganj, Tollyganj, Tiljola, Dhakuria, Kasba, Santoshpur, Garia, Behala, Barisha and Thakurpur in the marshy/swampy lands. In the levee deposits along the bank of river Hugli lenses of fine to coarse grained sand are also present above the top clay bed at some places. The thickness of this sand bed varies from place to place. Hydrogeological map (Fig.2) depicts the aquifer conditions in KMC area.

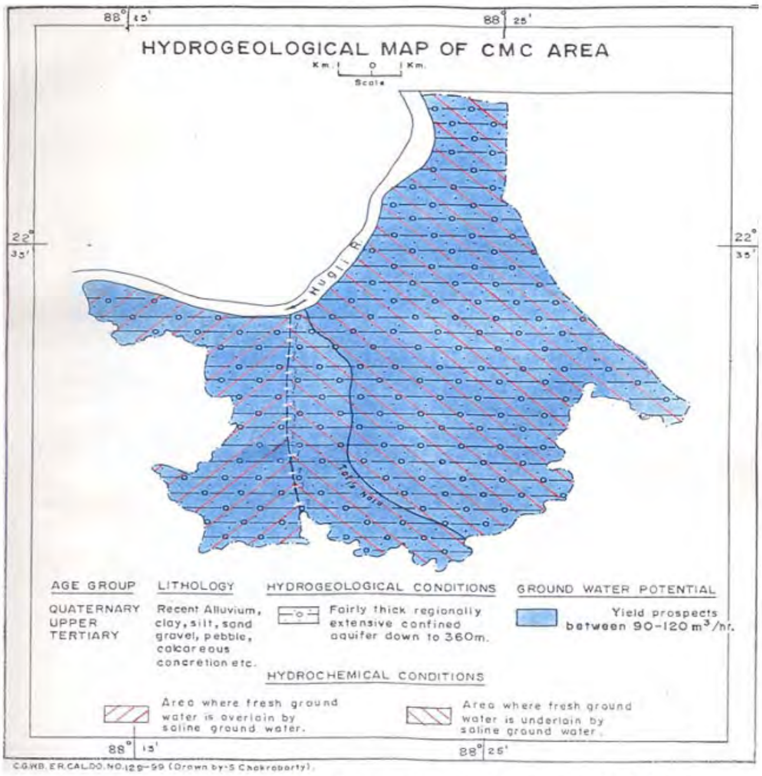


Fig.2 Hydrogeological map of Kolkata municipal corporation (earlier called CMC) area.

Potential Aquifers

The sub-surface disposition (Fig.3) of the aquifers indicates that the clay (10 to 60 m thick) at the top of the sedimentary sequence imparts confined to semi-confined condition to groundwater occurring in the aquifers below this clay blanket. The aquifers below this clay bed consist of fine to coarse sand, which are occasionally mixed with gravel. The sediments show facies variation at a few places, which is characteristic of typical deltaic deposition and the top clay bed shows a transition from aquiclude to aquitard. The thickness of the aquifer varies from place to place with the frequent occurrence of clay lens within them. The principal productive fresh water aquifer (yield = 90 to 120 m^3/hr) occurs within the depth span of 60-180 meter below ground level (mbgl) in the major part of the area except in the western part. In the western part, in Garden Reach-Barisha Sector and around Kashipur, west of Dum Dum, brackish water aquifers occur down to depth of 160 mbgl and

200 mbgl respectively from the surface. These brackish water aquifers are underlain by fresh water aquifers. In Santoshpur area in the extreme south all the aquifers within 300 m bgl are brackish. In general ground water in KMC area occurs under confined to semi-confined condition. In the levee deposit on the bank of Hugli river thin lens of shallow aquifer occur within 12 m bgl, where ground water occurs under water table condition. Ground water also occurs under unconfined condition within 17 m below ground level in the marshy/swampy lands around Ballyganj, Tollyganj, Tiljola, Dhakuria, Kasba, Santoshpur, Garia, Behala, Barisah and Thakurpukur. A number of open well are present in these areas. In general potentiality of this unconfined aquifer is low. In most cases this unconfined aquifer is hydraulically connected with the surface water bodies like ponds, unlined nalas and stagnant water in the low lying marshy lands and the open wells get a constant supply of surface water. As a result the open wells which are hydraulically connected with the surface water bodies do not dry even in the peak summer season. The surface water in these ponds, the unlined nalas and water in the low lying marshy lands in these thickly habited areas is highly polluted and hence the ground water from these open wells is not suitable for domestic uses without proper treatment.

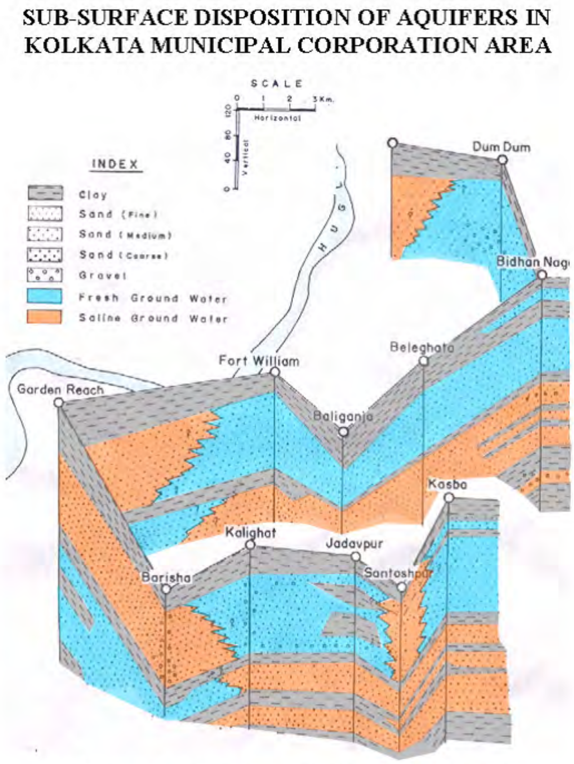


Fig. 3 Subsurface disposition of aquifers in Kolkata municipal corporation area.

Ground Water Level

The piezometric surface of the confined fresh ground water in KMC area was initially flat before the large scale development of ground water started. The flow of ground water initially followed the slope of land and movement of ground water was towards south and southeast. Withdrawal of more and more ground water in excess of replenishment has created adverse effect on ground water regime in KMC area and it is reflected in the pattern of piezometric surface(Fig.5). Premonsoon piezomertic level in KMC area varies from 13-14 mbgl (meter below ground level) to 17-18 mbgl during 2010. Postmonsoon piezometric level varies from 7-8 mbgl to 17-18 mbgl during 2010 (Fig. 4).Study of piezometric contours for KMC area for premonsoon 2004 indicates that the piezometric level is deepest (>-16 m) around Park Street forming a trough in Central Kolkata around Park Street, Rajabazar, For William etc., due to excessive withdrawal of ground water as well as due to interference effect of closely spaced tube wells running simultaneously.In post monsoon period the piezometric level comes up to <-11.5 m in the core of the trough around Park Street due to natural monsoon recharge . A comparative study for pre-monsoon piezometric level for the period from 1958

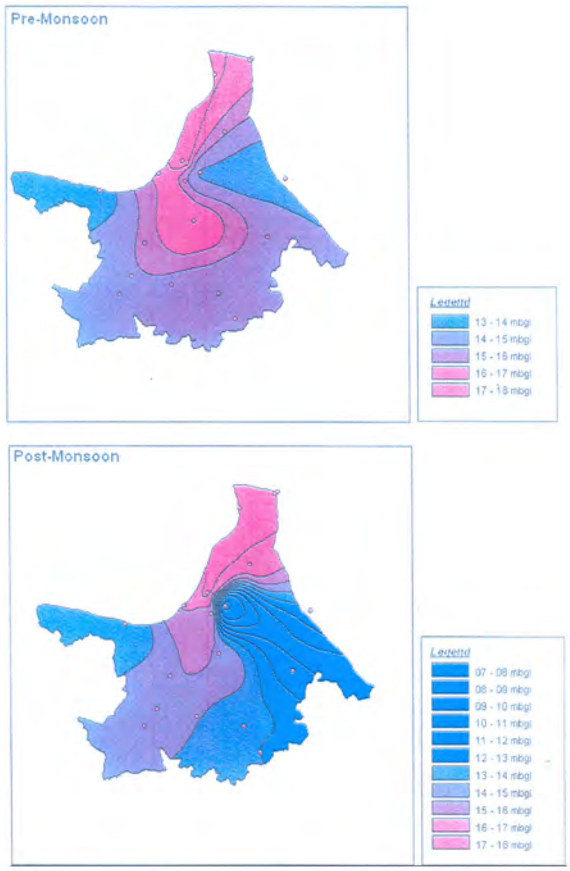


Fig. 4 Premonsoon (April, 2010) and postmonsoon (November, 2010) depth to water level map of Kolkata municipal corporation area .

to 2003 in KMC area (Fig.5) indicates that trough formed with a core of >-9 m has been expanded in area and the core has become >-16 m. This is due to excessive withdrawal of ground water from 1989 to 2003.

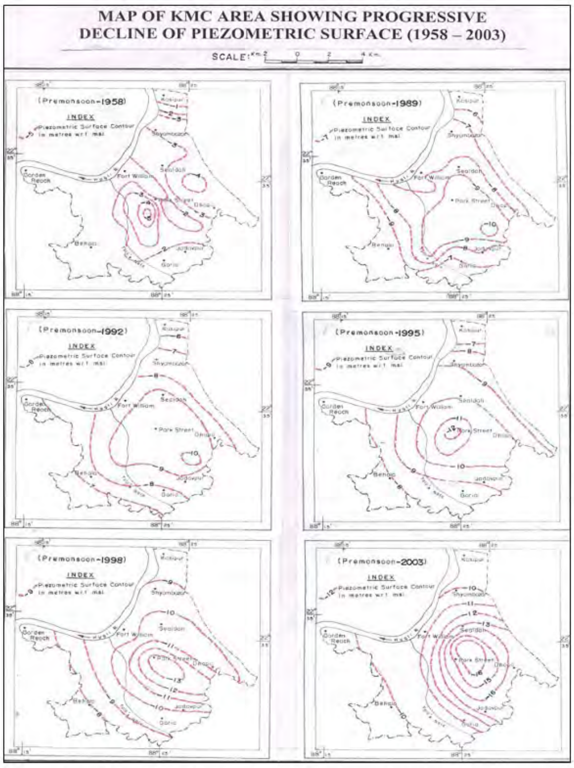


Fig. 5 Map of KMC area showing progressive decline of premonsoon piezometric surface from 1958 – 2003.

Ground Water Resources and Status of Development

Due to semi-confined to confined nature of aquifers estimation of ground water resources by water table fluctuation method could not be done. An attempt was made to evaluate the quantum of sub-surface out flow of ground water through the aquifers on the basis of **TIL**. Where **T** is the transmissivity of the aquifer, **I** is the hydraulic gradient of the ground water flow and **L** is the length of the flow path along the section. Depending upon the available data a total quantum of 204 million litres per day (45.3 million gallons per day) of ground water has been estimated by CGWB, which is entering into the central depressed zone.

Ground water in the localized water table aquifers around Ballyganj, Tollyganj, Tiljola, Dhakuria, Kasba, Santoshpur, Garia, Behala, Barisha and Thakurpukur area and in the levee deposit as discussed above has got limited yield prospects but estimation of ground water resources is not possible due to paucity of data as the aerial extension of the aquifer can not be determined due to cover by urban agglomeration.

Hydrochemistry

Ground water in KMC area may be classified under two principal types, viz. a) Bicarbonate type and (b) Chloride type. The anionic types may further be subdivided into two types on the basis of predominance of cation concentration. These are (i) Calcium-magnesium bicarbonate, (ii) Sodium bicarbonate; (iii) Calcium-Magnesium chloride; and (iv) Sodium chloride (Fig.).Ground Water in the area west of a line connecting BBD Bag, Park Street and Jadavpur is of Bicarbonate type whereas in the area east of this line ground water is of Chloride type.l

Bicarbonate type: Ca-Mg-HCO_3: Ground water in the entire Western and South-Central part of the city, south of Taltala-Kasba-Santoshpur tract in the NNW-SSE direction is of Ca-Mg-HCO_3 type. Concentration of chloride is low. In some places around New Alipur, Khidirpur, Elgin road and Harish Park etc., chloride concentration is as low as 11 mg/lt to 67 mg/lt. Sodium concentration ranges from 14 to 32 mg/lt and average total dissolved solid is 500 mg/lt.

Na-HCO_3: Ground water in the southern part of the city and particularly Behala, Tallygunj, Jadavpur and Putiari is of Na-HCO_3 type and ground water is soft with total hardness less than 150 mg/lt. The softening of ground water occurs as a result of Base Exchange of Calcium-magnesium ion with Sodium ion from Sodium montmorillonite clay.

Chloride type: Ca-Mg-Cl: Ground water in the entire Northern and eastern part of the city, north of Taltala-Kasba-Santoshpur tract in the NNW-SSE direction is of Ca-Mg-Cl type. Concentration of chloride is high (280-620 mg/lt) having more than 1000 mg/lt TDS. Ground water is hard with total hardness 460-775 mg/lt. Sodium rarely exceeds 40%. Generally high Chloride is mostly associated with sodium ions. Such unusual chemical type (Ca-Mg-Na) is caused due to ion exchange phenomenon. The sodium chloride ground water (originally existing in the aquifers in Bengal Basin) while passing through the clay complex exchanges sodium of the saline ground water for calcium-magnesium from the clay complex resulting the water of Calcium-magnesium-chloride type.

Na-Cl: Ground water rarely contains high chloride in combination with sodium in the depth range of less than 125 m bgl. At a few places in Dhakuria, Jadavpur, Garfa, Ranikuthi groundwater contains 55-69% sodium and 50-80% chloride. Occurrence of relatively high sodium-chloride in ground water in some localized pockets (Fig.6) is most likely due to entrapped condition preventing further dilution.

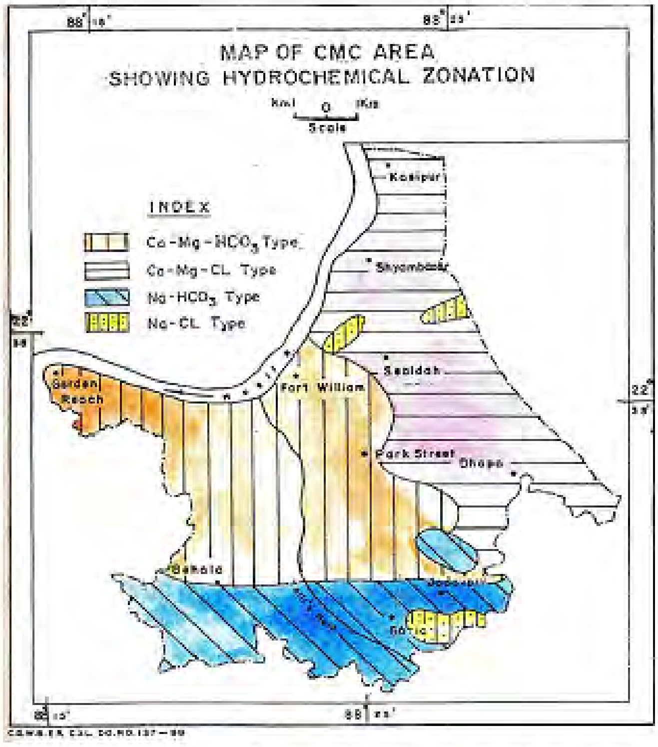


Fig. 6 Hydrochemical zonation map of Kolkata municipal corporation (earlier called CMC) area.

The total mineral contents and the chemical types gradually changes from Maidan area through Park Circus to Tangra and further south. The sequence is HCO_{3-} HCO_{3+} Cl-Cl + HCO_{3-} Cl. Ground water in the northern part extending from Kashipore-Sinthi down to BD Bag – Sealdah contains highly mineralized ground water. Similarly, highly mineralized ground water occurs between Picnic Garden and Baghajatin. Ground Water in the HCO_3 dominated area is neutral with pH value 7.0 Free CO_2 (42-200 mg/l) has been noticed in ground water present in south-western part. The quality of ground water, although being utilized for domestic, commercial and industrial uses, is considered by the users as problematic particularly in Bidhannagar to Baghajatin in the east and in the southern part, where mineralization increases depth-wise. Ground water in the southwestern part is fresh and is suitable for all purposes. The mineralization is due to relict salinity of deltaic alluvium formed at the time of deposition and simultaneous dilution/flushing of the seawater. With the process of dilution base exchange, SO_4 reduction, production of CO_2 and dissolution took place. Thus mineralized ground water is low in SO_4 high in HCO_3, Cl and Ca + Mg.

Major Ground Water Related Problems

Pollution of Ground Water: Due to the presence of the thick clay layer at the top of the sedimentary in KMC area, there is no direct ground water recharge from rainfall or surface water sources in KMC area. Therefore, the chances of ground water pollution arises from external sources (anthropogenic) in major parts of KMC area is less. However, ground water pollution has been noticed in some parts, which are as follows:

- In the eastern part of KMC area near Tangra-Topsia-Tiljala toxic trace elements like Cr, Co were found in excess of 0.01 mg/lt in the shallow aquifers within 20 m bgl, which is under semi-confined conditions. Leather industries were present in those areas. Industrial effluents from Tanneries cause serious environmental hazards due to pollution in the *Bheris*, Wetlands and Agricultural fields. Ground water here occurs under semi confined condition as a result of which polluted water from the surface finds its way to reach this shallow aquifer.
- Presence of thick clay layer does not permit these pollutants to go further below. In the deeper aquifers below 80 m bgl Cr, Co and other heavy metals are below permissible limit. Ground water tapped by open wells in Ballyganj, tollyganj, tiljola, Dhakuria, Kasba, Santoshpur, Garia, Behala, Barisha and Thakurpukur area in the marshy/swampy lands is hydraulically connected to the surface water bodies like ponds, unlined drains etc.
- Kolkata Municipal Corporation has reported the sporadic occurrence of Arsenic in ground water in excess of permissible limit (0.05 mg/lt) in some places. The concentration of arsenic varies from 0.054 mg/lt to 0.71 mg/lt .

Depletion of ground water level in KMC Area: In Kolkata Municipal Area the piezometric water level is deeper both during pre and post monsoon period. The average depth to water level ranges from14.67 to 18.63 m bgl during pre-monsoon and 12.10 to 16.08 m bgl during post monsoon period. The long-term trend analysis for the existing hydrograph network stations have also indicated the lowering of water level at the rate of 30 cm/yr during pre-monsoon and 45 cm/yr during post-monsoon period. Consequent to the significant fall in Piezometric level especially in central and south central part of Kolkata, ground water trough has been formed with the piezometric surface resting at 12 m a msl spread over an area of nearly 60 sq.kms in pre-monsoon 1989, 90 sq. kms in 1998 and 100 sq kms in 2004 (Fig.5). These can be explained by the increase in ground water draFt due to domestic use in consequence to the rapid growth of population and urbanization in the KMC Area. As a result the ground water flow direction has been changed and original southern flow direction has been reversal and flow of ground water became radial towards the central part of the trough. The components of Surface and Ground water utilized for KMC area from 1986 to 2003 has been presented in Table -5.

Table – 5: Yearwise Ground Water and Surface Water Supply in KMC Area

Year	**Surface Water Supply in KLD (approx)**			**No. of DTW**	**No. of STW**	**GW Supply in KLD (Approx)**	**Total Supply of Water in KLD (approx.)**
	Palta	**Garden Reach**	**Total**				
1	**2.a**	**2.b**	**2.c**	**3**	**4**	**5**	**6**
1986	720000	157500	877500	232	5000	121500	999000
1991	720000	157500	877500	285	10500	184950	1062450
1993	720000	157500	877500	308	11877	202720	1080220
1998	810000	180000	990000	325	12000	209700	1199700
2000	810000	180000	990000	350	12000	210000	1200000
2001	810000	301500	1110500	380	12000	250000	1360500
2002	817000	301500	1118500	320	11000	210000	1328500
2003	817000	301500	11185000	245	10000	123100	1241600

Feasibility of Rain Water Harvesting and Artificial Recharge

Considering the hydrogeological condition in KMC area vis-à-vis the withdrawal of ground water, it is very much necessary to reduce the stress on ground water resources. In addition to increase the dependence on surface water resources of the river Hugli rainwater harvesting may be adopted, as there is a bright scope for rainwater harvesting in the area. This will reduce the stress on both ground water and surface water resources and will be able to help controlling further decline of ground water level. In 187.33 sq. km. area of KMC normal annual rainfall is 1647 mm and net annual rainwater availability is 247 million cubic meter. Therefore roof top rainwater conservation methods and artificial recharge to ground water may be adopted in central and southern parts of KMC, where ground water trough is formed due to heavy ground water withdrawal (Fig.7).

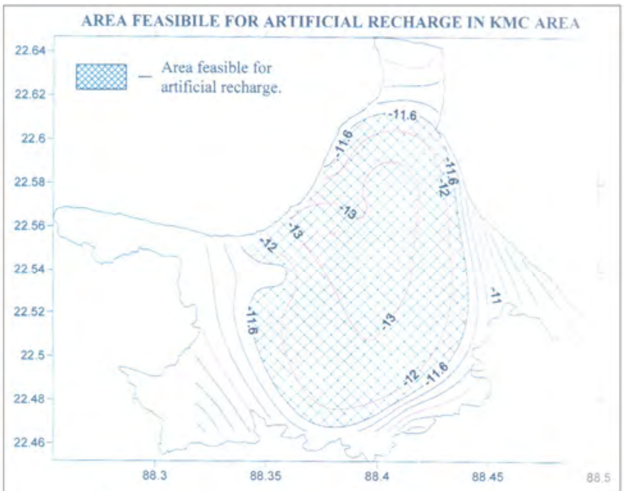


Fig. 7 Map of KMC area showing area feasible for artificial recharge.

GROUND WATER DEVELOPMENT STRATEGY

From Existing Ground Water Resources

In order to control the excessive withdrawal of ground water and the interference effect caused due to simultaneous running of closely spaced tube wells in KMC area, which are responsible for the formation of ground water trough in KMC area the following regulatory measures need to be taken.

- Further ground water exploitation is to be restricted.
- Withdrawal from existing tube wells should be regulated by phasing out tube well operation time in area where recession of piezometric level has taken place conspicuously.
- Emphasis is to be given to lower the stress on ground water development by covering more and more area under pipe water supply gradually in different phases.
- Minimum spacing between two tube wells is to be maintained to avoid the risk of interference. In case of already existing closely spaced tube wells, the adjacent tube wells should not be run simultaneously instead alternate pumping for a short period of different intervals may be adopted.
- Close monitoring system should be developed to record the piezometric levels at regular intervals of time vis a vis withdrawal of ground water from the deep tube wells.
- Presence of a thick clay layer at the surface prevents any contaminates to migrate from the surface to the underlying aquifers but the lace of proper construction of tube wells may permit the pollutants to spoil the ground water quality. Moreover, sporadic occurrence of arsenic above toxic limit has been reported in some parts of the corporation area. It is, therefore, very much necessary to assess the quality of ground water along with quantity.
- Regular monitoring of quality of ground water is to be done systematically. This will help to understand the change in ground water quality and to identify the tube wells affected by arsenic or any other chemical and/or biogenic contamination. The tube wells affected by any shot of pollution should be discarded.
- Ground water from open wells, wherever present, may be used for domestic purposes after proper treatment.

Roof Top Rainwater Conservation

Roof Top Rainwater Conservation for Individual Houses – The roof top rainwater conservation, which is simplest, may be done everywhere by all. West Bengal Pollution Control Board has constructed two such structures at Salt Lake using the roofs of Administrative building of Bidhan Nagar Municipality and College building. Use of conserved rainwater even in rainy season will save same amount of ground water from withdrawal.

Collection of Roof Top Rainwater from a Number of Buildings at a Central Place for Community Water Supply – Rainwater collected from roofs of some buildings may be stored at a centrally located reservoir for community water supply. This will save a substantial quantum of ground water from withdrawal. The conserved water may be used for both drinking and non-drinking purposes. For drinking a little treatment is required before use.

Artificial Recharge to Ground Water

Besides Central Ground Water Board, there are other State Govt. Departments and NGOs which are actively involved in implementation of artificial recharge and rain water harvesting schemes throughout the state of West Bengal. However, a definite and reliable monitoring system to test the practical efficacy of these schemes is not available at present.

In Kolkata Municipal Corporation area the presence of a thick clay layer at the top of the sedimentary sequence and the metalled and concrete pavement in the surface restrict the rainfall recharge to ground water in the area. Considering hydrogeological set up of KMC area gravity head recharge tube well using the roof top rainwater is the only recharge structure feasible. The roof top rainwater after being filtered through beds of coarse sand (1-2 mm size & 50 cm thick), gravel (2-5 mm size and 50 cm thick) and boulder (6-9 mm size & 50 cm thick) placed successively from the top in the recharge trench will enter recharge well through the slot put against the bottom filtered beds. This water will then disperse into the aquifer to be recharged through the slots put against the aquifer. The exact depth, dimension of the tube well and position of slots will be decided on the basis of the depth of aquifer to be recharged and the quantum of roof top rainwater available.

Areas feasible for Artificial Recharge: In Kolkata Municipal Corporation area, gravity head recharge tube well may be used where a huge ground water trough has been formed in Central Kolkata around Park Street, Camac Street, For William, Kalighat, Ballyganj etc., and has been demarcated in Fig.7. In Kolkata Municipal Corporation area the following precautions are to be taken in artificial recharge schemes.

- The borehole needs to be electrically logged to ascertain the exact position of the fresh water zone because of the typical hydro-chemical situation in Kolkata Municipal Corporation area.
- In KMC area the occurrence of both fresh water and brackish/saline water aquifers are not following a particular pattern. At some places the brackish/saline aquifer overlies the fresh water aquifer and at other places it underlies the freshwater aquifer. In addition to this brackish/saline water occurs laterally in the same freshwater aquifer. For artificial recharge only fresh water aquifer is to be selected.
- The upper part of the recharge tube well is to be properly sealed with cement against the clay zone to avoid any contamination from the top.
- In the area where upper zone is brackish/saline the lower fresh water zone is to be separated with proper cement sealing.
- Proper monitoring of water level is to be carried out to study the effect of recharge.
- Combination of conservation and artificial recharge will also be very successful.
- Blending of arsenic/fluoride contaminated or saline ground water with conserved rainwater will reduce the concentration of arsenic or salinity and makes this blended water fit for use.

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LUCKNOW CITY, UTTAR PRADESH

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INTRODUCTION

Lucknow is one of the major cities of Northern India named after Laxman devoted brother of legend Rama who gifted territory of Lucknow to his brother after he had conquered Sri Lanka. Lucknow is the capital city of Uttar Pradesh and it has always been a multicultural city. Courtly manners, beautiful gardens, poetry, music, and fine cuisine patronized by the Persian-loving Shia Nawabs of the city are well known amongst Indians and students of south Asian culture and history. Lucknow is popularly known as the "City of Nawabs"

GENERAL FEATURES

Area / Administrative Divisions

Lucknow city, the capital of Uttar Pradesh, lies on the banks of river Gomti and occupies an area of 340 sq km in parts of three blocks namely Sarojini Nagar, Chinhat and Kakori. It stretches over 10 kms along Gomti river on either side of the banks. The population density of 6600 persons /sq km with a high decennial growth has put on tremendous stress on ground water resources for drinking and other purposes.The salient Features of Lucknow City is given below:

1.	Geographical Area	340.00 Sq.Km
2.	Latitude	26º40' to 27 º00'
3.	Logitude	80 º 45' to 81º 05'
4.	Length of Gomati river	23.98 Km
5.	Area of Gomati river	2.16 Sq.Km
6.	Length of Kukrail Nala	17.07 Km
7.	No of Water Bodies	37
/8.	Area of Water Bodies	1.35 Sq.Km(0.39%)
9.	Area of forest in Lucknow city	20.86 Sq.Km(6.13%)

Demography

As per 2001 census the population of city area is as given in table.

Lucknow Municipal Corporation	Total	S/C	ST
Persons	2185927	220035	2320
Males	1156151	116972	1233
Females	1029776	103063	1087
Lucknow Cantonment Board			
Persons	59582	10024	91
Males	33315	517	46
Females	26267	4853	45
Total Population	**2245509**	**230059**	**2411**

It is evident from the above that total population of the city area is 22.45 lac in the year 2001 against the population of 17.31 lac in the 1991.The population increase of 5.14 lac has been recorded in the last 10 years showing growth rate of 51.4% .Projected population for 2011 will be 33.90 lacs. The alarming increase in the population of the city is putting an immense pressure on the available water resources. Thus swelling demand of water supply is attracting water planners & Managers for its critical examination.

Hydrometeorology

The climate of the city is sub-tropical with three distinct seasons viz; monsoon, summer and the winter. The normal maximum mean temperature is 40.5 ºC during May and minimum is 6.9 ºC during January.

The long term normal annual rainfall (1901 to 1970) recorded at Lucknow and is 1019 mm. The monsoon normal and annual rainfall from the same observatories is 902 mm and non-monsoon normal annual rainfall is 117mm. The area falls under sub humid climate condition and hottest month is June while the coldest is January.

Physiography and Drainage

Lucknow city occupies the interfluvial region of Gomti and Sai rivers of the Central Ganga Plain in Ganga basin. It is almost a flat country with conspicuous natural depression in north-eastern part around Jankipuram (Fig.1). The general slope of the city area is towards south and south-east. The elevation of city area varies from 110 to 124 m above mean sea level.

The drainage system of the area is controlled mainly by river Gomti which flows to south-east and Kukrail Nala is the only prominent tributary which joins on the northern bank of Gomti River. There are 23 nalas which drain into Gomati between Gaughat and Gomati Barrage. The drainage exhibits dendritic to sub- dendritic pattern and are highly sinuous in nature. Gomti river originate from the spring line in the Terai belt of Pilibhit district. It flows southeasterly over a distance of 490 km before joining the Ganga river in Ghazipur district. The catchments area of the river is 30500 sq km.

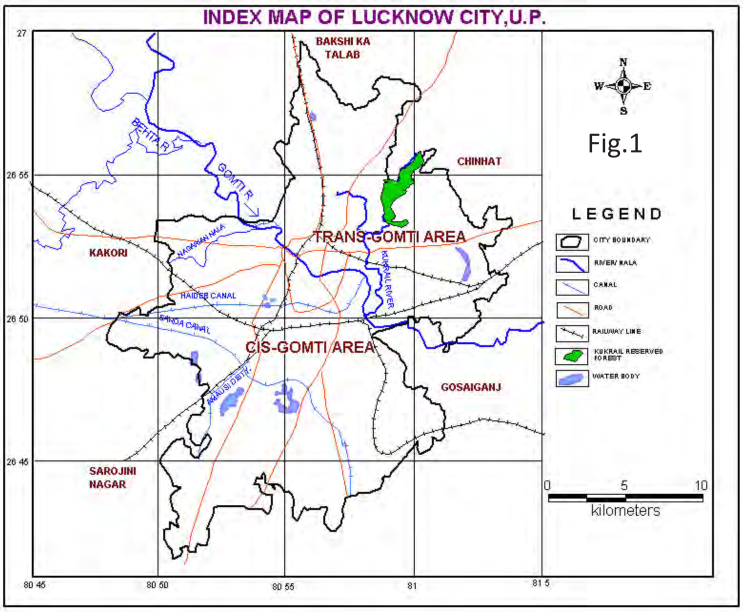


Fig.1

Soil Type

Soils of the City exhibits a wide variation in composition, texture and appearance. The major position of the city is occupied by soils locally known as "Bhur" or "Silty Sand" on the ridges. "Matiyar" or "Clay Soils" occurs along topographic lows and "Dumat or Loamy soils" in the level lands. Clay is dominant in the areas where "Reh" (Usar) prevails. Along the river valleys, a very fertile soil called "Dumat" is prevalent which is youngest.

STATUS OF WATER SUPPLY AND DEMAND

As per WHO norm of 250 lit/day/capita (lpcd) the total requirement of Lucknow city is 849.75 MLD (say 850 MLD) thus a deficit in water supply is 370 MLD approximately in the year 2011.Considering the water requirement of 150 lpcd which is being taken as a norm , the total requirement is 509.85 MLD in the year 2011 leaving behind a gap of 29.85 MLD. It is worth mentionable that there is a transmission losses during water supply which is approximately 40% and quite significant. It is suggested to control these losses to minimize the gap of requirement and water supply. However it is equally met with surface and ground water both. Ground water is exploited through 600 tubewells constructed in first aquifer group by state usar agencies as well as by private builders and colonizers.In sustaing water supply of Lucknow city, ware table is declining at the rate of 0.66m year especially in central part and in trans gomti area. As per decinal population growth of 51.4% the projected population and demand has been calculated as follows:

Future projection of demand and supply in Lucknow City

Year	Projected Population (Lacs)	Projected Demand @ 150 Lpcd	Supply (ML/D)	Gap between Demand & Supply (ML/D)
2011	33.99	509.85	480.00	29.85
2021	51.46	771.9	480.00	291.9

WATER PROFILE

Surface Water

The present supply from surface water is met through river Gomati through its water works at Aishbagh and Balagunj. Lucknow Jal Sansthan supplies the water supply to Lucknow city. Another water works is under construction stage at Gomti Nagar . The water works will get water from Sharda canal which will benefit the residence of Gomti Nagar and trans –gomti area.At present 30 lacs people are benefited by Jal Santhan supply. The present Supply through Jal Sansthan is as follows:

1. Supply through Aishbagh Water works-172 MLD
2. Supply through Balagunj water Works -70 MLD.

Total Surface Water Supply - **242 MLD**

Ground Water

Ground water supply is met through deep ,shallow tubewells, Indiamark II Handpumps & Indara wells through Jal Sansthan as follows:

1. Supply through more than 350 tubewells. 185 MLD.
2. Supply through 5000 india Mark II Handpumps. 25 MLD.
3. Supply through 55 Indara wells.- 28 MLD.

Total Ground water supply- 238 MLD.

Thus the total supply at present is 480 MLD, out of which surface contributes 242 MLD.and Ground water contributes 238 MLD.

GROUND WATER SCENARIO

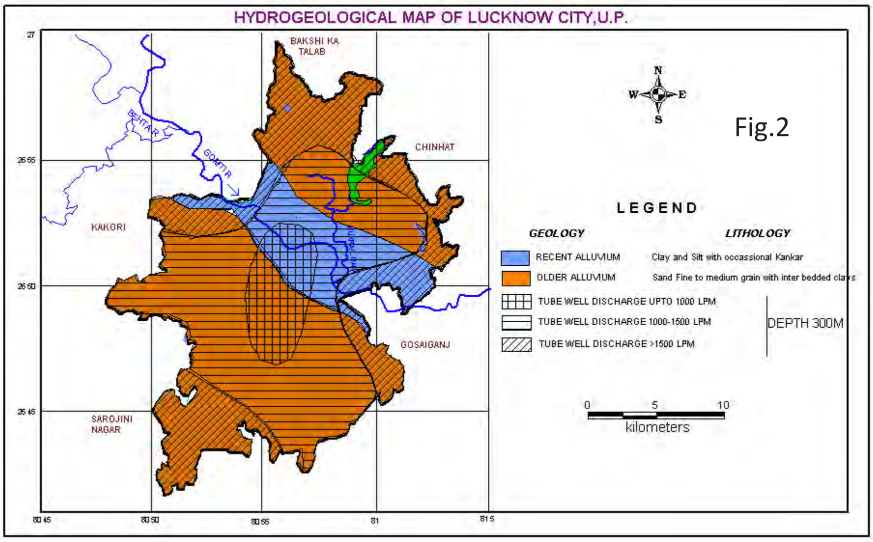


Fig.2

Area of Lucknow city forms a part of central Ganga plains and is piled up of alluvial sediments of Quaternary age and can be classified as Newer and Older Alluvium. The Newer alluvium occurs in the active flood plains of river Gomti at topographic low areas. The sediments in the Newer Alluvium are generally micaceous grey sands, silt and clay belonging to Upper Pleistocene to Recent age group. The Older Alluviums occur at topographic high areas & do not get flooded. The sediments in Older Alluvium are generally sand of various grades, clays, kankar, and silt. Alternate beds of sand and clay occur with intermixing of kankar bed. These sediments belong to upper to middle Pleistocene age. Ground water occurs in the pore spaces of unconsolidated alluvial sediments in the zone of saturation under phreatic and semi-confined conditions. In deeper aquifers it occurs under semi-confined to confined conditions.

Potential Aquifers

To know the aquifer geometry of the district Central Ground Water Board has carried out extensive exploration down to depth of 750 m bgl. A total number of 31 exploratory wells, 5 Piezometres have been constructed (Fig.2)

Aquifer group		
S. No.	**Aquifer Group**	**Depth range (mbgl)**
1.	First Aquifer Group	00.00-150.00
2.	Second Aquifer Group	160.00-240.00
3.	Third Aquifer Group	260.00-370.00
4.	Fourth Aquifer Group	380.00-480.00
5.	Fifth Aquifer Group	483.00-680.00

The hydrological properties (hydraulic conductivity, transmissivity, storage coefficient and specific capacity etc.) of each and individual aquifer group and cumulative aquifer groups has been determined by conducting hydrological tests on these tubewells. On the basis of lithological logs, electrical logs and linear cross sections and fence diagram it has been established that five tier aquifer system exist in the Lucknow City which is as follows. The aquifer material in these groups is sands of various grades, clays, kankar and silts.

The hydrogeological details of the tube wells constructed in different aquifer groups are given in the following tables:

Hydrogeological details of tubewells of Lucknow

Aquifer Group	Depth Range of aquifer group in m bgl	Water Level (m bgl)	Discharge Range (lpm)	Draw-Down Range (m)	Specific Capacity (lpm/m)	Transmissivity (T) (m^2/day)	Hydraulic Conductivity (K) (m/day)	Storativity (S)	Quality
1	2	3	4	5	6	7	8	9	10
I	00.00-150.00	20-26	1100-1700	4-10	150-325	250-1050	1.8-7.6	$4.2x10^{-4}$	Good
II	160.00-240.00	17-27	300-600	23-31	13-19	40-70	1.2-1.7		Inferior to Ist Aquifer
III	260.00-370.00	20-22	1000-1500	25-33	40-50	140-160	3.0-4.0		Good
IV	380.00-480.00	10-13	1400-1600	18-33	40-100	140-280	2.0-3.0	$3.65x10^{-5}$	Good
V	483.00-680.00	11-12	-	-	-	-	-		Good
I+II	00.00-250.00	15-30	1100-1600	4-10	130-320	160-670	1.4-5.6		Good
I+II+III	00.00-300.00	20-35	700-1600	7-33	50-250	100-700	1.0-5.6		Good
III+IV	300.00-474.00	8.00	2300	24	96	306	2.04	$4.8x10^{-4}$	Fresh

The Location of Exploratory wells and Piezometers constructed by CGWB in Lucknow city has been depicted in Fig.3. Based on the exploration carried out by CGWB it is inferred that maximum discharge of 1100-1700 lpm can be obtained from the First aquifer group at moderate draw down and the quality formation water is fresh and potable (Fig. 4). The formation in the Second aquifer group is silty and discharge of 300-600 lpm can be obtained at higher draw down, moreover quality of this aquifer group is inferior to other aquifer groups. The third and fourth aquifer groups have a yield potential of 1000-1600 lpm at moderately high draw down with potable water quality. The fifth aquifer group below 483 m has been tapped along with other group of aquifers and has resulted a free flow discharge of 200 lpm at Lucknow University with the piezometeric head of 0.70 m. above ground level.

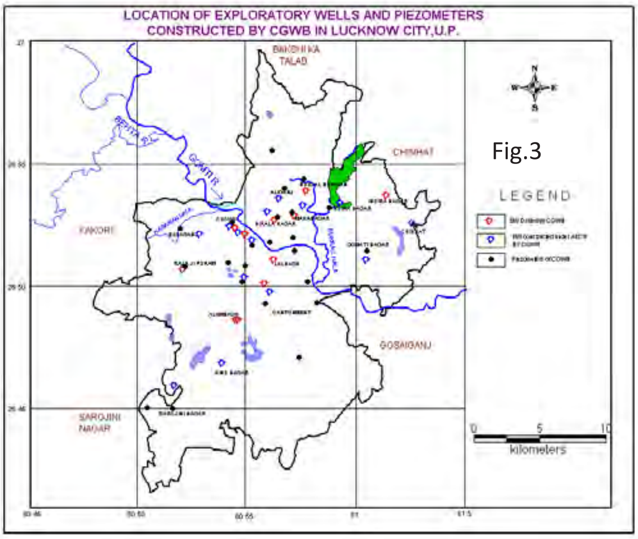


Fig.3

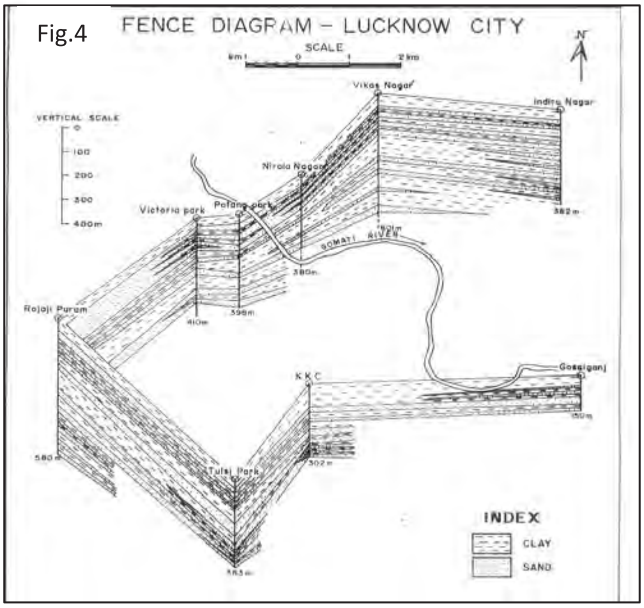


Fig.4

On perusal of the above table the occurrence of ground water is quite encouraging in northern and north eastern part of the city in Janakipuram, along Kursi Road and Chinhat. Moderate yield potential lies in the north west and western part of the city. To augment the demand of the future mega city, all ground water abstractions should be done from Trans–Gomti area in the north and north east and beyond Sarojani Nagar. Further flood plains of Gomati river can be exploited by constructing shallow tubewells ,radial wells, collector wells, rainy wells. These structures may be taken up in the up stream of Gaughat.

Ground Water Level

Depth to water in Lucknow city is being monitored monthly by CGWB through 19 piezometers since 2003. The summarized comparative data of is given in the following tables.

Pre-Monsoon Water Level and Trend: The Pre-Monsoon Water level in 2003 & 2010 and trend of Water Level is summarized below-

Cis Gomti Area

Sl. No.	Location	Pre-monsoon Depth to Water Level (mbgl)		Pre-monsoon Trend (2003 to 2010) (m/year)
		May'2003	May'2010	
1	River Bank Colony	19.63	23.07	Fall- 0.52
2	Sarojini Nagar	10.07	11.85	Fall-0.41
3	MahilaCollege,Aminabad	13.00	14.55(2009)	Fall-0.50
4	Dilkusha	29.60	32.62	Fall-0.44
5	Narhi	27.05	33.12	Fall-0.94
6	Arya Nagar	20.13	19.73	Rise-0.09
7	Campbell Road	14.17	10.00	Rise-0.26
8	Gulistan colony	28.82	33.15	Fall-0.64
9	Rajaji Puram	25.55	29.20	Fall-0.52
10	Cantt	17.99	22.45(2009)	Fall-0.84

Trans Gomti Area

Sl. No.	Location	Pre-monsoon Depth to Water Level (mbgl)		Pre-monsoon Trend (2003 to 2010) (m/year)
		May'2003	May'2010	
1	BhujalBhawan, Aliganj	16.06	19.20	Fall-0.47
2	New Hyderabad	19.21	24.37	Fall-0.80
3	L.U. New Campus	11.17	12.95	Fall-0.33
4	L.U. Old Campus	24.95	29.51	Fall-0.68
5	Vikas Nagar	22.06	27.75	Fall-0.86
6	Mahanagar-H Park	24.05	28.66	Fall-0.75
7	Gomti Nagar	15.47	21.55(2007)	Fall-1.69*
8	Indira Nagar	21.49	26.13(2007	Fall-1.11*
9	Nirala Nagar	26.30	29.55(2007)	Fall-0.79*

* Period of trend 2003 to 2007

It is found that out of 10 piezometers in Cis-Gomti area, 8 have shown a falling trend in pre-monsoon period for the period 2003 to 2010. The minimum fall is observed at Sarojininagar-0.41 m/year and maximum at Narhi-0.94 m/year. The rising trend is seen at Arya Nagar and Campbell road where the extraction of Ground water is minimum. It is found that all piezometers in Trans-Gomti area show a falling trend in Pre-monsoon period. The minimum fall is observed at Lakhnow University New Campus-0.33 m/year and maximum at Gomti nagar-1.69 m/year. Depth to water level of pre-monsoon season is given in Fig. 5.

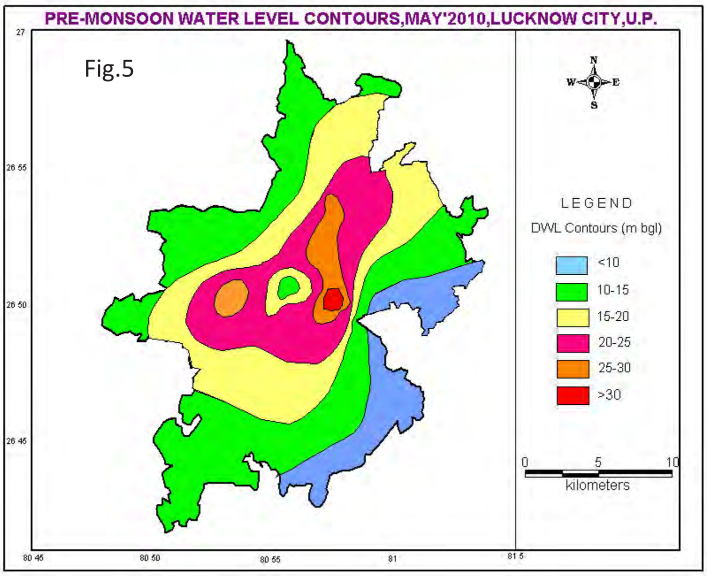
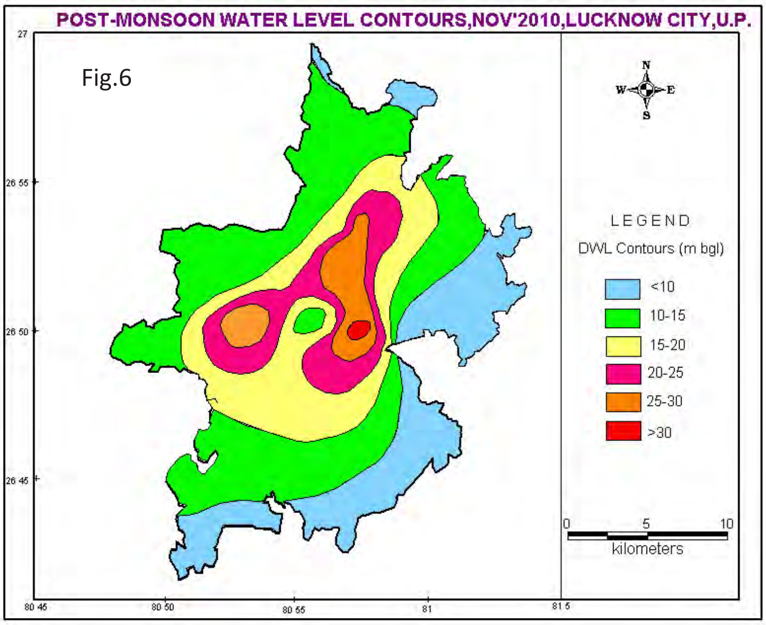


Fig.5

Post-Monsoon Water Level and Trend

The Post-monsoon water level in 2003 and 2010 and trend of water level is summarized in Table below. It is found that out of 10 piezometers in Cis-Gomti area 8 have shown a falling trend in Post-monsoon period. The minimum fall is observed at Sarojininagar-0.14 m/year and maximum at Narhi-1.07 m/year. The rising trend is seen at Arya Nagar and Campbell road. It is found that all piezometers in Trans-Gomti area show a falling trend in Post-monsoon period. The minimum fall is observed at Bhujal Bhawan, Aliganj- 0.44 m/year and maximum at Gomti Nagar.



The water elevation map of Lucknow city (Fig. 6) shows two conspicuous ground water troughs in the city area, one located in the Cantonment, Charbagh and Narhi in Cis – Gomti and the other one in the Trans-Gomti area covering Nirala Nagar, Vikas Nagar, Indira Nagar and Gomti Nagar. These troughs indicate heavy withdrawal of ground water. Even the River Gomti becomes influent in the central part due to heavy withdrawal of ground water through various tubewells located in this area.

Cis Gomti Area

Sl. No.	Location	Post-monsoon Depth to Water Level (mbgl)		Post-monsoon Trend (2003 to 2010) (m/year)
		Nov'2003	Nov'2010	
1	River Bank Colony	18.78	22.40	Fall-0.37
2	Sarojini Nagar	8.40	10.50	Fall-0.14
3	MahilaCollege,Aminabad	11.58	12.87(2008)	Fall-0.33
4	Dilkusha	28.20	29.85	Fall-0.26
5	Narhi	27.25	33.70	Fall-1.07
6	Arya Nagar	19.33	18.85	Rise-0.17
7	Campbell Road	12.05	10.40	Rise-0.08
8	Gulistan colony	28.40	33.40	Fall-0.73
9	Rajaji Puram	24.99	29.82	Fall-0.46
10	Cantt	18.19	23.95	Fall-0.78

Trans- Gomti Area

Sl.No.	Location	Post-monsoon Depth to Water Level (mbgl)		Post-monsoon Trend (2003 to 2010) (m/year)
		Nov'2003	Nov'2010	
1	Bhujal Bhawan, Ailganj	16.33	19.55	Fall-0.44
2	New Hyderabad	18.25	24.97	Fall-0.78
3	L.U. New Campus	8.55	13.10	Fall-0.49
4	L.U. Old Campus	23.75	28.73	Fall-0.67
5	Vikas Nagar	21.30	27.56	Fall-0.73
6	Mahanagar-H Park	23.90(2004)	29.06	Fall-0.77
7	Gomti Nagar	10.00	19.65(2006)	Fall*
8	Indira Nagar	21.80	24.20(2006)	Fall-0.93*
9	Nirala Nagar	26.80	29.05(2006)	Fall-0.75*

** Period of trend : 2003 to 2006

Ground Water Resources and Status of Development

The dynamic ground water resources as on 31.3.2009 is as follows:

Dynamic ground water resource as on 31.3.2009

Sl. No.	Assessment Units – Blocks	Annual Ground Water Recharge (in ham)	Net Annual Ground Water Availability (in ham)	Existing Gross Ground Water Draft for all Uses (in ham)	Net Ground Water Availability for Future Irrigation Development (in ham)	Stage of Ground Water Development (in %)	Category of Block
1	2	3	4	5	6	7	8
1	Kakori	6056.87	5451.8	352.46	1589.23	66.56	Safe
2.	Chinhat	3489.30	3140.37	2749.70	201.68	87.56	Safe
3	Sarojani Nagar	9869.05	9375.60	5782.08	3370.16	61.67	Safe

Hydrochemistry

The chemical quality of water is an important parameter and its suitability for public water supply needs to be ascertained. To study the water quality and to know the impact of faster growth of urbanization in Lucknow city area, 50 numbers of ground water samples from shallow and deeper aquifers were considered and chemical analysis data were compiled for their basic parameters such as- pH, electrical conductivity, carbonate, bicarbonate, chloride, nitrate, sulphate, fluoride, phosphate, calcium, magnesium, total hardness, sodium, potassium, and silica. 8 numbers of samples were also collected at different sites of river Gomti.

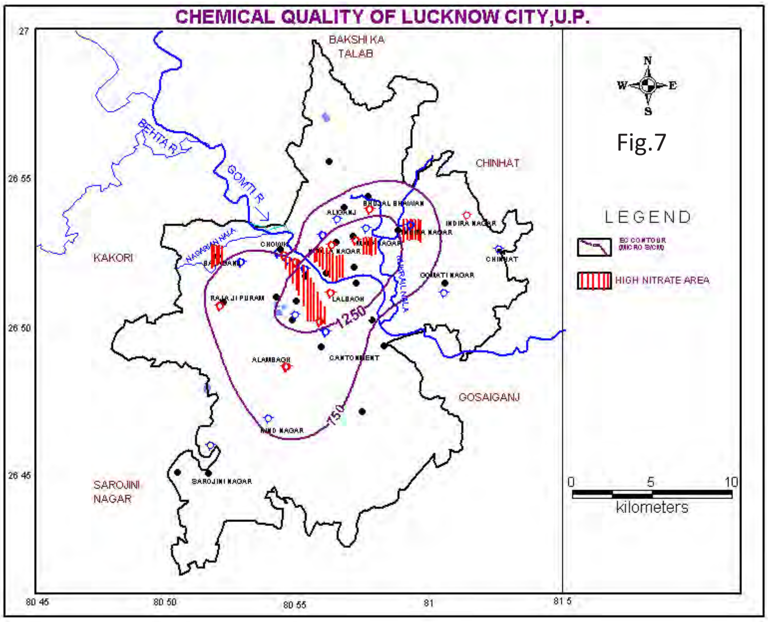


Fig.7

Chemical Quality of Surface Water: It has been observed that all the constituents present in the river water samples are within permissible limit before the river enters the Lucknow city and as it passes through the city the quality of river water deteriorates due to the mixing of several city drains specially near Mohan Meakins disposal drains and Haider Canal (Gomti barrage). The Dissolved Oxygen content decreases from 7.0 mg/l from outskirt to 2.0 near Mohan Meakins disposal drains and Haider Canal. There are few Dhobi ghats and cloth dyeing units at the bank of river Gomti, which are also polluting the river water.

Chemical Quality of Ground Water : The chemical analysis data of the ground water samples reveals that most of the chemical parameters are well with in permissible limits of Bureau of Indian Standards (BIS). The various chemical characteristics of ground water samples in Lucknow city have been summarized in the table & also given in Fig.7. In central part of the city area near IT college, Nirala nagar, Mahanagar, part of Indira nagar, Aminabad and Arya nagar area, electrical conductivity value ranges from 1250 to 1500 µS/cm at 25 ^{0} C .In other areas the electrical conductivity value ranges between 750 and 1250 µS/cm at 25 ^{0} C. In outskirts of the city the electrical conductivity values have been observed to be below 750 µS/cm. the pH values ranges from 7.35 to 8.4 in the city. The nitrate concentration more than permissible limit of 45 mg/l has been found in 12% of samples specially at Nirala nagar, Compell road, Aminabad, Indiranagar, Mahanagar, Chowk and Buland bagh areas .The maximum value of 244 mg/l of nitrate has been observed at Buland bagh. High nitrate concentration in ground water is a matter of concern and is mainly due to disposal of domestic and untreated sewage through open and unlined drains and wrong landfill sites on permeable formations, thereby polluting the ground water system. Chemical character of groundwater is given below:

Chemical Characteristics of Ground Water samples in Lucknow city

Sl No	Parameters	No. of samples	B. I.S.; IS:10500		Values Observed	
			Desirable limit	Permissible limit	Min.	Max.
1	pH	50	6.5	8.5	7.35	8.4
2	Alkalinity; mg/l	50	200	600	171	659
3	Chloride; mg/l	50	250	1000	7	213
4	Nitrate; mg/l	50	45	45	nil	244
5	Sulphate; mg/l	50	200	400	nil	165
6	Fluoride; mg/l	50	1	1.5	nil	1.66
7	Phosphate; mg/l	33	-	-	nil	nil
8	Calcium; mg/l	50	75	200	8	96
9	Magnesium; mg/l	50	30	100	2.4	141
10	T.H.as CaCO3; mg/l	50	300	600	30	600
11	Sodium; mg/l	50	-	-	9	276
12	Potassium; mg/l	50	-	-	1	32
13	Silica; mg/l	17	-	-	15	27
14	Iron; mg/l	3	0.3	1	0.25	1.9
15	E.C.µS/cm	50	835	3300	325	1507

Fluoride concentration of more than permissible limit of 1.5 mg/l has been observed in Tulsi park (1.59 mg/l), and at Lucknow University campus (1.66 mg/l). in deeper aquifers in the tubewells below 370 m and form the fourth aquifer system group, which further indicates that the high fluoride in this area are may be due to the minerals assemblage in the of the geological formations belonging to Siwaliks. High iron content (up to 1.9 mg/l) has also been observed in few cases. The other constituents are mostly well with in permissible limits and hence suitable for domestic and drinking purpose.

Major Ground Water Related Problems

Lowering of Water Level : There is heavy demand of ground water to cater the needs of domestic and industrial sectors due to which almost all parts of the city area are facing this problem both during Pre-monsoon and Post-monsoon periods. The fall in water level ranges from 0.33 to 1.69 m/year in Pre-monsoon period and from 0.14 to more than 1.50 m/year in Post-monsoon period. Three is heavy withdrawal of ground water in the Cantonment, Charbagh and Narhi in Cis – Gomti and Nirala Nagar, Vikas Nagar, Indira Nagar , Gomti Nagar.in the Trans-Gomti area. Even the River Gomti becomes influent in the central part due to heavy withdrawal of ground water through various tubewells located in this area.

Stressed Aquifer : Since last two decades, the city is witnessing widespread exploitation of groundwater. The top Aquifer Group (< 150 mbgl) of the city is presently under high stress. The granular zone of this dynamic aquifer is gradually drying up, causing almost irreversible damage to groundwater domain of this capital city of the state. The trend of groundwater exploitation of First aquifer group in Lucknow shows continuous rise in resource withdrawals. Private tube well construction activity in the city (Table) has almost mushroomed, causing intensive and unregulated extractions, which is yet to be assessed.

No. of groundwater structures	
Jal Sansthan Tubewells	More than 350
Handpumps (Public)	>6000
Mini tube wells/Borings	300-400
Tube wells : Government /Private establishments	>150
Tube wells : Private colonies/multi story buildings	>400
Private domestic borings	Innumerable (no inventory)
Tentative withdrawals	550 MLD or even more

It is evident from the above table and water level data of Lucknow city the over exploitation of first aquifer is continued and water level is declining at different rates and pace in different localities. the average rate of decline is 0.66m /year in the city area. Since the shallow aquifer is overexploited ,search may be made for deeper aquifers in North & North –East part of the city particularly in Trans Gomti area for future development.

Changes in Land-use Pattern in Lucknow City				
Sl. No.	**Land use type**	**Land use in % per cent**		
		1965	**1987**	**2001**
1.	Residential	29.29	48.91	67.20
2.	Commercial	1.85	2.43	4.10
3.	Industrial	3.31	6.50	3.10
4.	Industrial Public/semi-public	16.86	15.02	8.20
5.	Transport	13.69	10.38	9.50
6.	Recreational	4.0	3.78	7.90
7.	Vacant and water body	31.0	12.98	-
	Total	100	100	100
(Source-Master plan-2021)				

Retarding Ground Water Recharge : The city population which was 256239 in year 1901 with a growth rate of 18.97% in the last decade reached upto 2245509 in year 2001.The table clearly indicates the increase in residential area and decrease in open space and water body areas in Lucknow.

Increase in Surface Runoff : Less infiltration of precipitated water causes increase in surface run-off from the city area. The city area which was 145.94 sq. km. in year 1981 grown to 340sq. km. in recent time and it is increasing day by day. The Population density at present is 6600 persons per sq. km.which is directly proportional to. building density. An increase in building density will increase the surface- runoff since paved and cemented area will increase.

Ground Water Quality Problem : Ground water quality reveals that the central part of the city area near IT college ,Nirala Nagar, Maha Nagar,Aminabad and part of Indira Nagar affected by higher concentration of TDS, Cl , SO4 ,Fl .NO3 & PO4. The high concentration of NO3 & PO4 indicates pollution due to anthropogenic activity and unlined sewerage system. However now the Government is laying down deep sewerage line in the city. This may improve the ground water quality in near future or atleast this will stop further deterioration of Ground water quality.

Feasibility of Rain water Harvesting & Artificial Recharge

Roof top Rain water Harvesting and Artificial Recharge to ground water in Lucknow City are feasible in the following:

Institutional buildings : Roof top rain water harvesting and artificial recharge to ground water should be taken up in UP State Govt. Buildings such as Pariyavaran Nideshalaya, RTO, Transport nagar, DGM building, UP Bhoomi Sudhar Nigam building, Krishi Bhawan, Pikup Bhawan in the first phase.

Stadiums : The Lucknow city has number of play grounds having various sizes of stadiums such as K. D. Singh Babu, Sports College Chowk Stadium, Railway Stadium and Aliganj Stadium.

Parks/ Zoo: In order to take up rain water harvesting and artificial recharge to ground water in parks- the Aurobindo and Swarnajayanti parks should be identified and parks in the residential as well as in open areas be taken up for recharge projects. The museum building in the zoo complex can be taken up for Roof top rain water harvesting and artificial recharge to ground water. Possibilities have to be explored to harness rain water runoff in the adjoining areas of the museum building in zoo complex so as to make a comprehensive project.

Airport Complex: A scheme to harvest rain water in the Amausi Airport has been prepared by CGWB, NR office in the recent past and can be taken up.

Artificial recharge utilizing monsoon flood water in Old Sharda Canal: Possibilities to take up Artificial recharge to ground water utilizing monsoon flood water in Sharda Canal (Old) are suggested.

Artificial recharge utilizing monsoon flood water along Gomti river: Artificial recharge to ground water utilizing monsoon flood water along Gomti river is also feasible. It is proposed to construct long/ multiple lateral shaft filled with inverted filter and injection well depending upon the surplus monsoon discharge by diverting Gomti flood water.

Artificial recharge utilizing monsoon runoff in Kukrail forest area: The field investigations have revealed that the Kukrail forest is drained by Kukrail nala, having a length of 28 km. The catchment area upstream of Kukrail barrage is 192 sq.km. The suitable artificial recharge/ water harvesting structures such as check dams, nala bunds, cement plugs, gabion structures should be identified.

Artificial recharge utilizing lake water: The Lucknow city has no. of ancient surface water bodies such as Moti jheel, Aishbagh, Tikaitrai jheel, jheel near Husain marg, jheel behind B-Block Indira Nagar that can be considered for artificial recharge to ground water.

GROUND WATER DEVELOPMENT STRATEGY

Rapid change in demography and technological advancements together has led to unplanned and indiscriminate growth of urban settlements which, in turn, has created escalating demand for drinking water causing excessive stress on ground water resources. Since surface water sources are inadequate to meet the rising demand of drinking water in Lucknow city, Groundwater has gradually become the main contributor to water supplies and hence, there is tremendous pressure on groundwater resources to fulfill the drinking water requirements. Following development strategies are suggested to be adopted

1. Withdrawals from Stressed Aquifers should be strictly regulated & minimized. Excessive withdrawals from top aquifers should be effectively regulated through a suitable legislative provision.
2. The peri-urban regions of urban agglomerates of Lucknow, prolific aquifers can be systematically exploited to supplement city's water supply. New tube wells for water supply should be avoided in the first aquifer system.
3. An action-oriented policy for rehabilitation and maintenance of existing ponds/ tanks is needed so that they may continue to augment groundwater in future also.
4. Abandoned channels, Ox-bow lakes old-brick-kilns, ravines and excavations should be converted into rain water conservation tanks instead of garbage dumping ground.
5. Domestic waste water from ever-increasing number of hotels, restaurants, commercial complexes due to growing urbanization should be recycled and reused after making it utilizable through natural filtration processes. The recycle and reuse of utilizable waste water should be made mandatory on part of all commercial complexes.
6. Long term comprehensive urban ground water management plans (City Master plan) with regulatory provisions should be prepared for effective Integrated Water Resource Management envisaging interventions for a more harmonized conjunctive use of surface and groundwater.
7. River bed filtrate method is efficient and economical to cater the need of growing urban areas. Lucknow city is located on the River Gomti and there is a fair possibility of harvesting large volume of water through river bed filter techniques. There is a thick and continuous aquifer of over 150 m along the river Gomti covering about 20 sq Km in the west and North west of the Gaughat of the old city area. Tube wells tapping the aquifers in this area will be charged through induced recharge from the Gomti river. Individual well is expected to yield about 200 cubic m / hour with the normal draw down of less than 6 m . Battery of such tube wells can provide over 100 mld of water to cater the needy populace in the old city area of Lucknow.
8. Transmission losses up to 40% during water supply should be reduced to maximum extent possible. There should be a city-oriented regulation on excessive groundwater withdrawal/ misuse.
9. Proper surface drainage and sewerage systems should be developed to prevent leaching of pollutants and consequent degradation of groundwater quality. Periodic monitoring of quality is essential to plan for alternative sources of potable water considering its long term health effects. In the zero discharge toilet system the residues generated per person is about 1/5th as compared to conventional toilet system results in significant saving of fresh water.
10. The positive correlation between extent of water level decline and intensity of urban activity amply demonstrates that there should be purpose-built piezometers in urban areas for proper ground water regime monitoring so as to facilitate decision making as regard to corrective measures for sustainable development of urban area aquifers.

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MUMBAI CITY, MAHARASHTRA

Saurabh Gupta, CGWB, Pune

INTRODUCTION

Greater Mumbai is located on the western most periphery of the Maharashtra State. The city in the past (year1885) was comprised of elongated shaped group of seven islands viz., Bombay, Mazgaon, Matunga, Mahim, Worli, Soyster Rode and Old Woman's Island which over the period of time, have been connected to main land by a series of reclamation measures such as filling of narrow creeks etc.

The Mumbai city is known as financial capital of India. Due to continuous expansion of infrastructural facilities, industries, and commercial units in the city, a wide business opportunities and massive employment were generated. Many people from western Maharashtra, Konkan and other states came to Mumbai in search of employment. Therefore continuous migration has resulted in to overcrowding of the city. The ever increasing water demand of growing city is being met, mainly, by a number of water supply dams situated in the adjacent districts and areas. Whereas, the availability of ground water in the city is not found sustainable because of limited quantity as well as was of poor quality.

GENERAL FEATURES

Area and Administrative Divisions

Greater Mumbai district comprises South Salsete, Trombay and Bombay islands having a geographical area of 603 sq. km. (Mumbai City- 69 sq. km. and Mumbai Suburbs- 534 sq. km.). The district is bounded by north latitude 18°53' and 19°19' and east longitude 72°47' and 72°58'. Arabian Sea lies on the southern and western side of the district while it borders Thane district in the north and eastern side. A map of the district showing the district boundary and headquarter, physical features and location of monitoring wells is presented as Fig. 1

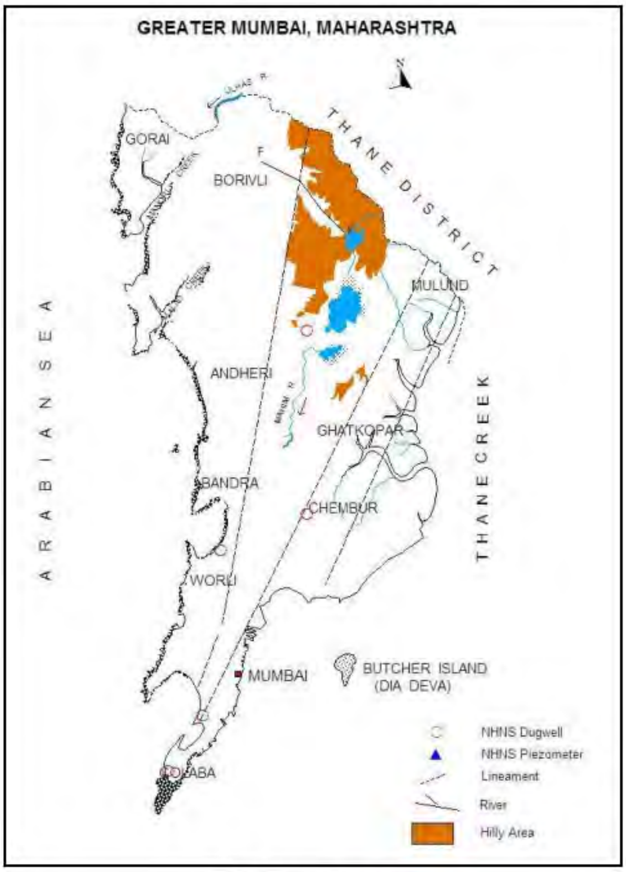

Fig. 1 Location map

Demography

The population of Greater Mumbai as per 2001 census is 11,914,398 which includes population of city 3,326,837 and its suburb 8,587,561.Mumbai city is the third most populous city in the world after Tokyo and Sao Paulo. The population of city is projected to be 20.5 million in year 2011A.D. It is observed that population is being doubled in every 20 years.

Hydrometeorology

The climate of the district is characterized by an excessive summer, dampness in the atmosphere nearly throughout the year and heavy south – west monsoon rainfall from June to September. The mean minimum temperature is 16.3°C and the mean maximum temperature is 32.2°C at Santacruze.

The average annual rainfall varies from about 1800 mm to about 2400 mm, minimum being in the central part of the district around Kurla (1805 mm) and it gradually increases towards north and reaches a maximum around Santacruze (2382 mm).

Physiography and Drainage

The broad physiographic feature of the Mumbai district is broad and flat terrain flanked by north – south trending hill ranges. The hill ranges form almost parallel ridges in the eastern and western part of the area. The Powai – Kanheri hill ranges are the other hill extending in the eastern and central part running NNE – SSW. The maximum elevation of the area is 450 m above mean sea level (m amsl) at some of the peaks of hill ranges. Trombay island has north – south running hills with maximum elevation of 300 m above man sea level (m amsl). Malbar, Colaba, Worli and Pali hills are the isolated small ridges trending north – south in the western part of the district. The Powai – Kanheri hills form the largest hilly terrain in the central part of the Salsette island and are the feeder zone for the three lakes viz., Powai, Vihar and Tulsi. There are a number of creeks, dissecting the area. Among them, Thane is the longest creek. Other major creeks are Manori, Malad and Mahim which protrudes in the main land and give rise to mud flangs and swamps.

The area is drained by Mahim, Mithi, Dahisar and Polsar rivers. These small rivers near the coast, form small rivulets which inter mingle with each other resulting in swamps and mud flats in the low lying areas.

Soil Types

Two types of soils have been observed in the district viz., medium to deep black and reddish colored soil. The deep black soils found in the area belong to the Soil Group of "Andosols". These soils develop in volcanic materials as black soils of volcanic landscapes. The parent material is mainly volcanic ash, but also tuff, pumice, cinders and other volcanic ejecta. It is found in undulating mountains, humid, arctic to tropical regions with a wide range of vegetation types. The reddish coloured soil is developed from the lateritic parent rock materials.

STATUS OF WATER SUPPLY AND DEMAND

The entire Greater Mumbai is an urban area. All the major surface water reservoirs located in surrounding districts are used for water supply. The major rivers in the area and surrounding region are the Vaitarna and the Ulhas river which originate in Konkan region. The other two rivers are the Patalganga and the Amba. Even though these rivers does not flow in the Greater Mumbai, their basins form the major source of surface water for Greater Mumbai as a whole for its domestic and industrial consumption. The Mumbai Hydrometric Area (MHA) under Department of Irrigation, Government of Maharashtra, comprising these four river basins. They have a total catchment area of 575 Sq. Km. The total surface water potential of MHA is estimated to be 10439 mcm at 75% dependability and 7869 mcm at 90% dependability by the irrigation Department. The basin-wise available surface water is given in Table 1.

Table 1 Basin wise water availability to Greater Mumbai

S.No.	Basin	Catchment (Sq.KM)	Water availability 75% dep. (mcm)	Water availability 90% dep. (mcm)	Irrigation requirement as planned (mcm)	Water available for domestic & industrial supply (mcm)
1.	Vaitarna	1858	3130	2416	651	2416
2.	Ulhas	3205	6194	4881	1241	4881
3.	Patalganga	338	712	489	147	489
4.	Amba	365	403	283	146	257
	Total	5756	10439	7869	2157	7843

Water supply to Mumbai city is dependent on six lakes viz Tulsi,Vihar,Tansa,Upper Vaiterna,Bhatsa and Mumbai III. The source wise water supply through lakes is given in Table 2.

Table 2 Water sources to Mumbai city

Sources	Yield (MLD)	Percent
Tulsi	18	0.54
Vihar	110	3.28
Tansa	417	12.45
Upper Vaitarna	1025	30.60
Bhatsa	1650	49.25
Mumbai-III	150	4.48
Sub-total	3350	100
En-route supply	120	-3.58
Total water supply	3230	96.42

Demand of Water: The norms of water supply recommended for water supply as per Central Public Health and Environmental Engineering Department, Ministry of Urban Development for cities with population above one lakh is 150-200 liters per capita per day (1pcd). For Greater Mumbai at present water is being supplied @ 150 lpcd which may rise to 200 lpcd by 2011 and 225 lpcd by 2021. The total net domestic and gross requirements (taking norm as 150 lpcd) for different purposes are given in the Table 3

Table 3 Net and gross water requirements for Greater Mumbai.

Sl. No.	Type of use	Water requirement in mld	Water requirement in mld	Water requirement in mld(projected)
		1991	2001	2011
1.	Domestic	1489	2200	3080
2.	Industrial Institutional	400	400	400
3.	Other uses	38	54	69
4.	En-route	90	90	90
	Total (Net) requirement	2017	2823	3819
	Total (Gross) requirement	2521	3529	4525

Future water supply : The projected demand of water for Greater Mumbai for the year 2021 is estimated to be 5355 mld. To meet this additional requirement of water, four water supply projects are being under construction and by the completion of these projects the total supply will rise to 5479 mld. The source identified for augmentation of water supply is as below in Table 4.

Table 4 Identified sources of water supply

Source of water (future projects)	River	Water supply capacity (mld)
Middle Vaitarna	Vaitarna	455
Gargai	Vaitarna	455
Pinjal	Vaitarna	865
Kalu	Ulhas	590
Shai	Ulhas	1067

WATER PROFILE

Surface Water

The very old record indicates existence of dug wells, lakes and tanks for water supply in the district. However, the growing population led to spurt in demand of water, which necessitated the municipal corporation to install the surface water based pipe line distribution system in the city. Water distribution system is very complex in the city. The water transmission (650 km) and service pipes (3200 km) are covering the entire city. The water supply system of Greater Mumbai is more than hundred years old. Mumbai city has received first piped water supply in 1860. The present water supply to Mumbai city is depended on six lakes. Bhatsa is one of the important sources of water to city and it alone supplies 1650 mld water to city. Tulsi is one of the old water resources but it supplies only 18 mld water to Mumbai city. Upper Vaitarna resource supplies 1025 mld water. The total water yield from Tulsi (18mld), Vihar (110mld), Tansa (417 mld), Upper Vaitarna (1025mld), Bhatsa (1650mld) and Mumbai-III (150 mld) is 3350 mld. Water is also supplied to en-route villages, which is 120 mld. Therefore the total water supplied for the entire city is 3230mld.

Ground Water

Ground water is not suitable for drinking purposes. In order to reduce the illness prevalence in the city, Brihanmumbai Corporation (BMC) and Government of Maharashtra (GoM) have been discouraged the use of water from wells and ponds for domestic purpose. As result, the dug well based water supply was completely neglected. However, being a financial capital of the country, the population growth in the city is very high as compared to other part of country. The supply of water from surface water sources fluctuates depending upon the rainfall during the year. Therefore, there is always the gap between demand and supply. In order to meet the shortfall in water supply, ground water based supply as a supplementary source of supply has been used for all purposes other than domestic. As per the record, 3950 dug wells and 2514 bore wells are in operation under BMC for water supply purpose in the city. The aquifers in the district are of limited areal extent and of limited thickness. Ground water is quite vulnerable to contamination from sewage disposal and other human activities. The over pumping may also lead to sea water intrusion.

GROUND WATER SCENARIO

Potential Aquifers

The area is mainly underlain by Deccan Traps, Alluvium, and also having marshy swamps and mud planes. Along the coast, trachytes and Rhyolites are also present. The Deccan Trap basalts and alluvium are the major water bearing formation. The description of each is as below:

Alluvium : The thin alluvial patches along the river and the marine unconsolidated deposits in coastal area are highly potential aquifers but are of limited extent with respect to time and space. The Thickness of the shallow aquifer extends down to 5.0/ 7.0 m.bgl and is separated by marine clay from the underlying deeper basaltic aquifer. The ground water occurs in sandy/gritty layers under water table condition, but very often its occurrence and movement depends upon the ratio of sand and clay in a particular locality. The alluvial fill of low lying areas underlain by weathered basalt has relatively batter ground water potential as observed from well yields.

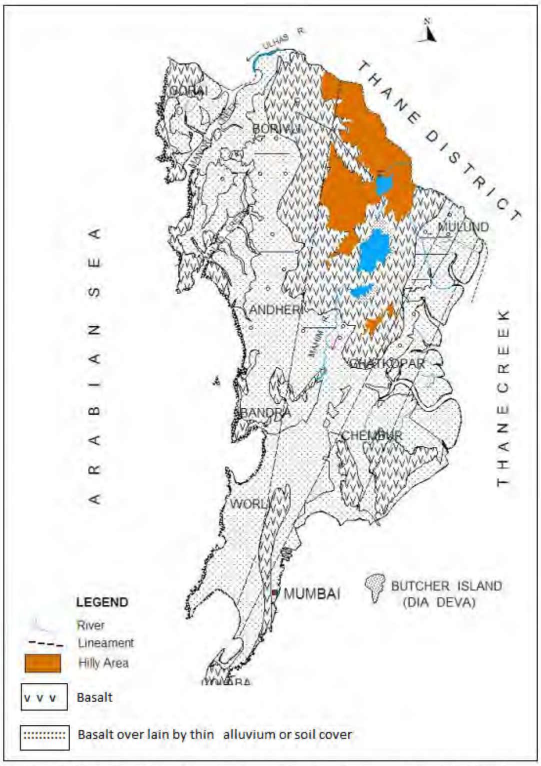

Fig. 2 Distribution of rock formation in Greater Mumbai District

Basaltic Lava : The ground water occurs in fractures, joints vesicles and in weathered zones of the basalt under water table condition at shallow depth and under semi-confined to confined condition at deeper depths. The leaky confined condition has also been observed in deeper aquifer in some area. The primary porosity that is due to the presence of vesicles along flow contacts and in lava tubes etc, and is completely missing in the area due to amygdular nature of basalt. However, the Secondary porosity is developed due to jointing and weathering of the rock formation in the area. The various flow units have also been weathered to varying extent giving rise to potential aquifer zones. The basalt flows dip westwards with 8^0 - 25^0 while strike joint planes dip eastwards. Due to this the westward movement of ground water is guided by the partition plains between lava flows and eastward movement by the major easterly dipping strike joint systems occurs. The distribution of rock formations is shown in Fig. 2.

Ground Water Level

The ground water level in the area has been observed based on the water level data of National Network hydrograph Stations established in the district. These wells are monitored four times a year i.e. August, January, May (Pre-monsoon), August, November (post Monsoon).

Pre-monsoon Depth to Water Level (May 2007)

The pre-monsoon depth to water levels monitored during May 2007 ranges between 2.77 m bgl (Church Gate) and 7.10 m bgl (A.M.C. Colony). The depth to water levels during pre-monsoon has been depicted in Fig.3.

The shallow water levels between 2 and 5 m bgl are observed in southern part, whereas moderate deep water levels in the range of 5 to 10m bgl are observed in northern and central part of the district. Shallow water levels of < 2 m bgl are observed in small area in southern part.

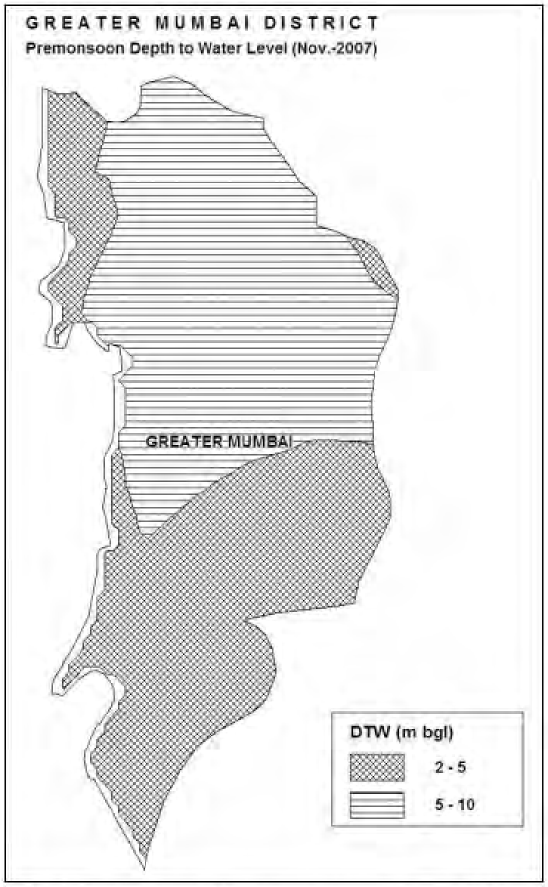

Fig.3 Depth to water Level (pre-monsoon, May 2007)

Post-monsoon Depth to Water Level (Nov.–2007)

The depth to water levels during postmonsoon (Nov. 2007) ranges between 1.80 m bgl (Church Gate) and 6.42 m bgl

(A.M.C. Colony). Spatial variation in postmonsoon depth to water level is shown in Fig. 4.

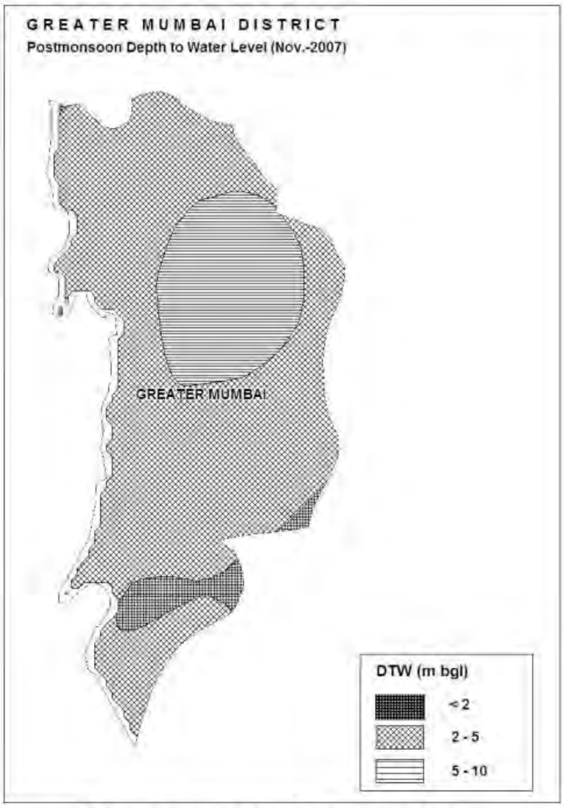

Fig. 4 Depth to water level (post-monsoon, Nov.2007)

Water Level Trend (1998 – 2007)

Trend of water levels for pre-monsoon and post-monsoon periods for last ten years (1998-2007) have been computed for 4 National Hydrograph Stations (NHS). Analysis of long term water level trend data indicates fall in water levels in the 4 NHS and it ranges between 0.11 (Church Gate) and 0.38 m/year (A.M.C. Colony). During post-monsoon period rise in water level of 0.09 m/year has been recorded at only 1 NHS located at Mahroli (Chemur) while at 3 NHS fall in water level have been recorded and it ranges between 0.02 (Colaba (Dandi)) and 0.26 m/year (A.M.C. Colony). Thus in major parts of the district, both during pre-monsoon and post-monsoon seasons declining water level trends have been recorded. The pre-monsoon and post-monsoon trend maps were also prepared and the same are presented in Fig. 4. During pre-monsoon period entire district shows fall in water level trend of up to 20 cm/year, whereas during post-monsoon period rise in water level trend of up to 20 cm/year is observed in extreme northern part and central southern parts and the rest of the district shows fall in water level trend of up to 20 cm/year.

Fig. 5 Premonsoon (L) and Postmonsoon (R) Water Level Trend (May and Nov. 1998-2007)

Ground Water Resources

Based on the available data, the ground water resources for Greater Mumbai are computed as below.

1.	Total Geographical area	603 Sq. Km
2.	Area considered suitable for ground water recharge/development	300 Sq. Km.
3.	Ground water recharge	105 mcm
4.	Ground water withdrawal	Not computed
5.	Balance ground water for development	--

The Mumbai district which forms the Mumbai city, is thickly populated. The ground water utilization for irrigation is nil and for other domestic and industrial purpose is comparatively less due to its poor quality and quantity. However, the authentic record on number of ground water structures is not available hence the calculation of draft is not possible. The state government has also excluded Mumbai from the list of assessment items and it has been accepted by assessment committee. In absence of any such authentic assessment, the above estimates are tentative and need to be revised based on detailed data to be collected.

The total ground water recharge of 105mcm can be utilized for ground water development in a regulated manner considering the local hydrogeological situations.

Hydrochemistry

The ground water quality of the district has been monitored during year 2007 through analysis of water samples collected from its National Hydrograph Stations (NHS) which represent the shallow aquifer of the district.

The results of chemical analysis show that the ground water in the district is alkaline in nature. The concentration of major ions indicates that among the cations, the concentration of sodium and magnesium ion is almost same followed by calcium, while among the anions the concentration of bicarbonate ion is highest, followed by chloride, sulphate and nitrate ions. The suitability of groundwater for irrigation purpose was not assessed as the entire area is urban.

Suitability of Ground Water for Drinking Purpose : The suitability of ground water for drinking purpose is determined keeping in view the effects of various chemical constituents in water on the biological system of human being. The standards proposed by the Bureau of Indian Standards (BIS) for drinking water (IS-10500-91, Revised 2003) were used to decide the suitability of ground water. The classification of ground water samples was carried out based on the desirable and maximum permissible limits for the parameters viz., TDS, TH, Ca,Mg, Cl, SO4, NO3and F prescribed in the standards and is given in Table 5. Total five samples were analysed.

Table 5 Classification of Ground Water Samples for Drinking based on BIS Drinking Water Standards (IS-10500-91, Revised 2003)

Parameters	DL (mg/L)	MPL (mg/L)	Samples with conc. < DL	Samples with conc. with in MPL	Samples with conc. >MPL
TDS	500	2000	5	Nil	Nil
TH	300	600	4	1	Nil
Ca	75	200	5	Nil	Nil
Mg	30	100	3	2	Nil
Cl	250	1000	5	Nil	Nil
SO_4	200	400	5	Nil	Nil
NO_3	45	No relaxation	5	Nil	Nil
F	1.0	1.5	5	Nil	Nil

(Here, DL- Desirable Limit, MPL- Maximum Permissible Limit.)

The perusal of Table 5 shows that the concentrations of all the chemical parameters in all the samples are within the MPL. Therefore, it can be concluded that the ground water quality considering chemical constituents in majority of the area is good for drinking purpose. The ground water quality of deeper aquifer is brackish to slightly saline in some localities such as Colaba, Dharavi and Khar as observed from BMC data. This may be due to ingression of sea water. In view of this it is suggested that Samples with concentration >MPL borewells drilled especially along the coastal areas should be pumped at the optimum discharge(only water skimming is permitted), so that it does not result in sea water ingression, failing to do so, may spoil the fresh water aquifers.

Major Ground Water Problems and Issues

Though the ground water in the city area appears to be free from pollution by chemical constituents but in the shore area there is every possibility of pollution. The creeks in the region have become the dumping ground of sewage and industrial effluents. In addition to this, various industrial effluents from oil refineries, reactors, fertilizers plants at Chembur have polluted the sea water in eastern part and are hazardous to marine life.

The data of Maharashtra Pollution Control Board (MPCB) indicate high concentration of Mercury (Hg) than the prescribed limit of 1.90 ppm. The alkali and dye industries are responsible for mercury pollution in the Thane creek. The higher Arsenic (As) concentration of more than 2.00 ppm and slightly more is observed in fishes from Thane and Chembur. The other heavy metals like Lead (0.60 ppm), Cadmium (12.60 ppm) and Copper (8.84 ppm) are also reported from creek water.

Recently it has been observed that ground water exploitation for commercial purpose is being carried out in entire district and the water is extracted from existing dugwells and borewells, even new borewells are also being drilled for this purpose. The ground water is used for construction purposes, hotel industry and for domestic purpose of the housing societies. Excessive ground water development in the beach and coastal areas can lead to saline water intrusion as observed in some parts of Colaba, Dharavi and Khar as reported from BMC data.

Even though the borewells drilled in the area, are in large number, no adequate data regarding areal extent of the aquifer is available. The borewells in low lying area are affected by saline water whereas in upland areas the source water is relatively fresh but the potential of the aquifer is very poor.

Water Conservation and Artificial Recharge

The artificial recharge structures feasible in the city are Recharge through roof top rain water harvesting to existing dug/borewells may be taken up. However, the source water should be properly filtered before recharging into the wells. These sites need to be located where the hydrogeological conditions are favorable, i.e., where sufficient thickness of unsaturated/de-saturated aquifer exists and water levels are more than 3.0 m deep (post-monsoon). The post-monsoon depth to water level map and pre-monsoon/post-monsoon water level trend map gives a good idea of areas suitable for artificial recharge of ground water. Such areas are located in north central part of the district, where water levels are moderately deep and falling water level trends is observed. In other areas where water levels is shallow, ground water development along with augmentation is recommended. In the elevated area roof top rain water harvesting is also feasible by storing rainwater in storage tanks, thereby supplementing the main source of water.

GROUND WATER DEVELOPMENT STRATEGY

The ground water is presently developed through dugwells and borewells. Hydrogeological set-up and disposition of rock types show that availability of ground water resources is limited in ground water worthy areas mostly located in Salsete island and limited areas of Bombay and Trombay islands. About 500 to 800 wells can be constructed with the yield of wells varying from 30 to 50 m^3/day. In these areas the ground water can be developed through borewells also. However the sites for borewell need to be selected only after proper scientific investigation and they should only be used for drinking water supply and not for industrial and commercial exploitation. The promising and productive aquifers exist in the depth range of 60 to 80 mbgl. In the Alluvial areas shallow dugwells of 5 to 7 m depth, whereas in Deccan Trap Basalt areas dugwells of 7 to 15 m depth are the most feasible structures for ground water development. The ground water quality also needs to be ascertained and the wells used for water supply should be first checked for nitrate and other pollutants.
Ground water exploitation for commercial purpose needs to be regulated, even as the ground water is extracted from existing dugwells and borewells needs to be monitored. Otherwise saline water intrusion in beach and coastal areas may happen.

Even though ground water is available in the area, more emphasis is given on creating surface water reservoirs, rather than developing ground water in a planned way. The conjunctive utilization of available surface and ground water in systematic and planned way will be the best solution for meeting present and future demands of water.

Rain Water Harvesting

Rainwater harvesting is an old method of capturing run-off rainwater from the terrace. In Mumbai city, there are 250000 private properties and commercial establishments. If we assume that each property has an area of 1000 sq. meters and the average rainfall is assumed as 2.0 meters in the city. Then after all the necessary arrangements, if eighty percent rain of water is captured at all the terraces, for example, commercial establishments and government buildings. It will yield more than 500 mld water in the city. The flushing need per person per day is 40 liter for 270 dry days. It has been calculated that around 400000 persons flushing need could be satisfied through rainwater harvesting in the city. The rainwater harvesting capacity of future constructions has not been calculated. Similarly, there are many old building and government offices in the city. Such establishments can yield considerable water through rainwater harvesting. Government has made compulsory rain water harvesting for each plot having area of more than 1000 square meters.. Rainwater harvesting system has number of advantages. It increases ground water level, provides ready and natural source of water. It is also helpful to reduce the salinity of groundwater.

Roof top rain water harvesting is also feasible by storing rainwater in storage tanks in elevated areas, thereby supplementing the main source of water.

The scope exists for constructing suitable artificial recharge structures like recharge shafts in limited areas located in north central part of the district. The existing dugwells/borewells can also be used for artificial recharge, however, the source water should be properly filtered before putting in the wells.

In the south central part of Mumbai the aquifer is although at a depth of 10m .below msl yet it is yielding fresh water .But the continued ground water extraction may deteriorate the quality. The artificial recharge in this area may not only increase the water availability but also control the water intrusion.

NAGPUR CITY, MAHARASHTRA

P.K. Parchure, CGWB, Nagpur

INTRODUCTION

Nagpur lies at the centre of the country with the Zero Mile Marker indicating the geographical centre of India. Human existence in an around present day Nagpur city can be traced back to 3000 years. However, the Nagpur as a city was founded by the Gonds but later became part of the Maratha Empire under the Bhonsles. The Nagpur was taken over by the British East India Company in the 19th century and was made the capital of the Central Provinces and Berar. After the first reorganisation of states, the city lost its capital status but was made the second capital of Maharashtra. It is popularly known as "Winter Capital" of Maharashtra and one session of the Legislative Assembly is held at Nagpur.

GENERAL FEATURES

Area/ Administrative Divisions

The Nagpur City is spread over an area of 217.56 km^2 and lies between latitude 21°5' N and Longitude 79°5' E. It is situated in the eastern part of the Maharashtra State in area popularly known as Vidarbha (Figure 1). It is located on the Mumbai-Howrah main rail connection at a distance of about 837 km from Mumbai and about 1,128 km from Kolkata.

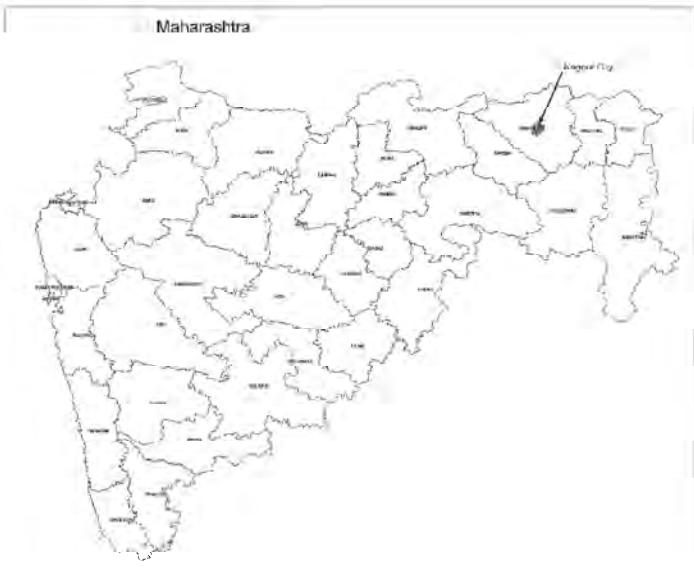

Fig. 1: Location of Nagpur City

Demography

The population of the city according to 1961 census was 6,43,659 persons, which increased to 8.27 lakhs in 1971. The population then increased from 8.27 lakhs to 16.29 lakhs in 1991. The population of the Nagpur City as per 2001 census was 20,52,066 (about 20.5 lakh) persons. It included 10,59,765 male and 9,92,301 Female. Thus the Male-Female ratio was 1.067. The Total Scheduled Cast Population was 3,43,031 (1,75,137 Male and 1,67,894 Female). The Scheduled Tribe Population was 1,81,975 (93,509 Male & 88,466 Female).

Marathi, the official language of Maharashtra, is the local language in Nagpur. The Varhadi dialect of Marathi is spoken in and around Nagpur City. Urdu and Hindi are also spoken.

Hydrometeorology

Nagpur has a sub-tropical wet and dry climate with dry conditions prevailing for most of the year. Summer season extends from March to June and is extremely hot with maximum temperatures (45-46^{0}C) occurring during May. The period between June and September is the Monsoon season. The winter season lasts from end-November to end of February, during which temperatures may drop below 10°C.

Climatological data for India Meteorological Department (IMD) is available as long term normal for the period 1951-1980. As per this data The Mean Daily maximum temperature during May is 42.6° whereas the mean daily minimum temperature, occurring in December, is 12.1°C. The IMD normal annual rainfall in this city is 1112.7 mm. This includes the Monsoon rainfall of 962.5 mm. The mean total number of rainy days during the year is 58, of which 48 are during monsoon and 10 during non-monsoon

Physiography & Drainage

The city stands on comparatively level country with average elevation of about 330 m amsl. However, there are small hills, the most prominent being the "Seminary Hills" with highest elevation of about 354 m amsl.

The Nag River, from which the city has taken its name, flows through the centre of the city. Another small stream, the "Pili Nadi" flows in east-west direction in northern part of the city.

Soil Type

The soils in any area are derived from the underlying rock formations. Thus the soils in Nagpur City area are also reflection of the underlying geological formations. The soils in major part of the city area are brownish to blackish in colour and medium deep. In general, they can be classified as of mixed type.

STATUS OF WATER SUPPLY AND DEMAND

The total quantity of 515 Million Litres per Day is being supplied to the city of Nagpur. About 85% of the city area has been covered by the water supply pipeline network. Presently there are five water treatment plants (WTP) in the city, the details are given below:

Sr. No.	Water Treatment Plant	Capacity (MLD)
1	Kanhan Water Treatment Plant at Kamptee	120
2.	Pench Water Treatment Plant, at Gorewada, Stage I	136
3.	Pench Water Treatment Plant, at Gorewada, Stage II	133
4.	Pench Water Treatment Plant, at Gorewada, Stage III	120
5.	Gorewada Water Treatment Plant	18

There are three Master Balancing Reservoirs (MBR) and 42 Ground Level/ Elevated Service Reservoirs.

For the present population of Nagpur City, the water demand is 361 MLD which has been worked out on the basis of norms suggested by the Maharashtra Jeevan Pradhikaran @ 170 lpcd The projected total demand of water for Nagpur Urban Agglomeration in the year 2021 is worked out to be in the range of 670 MLD.

The future planning for water supply to the Nagpur City includes:

- Providing piped water supply to the remaining areas
- Construction of 115 MLD Pench-V W.T.P
- Bringing the water from Pench Reservoir by close conduit (2300 mm)
- Providing continuous water supply to the city under a PPP mode project.

These future plans are being implemented under the Jawaharlal Nehru Urban Revival Mission (JNURM) under which 50% funding is being provided by the Govt. of India and 25 by the Government of Maharashtra. The total cost of the project under JNURM is Rs.1669.157 Crores.

WATER PROFILE (SURFACE AND GROUND WATER)

The important streams passing through the Nagpur City area are the Nag and the Pili Streams. There are three large Tanks/ Lakes within the city area:

Sr. No.	Tank	Catchment Area (sq. km)	Capacity (MCM)
1.	Gorewada	30.80	8.8
2.	Ambajhari	14.40	8.3
3.	Phutatal	0.50	-

Besides these, there are few smaller tanks like Gandhi Sagar, Lendi Talav, Naik Talav, Sonegaon Talav, Raghuji and Baradri Talav.

In the older part of the city almost every residential plot has a dugwell. However, these dugwells are seldom used. In the newer parts of the city, Borewells have been drilled in almost every residential plot. These are often used to supplement the water demand. In the peripheral areas, where new residential colony have come up recently, many of the households have water supply exclusively from ground water (borewell/dugwell).

GROUND WATER SCENARIO

Potential Aquifers

Crystallines (Granite Gneiss) and Deccan Trap Basalt are the main consolidated rock formation occurring within the city limits. The crystalline formations occur mostly in the western part of the city covering about 23% of the area. The Deccan Traps occur in the western part of the city and cover about 57% of the area. These formations do not possess any primary porosity due to its massive and compact nature but when it is jointed, fractured, weathered or subjected to any tectonic disturbances, secondary porosity take place and they form potential aquifer underneath.

The sandstone of Gondwana age occurs as an elongated patch in the north eastern part of the city covering about 12% of the area including the area overlain by alluvium. Because of granular nature of this formation, it possesses primary porosity and the presence of fracture and joints further increased its water bearing capacity.

The Lameta formation occurs as an elongated north-south trending patch in the central part of the city. It occupies about 9% of the city area. The water bearing capacity of Lameta formations depend upon the lithological composition. The calcareous sand stones and cherty limestone, which occur as very thin layers have relatively poor porosity and yield. The alluvium occurs as a small round patch, covering about 2% of the area, in the north-eastern part of the city. However, it does not form a potential aquifer due to limited thickness. The geological formations of the Nagpur City is shown in Figure 2.

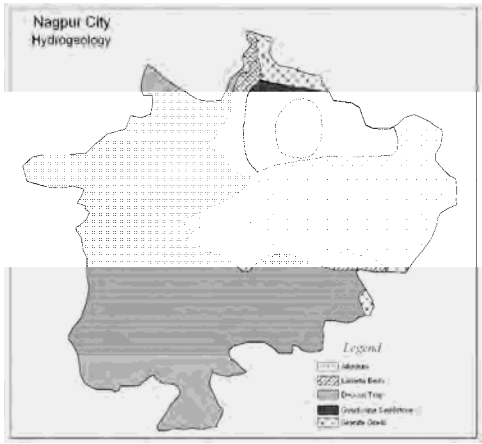

Fig. 2: Distribution of geological formation in Nagpur city

Ground Water Level

There are three National Hydrograph Stations (NHS) in the city. They area located at Ramdas Peth, VNIT Pz and Hanuman Nagar. The long term data for the well at Ramdaspeth is available since 1989. Fig. 3 shows the groundwater hydrograph for this well. The hydrograph shows a regular seasonal fluctuation with a very marginal rising trend of 0.004 m/year.

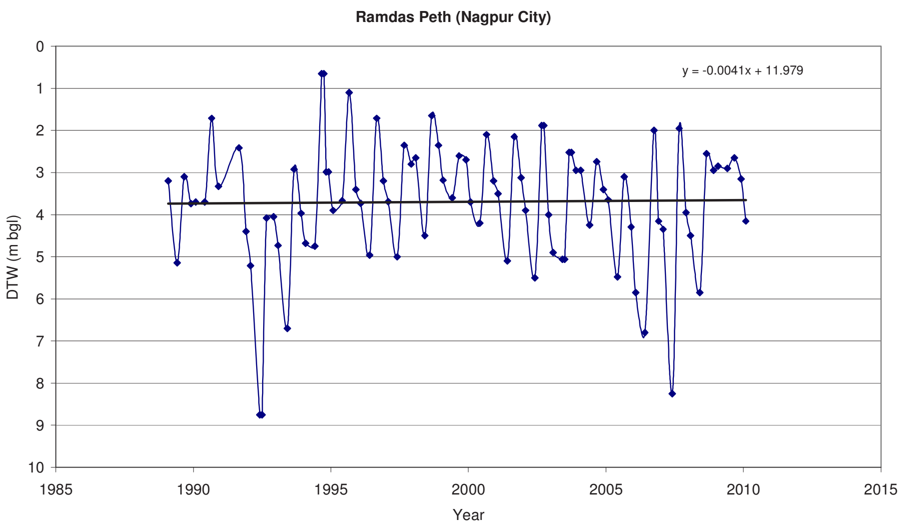

Fig. 3: Ground Water Level Hydrograph for Monitoring Station at Ramdaspeth.

Besides three National hydrograph Stations, a total number of 60 wells have been established in the city for monthly monitoring of water levels. These are being monitored for last one year. The data from these wells have been utilised for depicting the pre- and post-monsoon water levels and seasonal fluctuation of water levels.

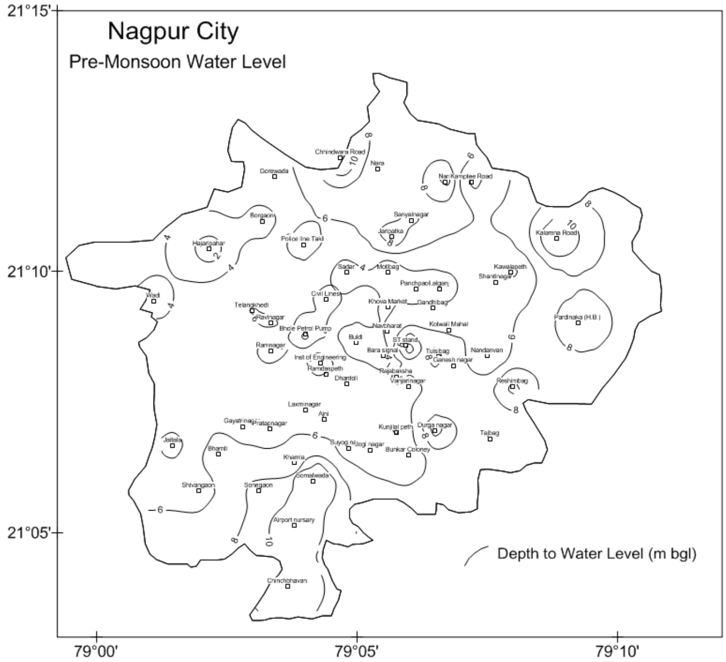

Fig. 4: Depth to Water Level (pre-monsoon – May 2010)

The depth to water level during pre-monsoon (May 2010) ranges from less than one metre to 18.5 m bgl. Shallow water levels, less than 2 m bgl are observed in central parts around Civil Lines and Sadar areas and north-western part around Hajari Pahad area. In major part of the city, central and western parts, the water levels are less than 4 m bgl. Water level in the range of 4 to 6 m bgl is observed in south-western, south-eastern, eastern and northern parts. Deeper water levels, i.e., more than 6 m bgl are mainly observed in southern parts (around Sonegaon), eastern parts (around Pardi Naka and Kalmana) and in few isolated areas. In general, the deeper water levels are observed in peripheral areas. A map depicting the pre-monsoon water levels is given in figure 4.

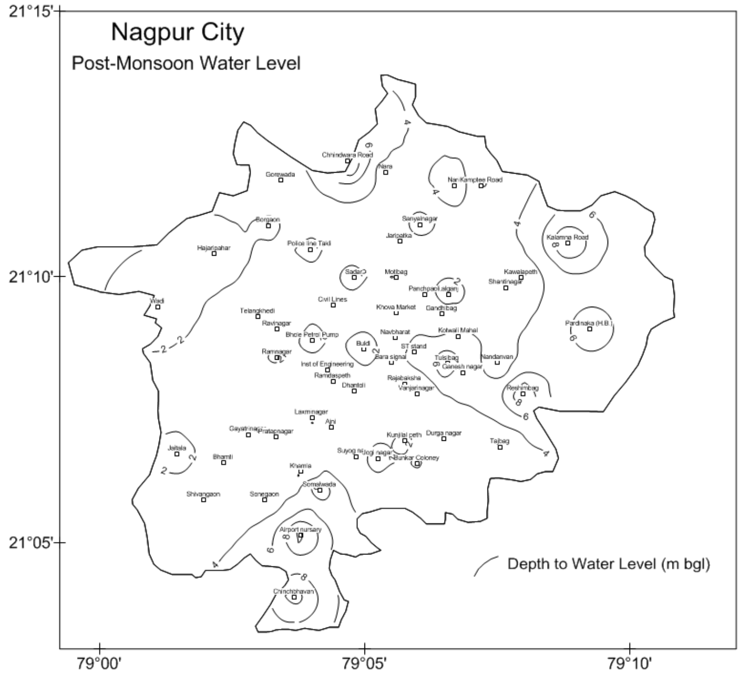

Fig. 5: Depth to Water Level (Postmonsoon – Nov 2010)

The depth to water level during post-monsoon (November 2010) ranges from almost ground level to 11.0 m bgl. The water levels are less than 2 m bgl in north-western part around Hajari Pahad area and as isolated patches in the central part. In majority of the central and western parts, the water levels are between 2 and 4 m bgl. Water levels in the range of 4 to 6 m bgl are observed in southern, eastern an northern parts. Deeper water levels, i.e., more than 6 m bgl are mainly observed in southern parts (around Airport and Chinchbhuvan), eastern parts (around Pardi Naka and Kalmana, Reshim bag and Tulibag) and in few isolated areas. In general, the deeper water levels are observed in peripheral areas. Figure 5 shows the post-monsoon water levels in the city.

The seasonal fluctuation of water levels (May – November 2010) ranges from less than 0.1 m to 11.2 m in major part of the area. The figure 6 shows the seasonal fluctuation in the City. In major part of the city, water level fluctuation varies from 2 to 4 m. In central part it is 0 to 2 m and is observed in elongated area stretching between Civil Lines in the west and Reshimbag in south-east and a small area around Hajari Pahad in the west.

Seasonal Fluctuation of more than 4 m is observed in isolated areas around Sonegaon, Durganagar and Jaripatka.

Ground Water Resources & Status of Development

Recently, ground water resources of the state have been estimated taking the base year as 2008. The data for the Nagpur taluka, which includes the Nagpur city and surrounding rural areas are available As per these estimates, the net ground water availability for Nagpur taluka is 6498.86 ha m. The existing ground water draft for all uses is 2026.68 ha m, out of which irrigation draft is of 1619.85 ha m and domestic and industrial draft is 406.83 ha m. A provision of 878.77 ha m has been kept for future (2005) domestic and industrial requirements. Thus a total of 3593.41 ha m of net ground water is available for future irigation. The present stage of development is 31.19% and the taluka has been categorised as "Safe".

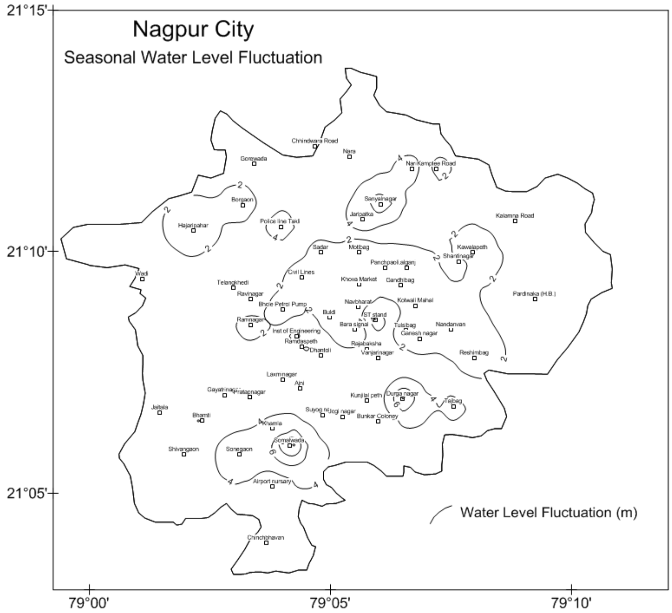

Fig. 6: Seasonal Water Level Fluctuation (May – Nov 2010)

Hydrochemistry

The water samples were collected from 45 wells set-up for urban water level monitoring during May 2010. A map showing distribution of Electrical Conductivity (EC) of ground water is shown in figure 7. It is seen from water quality data that the ground water is quite fresh in the western and central part with EC less than 1000 µS/cm. The EC is more than 1000 µS/cm in majority of the eastern part and a small area in southern part. EC values of more than 2000 µS/cm are observed in small areas around Pardinaka in eastern part and Nari in northern part.

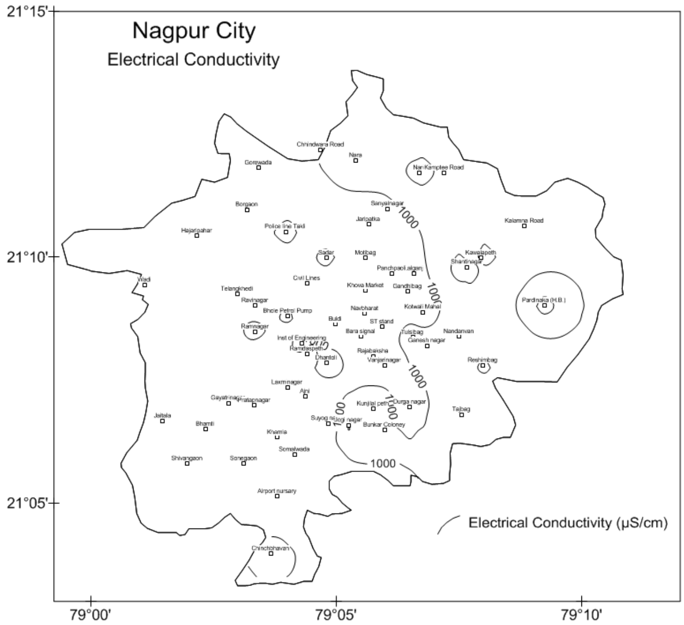

Fig. 7: Electrical conductivity map

Other quality parameters are within permissible limits at most of the places, however, high values of certain parameter are noticed. Higher value of NO_3 (> 45 mg/l) are observed at 9 locations, i.e., Chinchbhavan, Tulsibag, Tajbag, Pardinaka, Sonegaon, Bhamti, Nari, Joginagar, and Durganagar. Higher values of Fluoride (> 1 mg/l) have also been observed at several location, these are Ajni, Telangkhedi, Gayatrinagar, Tulsibag, Nara, Khamla, Tajbag, Nari, Joginagar and Nandanvan. Higher values of Ca, Mg and Total Hardness have also been observed to be higher at several locations. Metallic parameters like Cu, Fe, Pb, Zn and Mn were also determined. The values of Cu and Zn were found to be within permissible limits in all the samples. The value of Pb was below detection limits at most of the places, higher value of 0.058 mg/l was observed only at one place, i.e., Suyog Nagar. Higher levels of Fe (>0.3 mg/l) were noticed at 6 locations, i.e., Gandhibag, Ravinagar, Police Line Takli, Sonegaon, Tukdoji Square and Joginagar. Higher values of Mn were observed at several locations, it was found to be more than 0.1 mg/l at Pardinaka, Khova Market, Tukdoji Square, Police Line Takli, Nandanvan, Gandhibag, Joginagar, Nara, Panchpaoli and Shantinagar

Major Ground Water Related Problems

Urbanisation is normally identified with growth and development of the country. Industrialisation is one of the indicators of country's overall progress, which results in development of urban centres and related issues. The Nagpur Metro City is no exception to this problem and over the period of time multitudes of problems are cropping up. In order to cater to the need of this ever-growing demand of drinking and domestic water supply, the ground water based supply is the most dependable alternative. Every household prefers to construct a dug well or bore well in its premises. However, its sustainability, especially in hard rock formation is a problem during the summer season, and during drought years. The ground water is under stress in certain pockets of city due to shrinkage of recharge area caused by sudden spurt in constructional activities and asphalting of roads etc. This non-basis and unplanned development of ground water is witnessed particularly in peripheries and unauthorised/illegal layouts causing environmental degradation and lowering of water levels.

Ground water quality is also a major issue in the city. Though the different chemical constituents in ground water is well within the permissible limitshigher values of EC and and some of the contaminants like NO_3, F, Cu and Mn at isolated pockets should be taken care of.

Feasibility of Rainwater Harvesting and Artificial Recharge

Sufficient scope exists for augmenting the ground water resources for its sustainability during peak demand period. From the present study it is observed that there is around 45 sq km area where the ground water level was observed below 4.00 m bgl, and around 14 sq. km of area was observed to have the ground water level below 6.00 m bgl. Thus artificial recharge to ground water is feasible in around 60 sq. km of the area. Such area is mainly located in the eastern and southern part of the city. Majority of this area is underlain by Crystalline formations (Granite Gneiss) in eastern part and Deccan Trap in the southern part. Only a small area in north-eastern part is underlain by Gondwana Formations. Artificial recharge to ground water through rooftop rainwater harvesting may be practised in these areas This may not only help to augment the ground water resource but also help in improvement in quality.

GROUND WATER DEVELOPMENT STRATEGY

Proper ground water management strategy envisages that there should be planned and systematic management of the resources available. Therefore, the extraction of ground water need to be promoted in areas where the ground water levels remain above 4.00 m bgl even during in summer. The areas with water level below 4 m bgl may also be considered for ground water development with option for proper augmentation through rain water harvesting.

In order to cater the need of growing demand of safe drinking water, the ground water based supply is the most dependable alternative. However, its sustainability especially in hard rock formation possesses a problem during the summer and scarcity years. In basaltic terrain of the Nagpur City, the ground water pumping is taking place almost at every household in peripheral areas. However, the shrinkage of recharge area due to sudden spurt in constructional activities, unplanned ground water development the ground water resources are under stress in some parts.

The situation of ground water availability seems quite favourable in major part of the city, the peripheral areas, particularly the areas like Somalwada, Ujjwal Nagar, Pandey Layout are facing acute shortage of ground water. This is not only due to excessive ground water development alone but also the aquifers available in this area are not capable of large-scale development of ground water.

In the northern part of the city, i.e, the area between Beszonbag and Kalmana where Gondwana formations occur, are suitable for ground water development through tubewells. the eastern parts, which are underlain by the Crystalline formations, do not offer much scope for ground water development. However, shallow dugwells for individual household use may be constructed. The western part of the city, which is mostly underlain by the Deccan traps are also not very suitable for ground water development. In these areas, shallow dugwells for individual use are suggested. In some of the areas in central and southern parts, the Gondwana formations reportedly occur below Deccan Traps at shallow depth. Deeper tubewells, tapping underlying Gondwana formations may be constructed in such areas.

Considering the overall physiographic, Hydrogeological, hydrological, demographic and socio-cultural set up of the Nagpur City, following types of the schemes are found to be feasible for ground water augmentation
1. Roof top rainwater harvesting
2. Runoff rain water Conservation.

In Nagpur City, rooftop rain water-harvesting experiment has been done to recharge the ground water reservoir by the Central Ground Water Board. The experiment was done in Ujjwal Nagar area where the roof top water collected from the concrete roof of 100 m^2 was diverted into the existing water supply dug well of the house hold. About 80,000 litres is being recharged during the monsoon. About 500 litres of water was recharged at the expense of one rupee only.

The scheme is simple and easy to operate. The effect of such practices is instant and about l m rise in water level was recorded in the recharged well. Further, the quality of ground water also improved as nitrate concentration prevailing in the ground water got diluted considerably to the permissible limit due to mixing of nearly pure rainwater. Suitable modifications can be made in the system depending upon the actual site-specific conditions. Such a practice if replicated on larger scale can bring substantial relief to the scarcity prone areas of the city.

The rainfall runoff flowing from the roads open grounds and public parks are substantial during the Monsoon period. This water often creates the water logging and the drainage system is put under stress. This runoff ultimately flows out of the city unutilised. This water if, conserved and utilised properly for recharging the ground water reservoir may bring much needed relief to the water scarcity areas of the city.

In Nagpur City, rainwater Runoff harvesting experiment has also been done to recharge the ground water reservoir by the Central Ground Water Board. The experiment was done in Ujjwal Nagar area where the public ground (Park) of Municipal Corporation was selected for recharging the aquifer. During the experiment in year 1998 around 3790m^3 of runoff had been generated in the catchment which was utilised for recharging the aquifer through recharge shaft. To make source water free from silt and other pollutant a provision of filter pit to tackle around 50,000 lit/hrs was made considering the all the technical aspect. The initial observation and the end result of this study were very positive. The success of this scheme in view of land use in urban setup and local hydrogeological setup of the area, a scope of its replication on bigger scale is immense.

NCT DELHI

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INTRODUCTION

Delhi, the capital of India has a strong historical background. The history of the city is as old as the epic Mahabharata. The town was known as Indraprastha, where Pandavas used to live. In due course eight more cities came alive adjacent to Indraprastha: Lal Kot, Siri, Dinpanah, Quila Rai Pithora, Ferozabad, Jahanpanah, Tughlakabad and Shahjahanabad. In 1192 the legions of the Afghan warrior Muhammad of Ghori captured the Rajput town, and the Delhi Sultanate was established (1206). The invasion of Delhi by Timur in 1398 put an end to the sultanate; the Lodis, last of the Delhi sultans, gave way to Babur, who, after the battle of Panipat in 1526, founded the Mughal Empire. The early Mughal emperors favoured Agra as their capital, and Delhi became their permanent seat only after Shah Jahan built (1638) the walls of Old Delhi. In the year 1803 AD, the city came under the British rule. In 1911, British shifted their capital from Calcutta to Delhi. It again became the center of all the governing activities. After independence in 1947, New Delhi was officially declared as the Capital of India. The Constitution (Sixty-ninth Amendment) Act, 1991 declared the Union Territory of Delhi to be formally known as National Capital Territory of Delhi. The Act gave Delhi its own legislative assembly, though with limited powers.

GENERAL FEATURES

Area/Administrative Divisions

National Capital Territory of Delhi occupies an area of 1483 Sq.km. and lies between latitudes 28^0 24’ 15’’ and 28^0 53’ 00’’N and longitudes 76^0 50’24” and 77^0 20’ 30” E. Area is covered under Survey of India Toposheet Nos. 53D and 53H. For administrative purposes, NCT Delhi is divided into 9 districts and 27 Tehsils/Sub-divisions. NCT, Delhi has three Statutory Towns, 59 Census Towns and 165 Villages as per the census of 2001.

Demography

The Decnnial population census conducted during 2001, revealed that the population of NCT Delhi, as on March 1, 2001, worked out to be 13.85 million as against 9.42 million as on March 1991. The decennial growth recorded during 1991-2001, therefore, comes to 47.02%. The corresponding percentage at All-India level worked out to 21.34%. The total population of Delhi accounts for 1.34% of All India population whereas in area, it is only 0.05% of total area of the country. The population density is 9344 persons/Sq. km area. There is a vide variation in density of population from 4165 persons per Sq. km. in Southwest district to 29395 persons/sq. km in North east district. The projected population of Delhi in 2011 comes out to be 18.45 million and in 2021 to be 24.48 million.

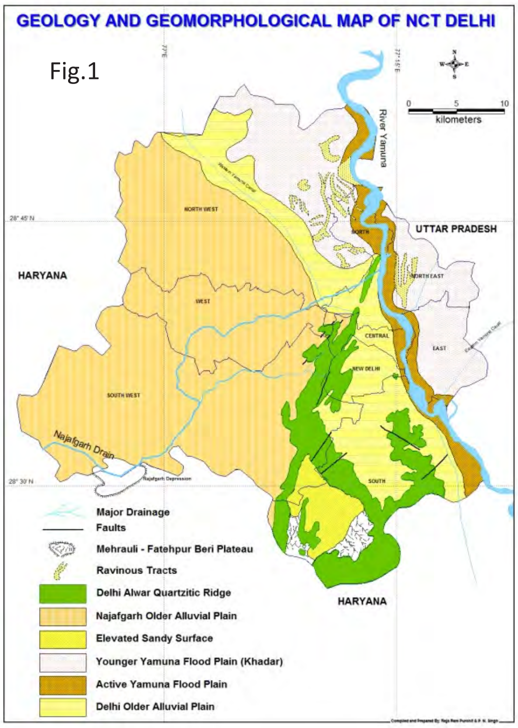
Hydrometeorology

The normal annual rainfall in the NCT Delhi is 611.8 mm. The rainfall increases from the southwest to the northwest. However slight increase in rainfall is observed towards Yamuna River. About 81% of the annual rainfall is received during the monsoon months July, August and September. The rest of the annual rainfall is received as winter rain and as thunderstorm rain in the pre and post monsoon months. January is the coldest month with the mean daily maximum temperature at 21.3ºC. and the mean daily minimum at 7.3ºC. May and June are the hottest months. While day temperature is higher in May the nights are warmer in June. From April the hot wind known locally as ‘loo’ blows and the weather is unpleasant. In May and June maximum temperature sometimes reach upto 46 - 47 ºC. Humidity is high in the monsoon months. April and May are the driest months with relative humidity of about 30% in the morning and less than 20% in the afternoons.

Physiography and Drainage

There are seven distinct landforms in Delhi viz. Mehrauli-Fatehpur-Beri Plateau, Masudpur-Wazirabad Ridge, Najafgarh Older Alluvial plain, Delhi Older Alluvial Plain, Sandy Upland Plain with ravenous tracts, Yamuna

Older Flood Plains and Yamuna Active Flood Plain. The river Yamuna is the only perennial river flowing in southerly direction. Either side of the river Yamuna is marked by the extensive alluvial flood plain. In general, alluvial flood plain slope is towards south. Eastern and Western Yamuna canals and Agra canal are the three major canals originating from the river with Bawana, Rajpur and Lampur distributaries. The drainage on the east of the ridge enters river Yamuna, whereas on the west, it enters natural depressions located in Najafgarh Tehsil of Southwest district. Geological and Geomorphological maps of NCT Delhi is shown in Fig.1.



Soil Type

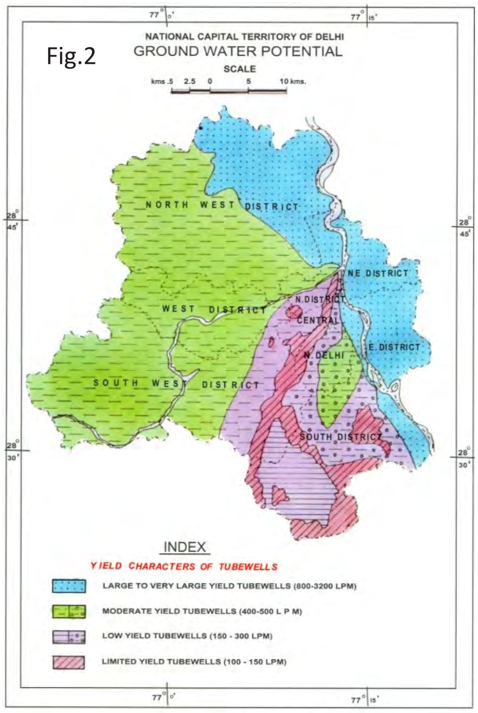
The soils in a greater part of Delhi are light textured, while medium texture soils are found in a small part of the area. Light textured soils are are represented by sandy, loamy, sand and sandy loam type of soils. The medium textures soils are represented by loam and silty loam.

STATUS OF WATER SUPPLY AND DEMAND

Delhi Jal Board (DJB) is responsible for supply of drinking water in Delhi and its distribution in the areas under the control of the Municipal Corporation of Delhi (MCD). DJB supplies water in bulk to New Delhi Municipal Corporation (NDMC) and Delhi Cantonment Board (DCB) for further distribution in their respective areas. DJB supplies 740 MGD water, of which 640 MGD is through surface water and 100 MGD is through ground water (~2400 tube wells and 20 renney wells). The demand for water considering a per capita requirement of 225 lpcd works out to be 914 MGD leaving a shortfall of 174 MGD.

WATER PROFILE

Delhi receives raw water mainly from three sources; river Yamuna- Delhi's share of this river's resources, as per interstate agreement is 4.6%, ground water - the net annual ground water availability in NCT Delhi is 27318 Ham. The annual gross draft for all uses 39619 Ham and the over-all stage of ground water development is 145%, rainwater – Delhi receives a normal rainfall of 611.8 mm in 27 rainy days. Apart from this, Bhakra storage and the Upper Ganga Canal also provide water. The Yamuna river provides 339 MGD of water, Ganga 171 MGD, Bhakra Storage 130 MGD and ground water 100 MGD. To augment the water resources, Delhi Government has proposed the construction of three dams; Renuka (275 MGD), Kishau (372 MGD) and Lakhawar Vyasi Dam (132 MGD). It has also started the construction of a parallel channel from Munak to Haiderpur which will result in augmentation of water to the tune of 80 MGD, which is currently being lost in the present water carrier system.



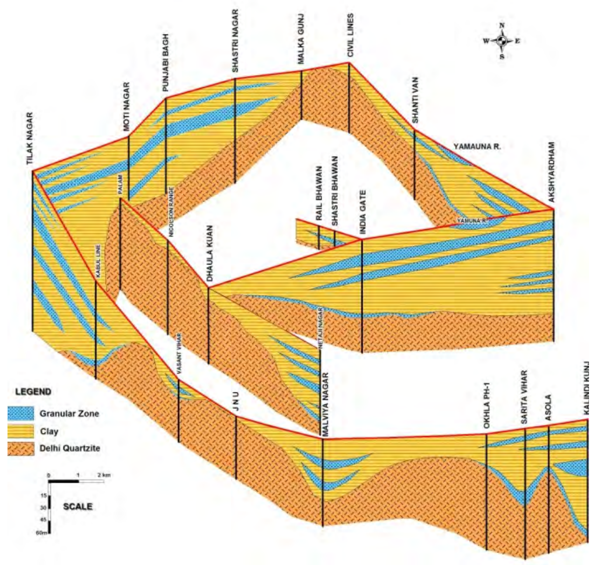
GROUND WATER SCENERAIO

Potential Aquifers

Ground water exploration carried out in the depth range of 50 to 150 m in Delhi in Quartzite recorded a discharge of in the range of 2 to 18 cubic metre/ hour with a drawdown of 8 to 30 m. The transmissivity of the formation is 5 to 135 sq.m/ day. The Quaternary deposits in the form of Aeolian and alluvial deposits constitute the major repository of ground water in the area. The thickness of unconsolidated sediments towards east of the ridge gradually increase away from the ridges, with the maximum reported thickness being 170m. In the south-western, western and northern parts of the area, the thickness of sediments is more than 300 m except at Dhansa where the bedrock has been encountered at 297 m below land surface. In Chattarpur basin, the maximum thickness of sediments is 116 m. The Aeolian deposits are mainly loam, silty loam and sandy loam. The bedrock is overlain by these deposits. Older alluvial deposits consists mostly of interbedded, lenticular and inter fingering deposits of clay, silt, and sand along with kankar. Tubewells in this formation are explored upto the depth of more than 300m. However, fresh water zones are encountered upto the depth of 90 m only. The yield of the wells are generally in the range of 8 to 35 cubic metre/ hour with drawdown of 6 to 24 m. The transmissivity of the formation ranges between 130 to 400 sq.m./day. These deposits overlay the Aeolian deposits and are in turn overlain by the newer alluvium, which occurs mostly in the flood plains of river Yamuna. The tubewells upto the depth of 50 m generally yield 100 to 210 cubic metre / hour with drawdown of 5 to 11 meter. The transmissivity of the formation ranges between 1300 to 2000 sq.m/day. The tubewells drilled in the Chattarpur basin have recorded yield of 7 to 14 cubic meter/ hour with drawdown of 12 to 20 m. The ground water potential map and fence diagrams are shown as Fig. 2 and 3.

Geological Cross Section and Aquifer Geometry

Fig.3



Ground Water Level

In the pre-monsoon, the depth to water level recorded in NCT Delhi ranges from 0.80 to 63.46 m.bgl. The deepest water level are found in South district where 46% wells show more than 40 m.bgl water level and 28% wells have 20 to 40 m.bgl water level. In New Delhi district and South-West district, water levels range 10 to 20 m.bgl, with deeper water levels of 20-40 mbgl in parts of South west district. In Central, East, West, North East and North West districts the water level ranges from of 5 to10 m.bgl respectively, with deeper water levels of 10-20 mbgl in certain areas. The entire Yamuna flood plain the water levels are between 2 to 5m.

The Depth to water level recorded in NCT Delhi during post monsoon ranges from 0.16 to 66.10 m.bgl. The deepest water levels of more than 40 m.bgl are again found in South district which also has 23% wells showing water levels between 20 to 40 m.bgl water level. In South-West district 26% and 7% wells have water level between 20 to 40 m. bgl and more than 40 m.bgl respectively. The depth to water level of East, North-East and North-West districts are in the range of 5-10 m.bgl. In North district and the entire Yamuna flood plain, the water levels are generally in the range of 2 to 5 m. bgl and at few places < 1 mbgl.

The decadal fluctuation in pre-monsoon shows a decline in water levels in majority of area, with a maximum fall of 7.92 to 9.25 m in South and South West districts. Only 5% wells of the North-West, West and New Delhi have been observed to show a rise in the range of 0 to 2 m. The decadal fluctuation during post-monsoon also shows a decline in water level in the majority of area. Only 25% wells of the North, East and New Delhi districts have a rising condition in the range of 0 to 2m.

Ground Water Resources & Status of Development

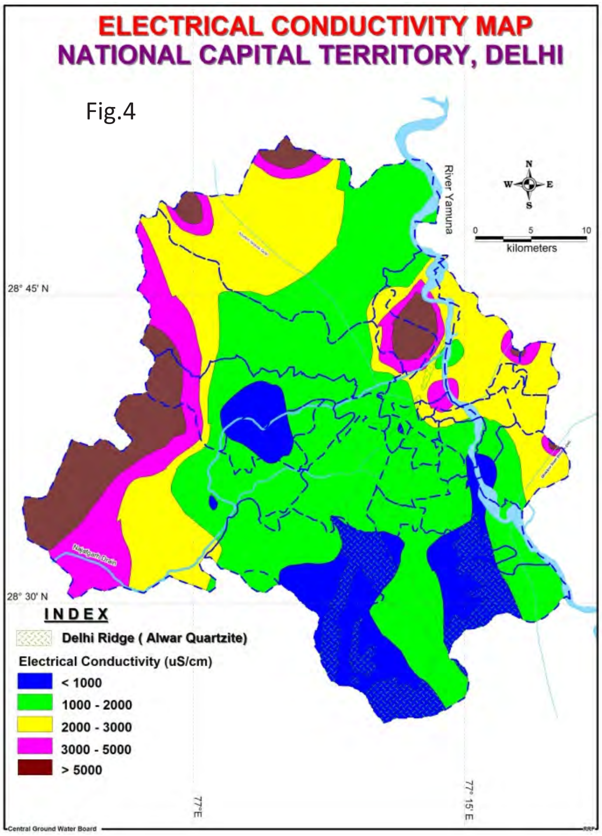
The net annual ground water availability in NCT Delhi is 27318 Ham. The annual gross draft for all uses 39619 Ham and the over-all stage of ground water development is 145%. Out of the 27 assessment units (tehsils), 2 (Daryaganj and Civil Lines) are falling in the ‘Safe’ Category, 5 (Gandhi Nagar, Connaught Place, Seelam Pur, Narela and Punjabi Bagh) are in the ‘Semi-Critical Category while rest 20 tehsils are over-exploited.

Hydrochemistry

Chemical quality of ground water in NCT Delhi varies with time and space. The fresh ground water aquifers mainly exist up to a depth of 25 to 35 m in Northwest, West and South-West districts and in minor patches in North and Central districts. In Southwest district, especially in Najafgarh Jheel area the fresh water occurs up to a depth of 30 to 45 m. A localized area located just north of Kamala Nehru Ridge (part of Delhi ridge falling in Central District) covering area of Dhirpur, Wazirabad and Jagatpur are characterized by shallow depth of fresh water aquifers that is in the range of 22 to 28m, regardless of proximity to River Yamuna.

In alluvial formations, the quality of ground water deteriorates with depth, which is variable in different areas. The ground water is fresh at all depths in the areas around the ridge falling in Central, New Delhi, South and eastern part (Ridge Area) of South-West districts and also Chattarpur basin. In the areas west of the ridge, in general, the thickness of fresh water aquifers decreases towards North-West, the thickness of fresh water zone is limited in most parts of west and southwest districts. In the flood plains of Yamuna, in general, fresh water aquifers exist down to depth of 30-45m and especially in Palla and Zero RD area it reaches to the depth of 60 to 75m below which brackish and saline water exists.

The chemical quality data indicates that South–West and West districts are the only fluoride affected parts of NCT Delhi. The fluoride minerals present in soil have mostly contributed fluoride pollution (geo-genic). High fluoride levels are mostly found in the areas where ground water is brackish to saline in nature. Human activities like use of fluoride salts in steel, aluminum, bricks and tile-industries and also agricultural discharges, are also contributing for fluoride pollution in ground water.



The studies carried out by CGWB indicates that nitrate concentrations in ground water of Delhi have wide range (0.75mg/l Palla Mandir to 140 mg/l Chatarpur Mandir).Three locations are showing more than 100 mg/l i.e. Inderlok Temple well (116 mg/l), Chattarpur Temple (140mg/l) and Chawala (136 mg/l). The higher nitrate concentration may be attributed due to combined effect of contamination from domestic sewage; livestock rearing, landfills and run off from fertilized fields, unlined drains and cattle sheds. The higher concentration of nitrates are found at the places where domestic effluent is discharged into open unlined drains. The higher concentration is mainly due to point source of contamination. Delhi's ground water has more nitrate contents at shallow levels but decrease with depth. This is mainly due to the sub-standard well construction and location factor of wells near potential source of contamination like domestic effluent. Water Quality map is shown in Fig.4.

Major Ground Water Related Problems

Qualitatively, NCT Delhi has three major problems – salinity, fluoride and nitrate. There is a large variation in saline fresh water interface in the horizontal and vertical direction. In NCT Delhi, the fresh saline interface varies from 22m (North West district, excluding the area of Yamuna Flood Plain) to > 100m (South district). The existence of saline water at shallow depth inhibits the development of fresh ground water. Fluoride concentrations in ground water is more than 1.5mg/l in more than 30 percent of the area. The fluoride affected areas are spread mainly in the South-western and Western part of the city comprising Southwest, West and Northwest districts. Nitrate concentration is significant particularly in the parts of West, Southwest and some pockets in Northwest districts. Concentration is more at shallow levels but decreases at deeper levels. Near Okhla – Kalindi Kunj Barrage, high nitrate in ground water is observed on the western bank of the river Yamuna.

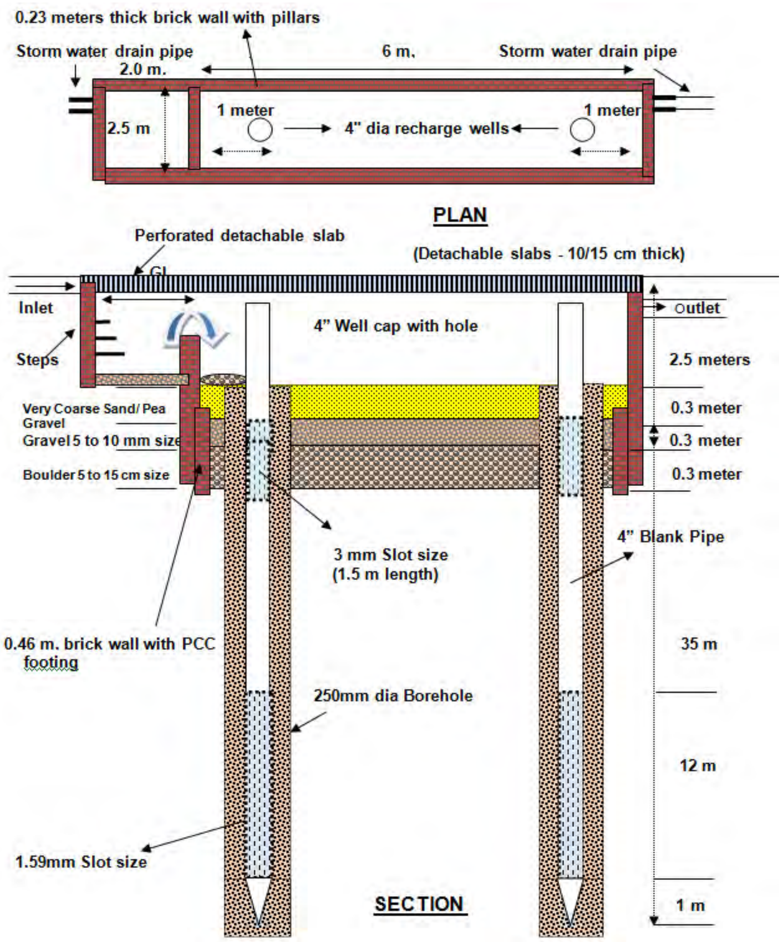
Feasibility of Rainwater Harvesting and Artificial Recharge

Delhi receives normal rainfall of 611.8 mm in 27 rainy days, most of which is going waste as runoff. The runoff being generated from the rainfall is about 194 MCM. Artificial recharge worthy areas have been demarcated based on the depth to water level and showing decline trend in water levels. These are:

- Area underlain by Newer Alluvium with water levels more than 8 m: Areas falling in this category are- Vasundhara Enclave, Preet Vihar, Vivek Vihar areas of East Delhi, Narela-Singhola areas of North Delhi,
- Area occupied by Older Alluvium with water levels 8 to 20 m: Areas falling in this category are Connaught place, Lodhi Road and Lodhi Colony, Parts of Lutyen Delhi, Karol Bagh, IARI Pusa, Parts of Southwest district-Dwarka, Najafgarh.
- Area occupied by Older Alluvium with water levels 20 to 40 m: Areas falling in this zones are: Central parts of Chattarpur Basin, Gadaipur , Ghittorni and Surrounding areas, Parts of South district-AIIMS, Green Park, Hauzkhas, R.K. Puram, Malviya Nagar
- Area occupied by Older Alluvium with water levels 40 to 70 m: Areas along Mehrauli-Badarpur Road, Tughlakabad-Pushp Vihar, Lado Sarai, Saket.
- Area occupied by Older Alluvium of depth 10 to 20 m followed by weathered and fractured quartzite with water levels varying between 20 to 40 m. (Fringe areas of ridge): Parts of C.R. Park, Kalkaji, Parts of Connaught place, Rajendra Nagar, Parts of Karol Bagh, Parts of Vasant Vihar
- Area occupied by Weathered and fractured quartzite with water levels varying between 20 to 60 m : Delhi ridge extending from Kamala Nehru ridge to South Delhi, Vasant Kunj, Vasant Vihar, Okhla Industrial Area.

A basic design for roof top rain water harvesting is shown in Fig. 5

Fig.5



Several seasonal streams located in Delhi Ridge which occupies about 145 Sq.km of area have substantial flows during the monsoon. A total of 17 watersheds have been recognized in the ridge and adjoining areas having estimated runoff of 6.785 MCM in a normal rainfall. Apart from this on-channel storage of storm water in Najafgarh, Mungeshpur, Bawana and Kushak-Barapullah will be the tune of about 122 MCM. Off-channel storage of flood water along these canals can also yield about 15 MCM of water.

GROUND WATER DEVELOPMENT STRATEGY

The ground water resources of 20 tehsils of NCT, Delhi are over-exploited with stage of development reaching to even 243% in south district. Moreover, the presence of saline aquifers below a depth of 30 to 40 m further limits the development of ground water resources. Thus the complex situation of ground water existence calls for scientific planning to make the ground water resources as sustainable source for water supply in NCT, Delhi. Few of the management strategies to develop ground water resources on sustainable basis are discussed below.

Utilizing Potential Aquifers Underlying Yamuna Flood Plains: Yamuna Active Flood Plain Aquifer System occupies an area of 97 Sq.km and stretches for about 35 Km along river Yamuna. The potential aquifers underlying the Newer Alluvium (Yamuna Sand), which is predominantly silty sand, mixed with clay and gravel can be developed on sustainable basis adopting the technique of abstraction during the non-monsoon period and recharging the same aquifers during the flood season. Total thickness of Newer Alluvium varies between 45 to 55 m (Plate-4.1). Aquifer system in Newer Alluvium is unconfined with depth to water level ranging from of 0.5 to 3.50 m bgl and can sustain the tubewells with yields ranging from 1400 to 2800 lpm.

Four Potential areas have been identified to construct high yielding tubewells. These are Palla-Hiranki Sector, Akshardham Mandir- Mayur Vihar Sector, DND Flyover Sector and Kalindi Kunj-Jaitpur Sector. From these four sectors 65 MGD of fresh ground water can be exploited on sustainable basis. The dewatered aquifer zones would be recharged during the monsoon period through flood water.

Water Supply Plan for Dwarka Township: The projected water requirement for Dwarka township is estimated as 10 MGD. As the Dwarka township, extending in an area of about 35 Sq. km has limited prospects for fresh ground water development. Hence it is proposed to have dual water supply scheme for the entire township where in 5 MGD of fresh water for drinking purposes can be supplied through a battery of 70 number of tubewells (of 30 m depth) proposed along the Najafgarh drain. Three pockets (topographical depressions) have been identified a) Gummenhera depression b) Pochanpur depression c) Kakraula depression. The fresh water supply can be supplemented by another 5 MGD of fresh to marginal quality of water through a battery of 70 number of tubewells proposed within the township and can be supplied through the same transmission line for domestic uses at pre-decided hours of the day or through separate pipe line.

Water Supply to Rural areas in Northwest Delhi: Central Ground Water Board, based on the detailed ground water exploration studies, identified the potential aquifers in the area along the Western Yamuna Canal. The area is underlain by sand, medium to coarse grained, admixed with varying proportions of kankar horizons predominantly at shallow depths and it acts as moderately potential aquifer zones. A thick column of fresh ground water aquifer system exists down to a depth of 50 to 70 m in the vicinity of Western Yamuna Canal and thickness decreases away from canal. The ground water development plan envisages the development of fresh ground water aquifers underlying Western Yamuna Canal by constructing 40 tubewells of depth 50 to 70 m all along the canal. The discharge of these tubewells will be about 600 to 800 LPM and can be pumped for 12 to 15 hours a day. These tubewells can yield about 5.0 MGD of water for drinking purpose to be supplied to the villages located in North west district.

Water Supply System for East Delhi: The area is underlain by Newer alluvium consisting of predominantly sand mixed with gravel and little amount of silt and clay upto a depth of about 30-40 meters followed by older alluvium. Presently shallower ground water level area are found in the vicinity of river Yamuna and also in scarcely inhabitated areas. In general the ground water in shallow aquifers in the vicinity of river Yamuna has lower salinity and it increases towards west reaching to its maximum in the vicinity of Gazipur landfill site.

It is proposed to develop the fresh ground water resources present in the areas where ground water levels are shallow about 3 to 5 m bgl. In these areas, it is recommended to construct tubewells of depth varying between 40 to 45 m. These tubewells will yield about 1000 to 1500 lpm of water and can be pumped for 12 to 16 hours a day. Development of ground water resources of East Delhi shall be coupled with effective promotion of recharging to ground water and water conservation techniques. About 35 Sq.km area has been identified in East and North East districts where water levels are shallow to construct the tubewells. About 40 tubewells are recommended in these two areas which can yield 10 MGD of water. These tubewells shall be developed with a caution of promoting the rain water harvesting to recharge the ground water aquifers.

Waste Water Re-use: In Dry season approximately 2,867 Mld of sewage including industrial effluent is discharged to the Yamuna River from the various drains and nullahs in the city. Thus there exist a great potential for recycling treated domestic wastewater that can be used primarily for irrigation and horticultural reuse. There is also some demand for use of wastewater as cooling water in the power stations. In addition other options include return to the raw water source, treatment and reuse of wastewater for toilets systems etc. At present about 1349 MLD of wastewater generated in the city is treated by sewage treatment plants and rest of the waste water is being discharged into the drains without any treatment. INTACH in a study, sponsored by DJB, has advocated the use of secondary/tertiary treated effluent as a regular recharge source. The main features of the plan revolve around the natural drainage basins of Delhi, the Sewage Treatment Plants (STP) located therein, the available government ownd land where detention basins could be flooded on a regular basis using treated effluent as well as rainfall runoff. A total of 56 projects have been identified with an estimated cost of 343.44 Crores resulting in an estimated recharge of approximately 30 MCM annually. The proposals are slated for implementation over 5 years.

Exploration and Development of Brackish Water Aquifers: Ground water over-development not only resulted in depletion of fresh ground water resources but also gradual invasion of brackish water into fresh water aquifers. Thus it has become eminent to explore the brackish water areas located within shallow/water logged areas to promote the scientific management and proper planning for exploitation of brackish water which is the only effective controlling method of spreading brackish water front. At present about 670 Sq. Km of area has brackish water at shallow depths which can be developed to use for domestic uses other than drinking purpose. Moreover, it will also result into arresting spreading of brackish water. Six areas have been identified for ground water exploration under the scheme

- Area extending from Sanoth-Bhaktawarpur-Bhalsawa-Jahangirpuri-Dhirpur-Burari-Hiranki areas.
- Bawana-Barwala-Puthkalan-Rohini- Kanjhawla-Majra dabas
- Subhey pur-Sonia vihar-Sadat pur area
- Pragati Maidan-National Zoological Park-Nizamuddin-Saraikalekhan-Okhla Village- Friends colony
- Sarita vihar-Jait pur and area along Agra canal
- Dwarka-Janakpuri area

Development of brackish water aquifers will yield about 80 MGD of water. Brackish water can be used by providing the dual water supply system where the same pipe lines can be used to supply fresh water as well as brackish water for domestic uses at pre-determined hours of supply. The brackish water can also be mixed with fresh water to bring the elements under permissible limits as per drinking water standards.

PATNA URBAN, BIHAR

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INTRODUCTION

Patna- the capital of Bihar state- is amongst the few oldest surviving cities of the world with a continuous recorded history dating back to the 5th century BC. Along with few other Indian cities like Varanashi, Madurai and Kanchipuram, it is symbolic of India's long urban heritarge (Ramchandran, 1999). Its strategic location with important rivers on three sides (Ganga, Sone and Punpun) has earned it the sobriquet of *'Jal Durg'* in historical accounts (NCERT, Ancient India). The original name of Patna was Pataliputra and in its journey through the pages of history, the city has been variously named as Kusumpur, Pushpapur, and Azeemabad. Modern Patna is the second largest city of eastern India and is vibrant with the trading, political and academic activities. The city is also a gateway to the internationally acclaimed Buddhist and Jain pilgrimage centres of Bodhgaya, Vaishali, Rajgir, Nalanda, and Pawapuri. The Patna Urban Area with a population of ~1.7 million and absolute dependence on groundwater to meet its domestic and industrial water demand is a unique example.

GENERAL FEATURES

Area/Administrative Division

Patna Municipal Corporation (PMC) along with Danapur Cantonment Area, Danapur Nagar Palika Parishad area, Khagaul Nagar Palika Parishad area and Phulwari Sharif Nagar Palika Parishad together constitute the Patna Urban Agglomeration Area (PUAA) which is spread over an area of 135.7 Sq Kms (Fig 1).

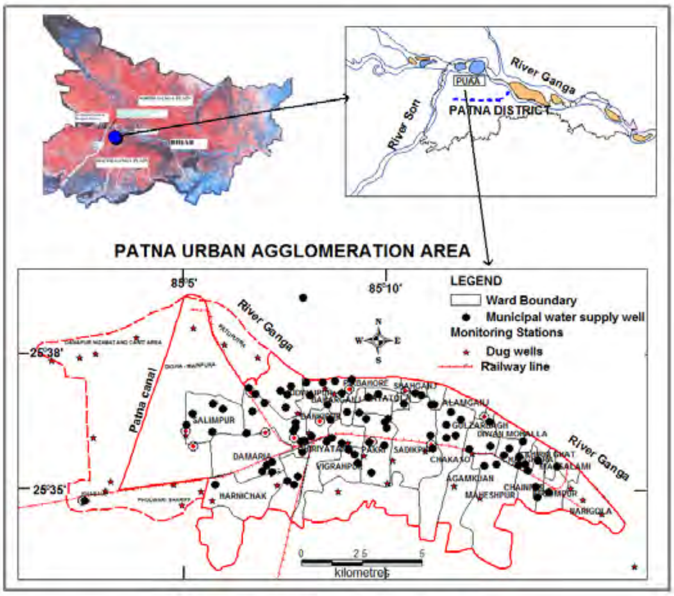


Fig 1 Map of Patna Urban Agglomeration Area

Demography

Patna is the only city in Bihar with a population exceeding 1 million (Census 2001), constituting ~20 % of the total urban population of Bihar. The population of the Patna Urban Agglomeration area has increased from 6.02 lakh in 1971 to 16.97 lakh in 2001. The projected population for 2011 and 2021 is 22.5 Lakh and 28 lakh respectively; however, owing to severe push factors in its hinterland the population is likely to surpass the projected increase.

Hydrometeorology

The city enjoys a sub-tropical sub-humid climate with three distinct seasons viz, monsoon (June to September), summer (March to May) and winter (December and January). The long-term average annual rainfall (1930-1980) is 1051 mm. The average annual rainfall during the last decade was 1115.9 mm. The city experiences extremes of temperature with the normal temperature going as high as 44^{0}C during summer and to as low as 4^{0}C in winter. The highest temperature recorded was 47.8^{0}C in June 1987. With the advent of monsoon, the temperature starts decreasing during July and August. The temperature is the lowest during the month of January. Relative humidity shows a sympathetic variation with the rainfall. The relative humidity in Patna ranges between 84.8% and 56.8% in the morning, with higher humidity during the monsoon season.

Physiography & Drainage

Physiographically, the area lies in the Middle Ganga Plain representing monotonously flat topography (Fig 1). The nucleus of the residential areas of Patliputra was the prominent natural levee along the southern bank of the River Ganga. Subsequent expansion followed the levee towards east and west rendering the town an elongated shape. Post-independence, the expansion has pushed the city southwards invading the low lying water logged areas along Patna bypass road. The low lying area of southern Patna is actually a back swamp of river Ganga in the north, Punpun in the East and South and Sone in the west. The topographical variation within the Patna urban area indicates that the general slope is from west to east with minor variations. Patna urban area within itself does not contain any major streamlets except for a few scattered drainage lines in the south western part trending generally towards south and south-east. The natural drainage pattern in north Patna is completely obliterated due to habitation. As a result of improper drainage a number of small water bodies are formed in east Patna and along the railway line.

Soil Type

The light to dark brown alluvial loamy soil of Patna with low to medium nutrient status and pH between 6.3 and 8.2 is characterised by moderate permeability.

STATUS OF WATER SUPPLY AND DEMAND

Ground water based piped water supply system was first introduced in Patna in 1916 when water supply in areas around Patna High Court was made through a large diameter dug well constructed at Digha. During 1920, three tubewells were constructed with an average depth of 122m. In the 1934 earthquake most of the wells were destroyed. To meet the city water demand and extend the water supply network to other part of the city “Patna Bankipur Joint Water Works Committee” was entrusted with task to supply water to Patna city and Bankipur Municipal Area. Further, after enactment of Patna Municipal Corporation Act 1951, the Corporation was formed in 1952 by merging Patna and Bankipur Municipal area.
The present water supply of city is done through a network of 89 deep tube wells tapping the deeper aquifer in the range of 150- 200m below ground. As per an estimate these wells cover about 52% of the population (JNNURUM, 2006) and the estimated annual production of water through these wells is ~140 MCM. About 40% of the households have their own tube wells, having a depth range of 40 to 100 m in different parts of the city. The annual abstraction through these private tubewells has been assessed as ~40 MCM. The progressive increase in the number of water supply wells in the municipal area and annual production of water from these wells is shown in Table 1

Table 1 Progressive increase in water supply wells and annual production of water

Year	No of Water supply wells	Total installed capacity m^3/hr	Annual abstraction of water (MCM)
1972	18	$0.5*10^4$	33.44
1980	44	$1.40*10^4$	81.76
1988	59	$1.83*10^4$	107.3
2008	89	$2.97*10^4$	136.87

GROUND WATER SCENARIO

Potential Aquifers

Aquifer geometry of Patna urban area has been delineated by combining the geological and hydrogeological information.

Thick pile of alluvial sediments of Quaternary age comprising various grades of clay, silt and sand, forms the ground water reservoir of Patna. A pervasive layer of clay with or without kankar constitutes the top of the succession. Towards the southern and the western part this overlying clay layer is admixed with fine sand. The presence of kankar and fine sand makes this clay layer semi

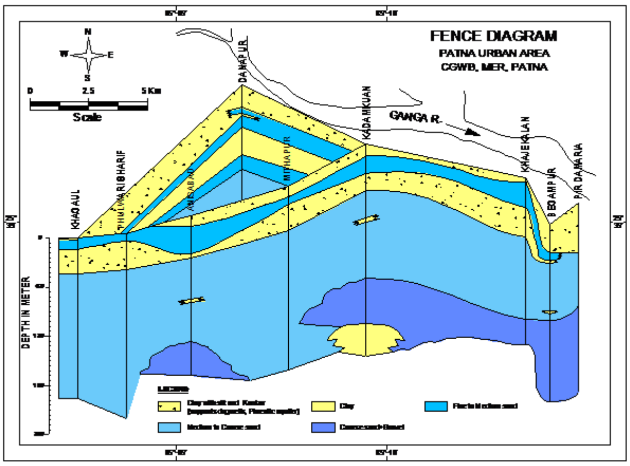


Fig 2 Aquifer disposition in Patna Urban area

pervious rendering the underlying shallow aquifer amenable to vertical recharge through infiltration. The aquifer system (based on exploratory drilling and geophysical logging) has been broadly divided into two groups (Fig 2). An aquitard layer made up of clay/ clay mixed with sand or kankar is present between the depth range of 45 and 70 m. This aquitard layer separates the overlying shallow aquifers with the underlying deeper aquifer. The top clay layer is underlain by sandy clay and fine to medium sand and together constitutes the shallow aquifer system. However, towards the eastern part of the urban area the shallow aquifer system is not well defined and is replaced by a thick aquitard layer.

The deeper aquifer which commences below the intervening aquitard layer is made up of medium to coarse grained sand often grading to gravelly sand at the bottom. In most parts of the urban area, the deeper aquifer has been found to continue uninterrupted upto 220 m. Below 220 m another clay layer has been found at several locations. The lateral continuity of this deeper clay layer could not be traced owing to insufficient depth of drilling at other locations. However, this clay layer may be considered as the base of the deeper aquifer which presently caters the entire water demand of Patna. The salient characteristic of the exploratory wells drilled in and around the urban area is summarized in Table 2.

Table 2 Summarized salient characteristic of the exploratory wells drilled in and around the Patna urban area

Sl.No	Location	Depth drilled (m bgl)	Depth range of tapped Granular zones (m)	Discharge (m^3/hr.)	Drawdown (m)	Transmissivity (m^2/day)	Storativity
1	Sanatan Dharamsala	250.12	078-173	209	2.22	6980	
2	Congress Maidan (Kadamkuan)	251.7	105-213	224	4	5892	
3	Mithapur	215.31	080-188	125	2.5		
4	Fire Brigade (Patna city)	226.7	107-210	238	4.09	8716	
5	Karbigahiya	250.64	068-209	176.2	2.88	8057	
6	Golghar	277.9	074-166	193.04	2.49	14113	
7	Begumpur Patna City	216.72	082-188	177.14	3.11	3786	
8	Khagaul	262.27	065-122	222.56	3.7	7000	
9	Anisabad	219.08	085-166	193.4	2.37	6621	
10	Khajekalan		088-154	199.85	3.16	10246	
11	Chajjubagh	196	075-161	194.62	2.7	7114.64	
12	Harding Road	245.4	073-200	222.3	2.21	6820	
13	Chaudharana	190.32	085-173	211.43	2.9	15479	
14	A.N.College (Pani Tanki)	225	093-181	208.93	2.15	7068	$7.7X10^{-2}$
15	Fatuha	250.11	080-160	188.72	5.44	10435	$2.29X10^{-3}$
16	Phulwarisharif	230.62	056-162	179.63	2.46	7894.56	
17	Pirdamaria	221.3	078-158	195	2.22	12235	
18	Alamganj	225	076-160	180	0.58	9882.9	$5X10^{-3}$
19	Maner	300	80-170	188.7	2.67	9735.12	$4.46X10^{-4}$

Ground Water Level

The water level of the shallow aquifer and the piezometric head of the deeper aquifers in Patna urban area are markedly different. Systematic monitoring of the piezometric level of the deeper aquifer was initiated from June 2008 at 7 locations within the urban area. During 2009, 3 more piezometers were installed tapping the deeper aquifer. The available records of the past along with the present data set exhibiting signs of stress on the deeper aquifer are presented in Fig 3.

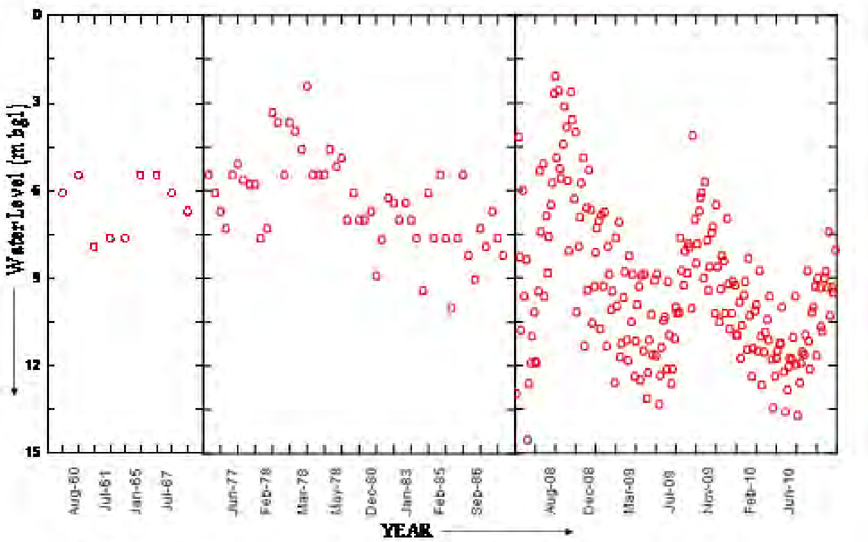


Fig 3 Long term Piezometric Level of Patna Urban Area.

The Piezometric level of the deeper aquifer in Gandhi Maidan area during 1988 and that of 2009 shown in Fig.4 reveals a decline of 2.5 m over the past 2 decades (0.12 m/ year).

The pre and post-monsoon (2010) depth of piezometric level of the deeper aquifer is shown in Fig. 5 and 6 respectively.

The piezometric level of the deeper aquifer exhibits moderate seasonal fluctuation of ~ 4 m.

During long duration pumping tests conducted on wells tapping deeper aquifer, no effect has been recorded in nearby dugwells reflecting poor hydraulic connection between the shallow and the deeper aquifers. The depth to water level of the shallow aquifers has been found varying between 0.78 and 10.78 m during pre-monsoon and 0.68 to 7.7 m during post-monsoon. The difference in the water level of the shallow and the piezometric level of the deeper aquifer monitored at same location at three different parts of the city is shown in Table 3.

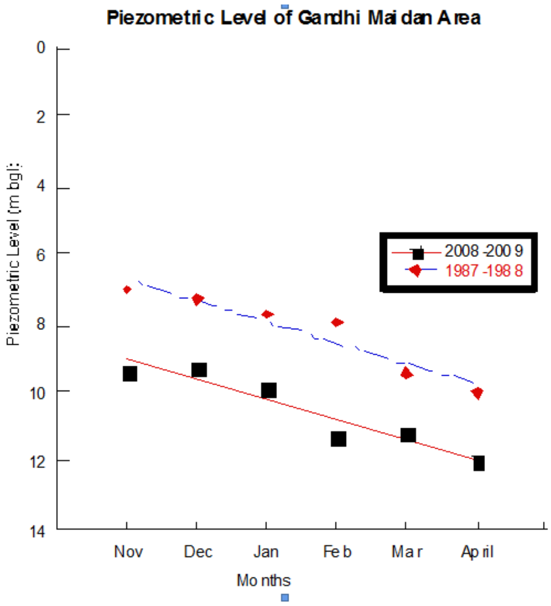
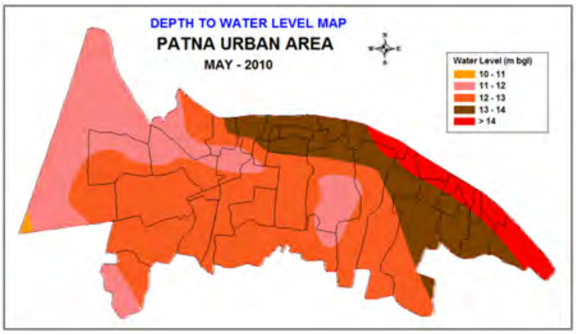


Fig 4 Comparison of Piezometric level of the deeper aquifer in Gandhi Maidan area during 1988 and that of 2009



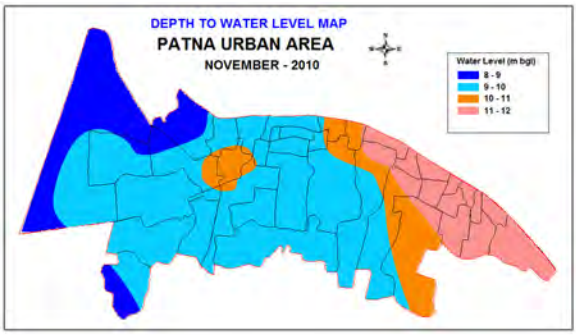


Fig 5. Pre-monsoon (2010) depth to piezometric level map

Fig 6. Post-monsoon (2010) depth to piezometric level map

Table 3: Comparison of water level of the shallow aquifers and the piezometric level of the deeper aquifer

Location	Shallow aquifer		Deeper Aquifer	
	Pre-Monsoon (m bgl)	Post-Monsoon (m bgl)	Pre-Monsoon (m bgl)	Post-Monsoon (m bgl)
Gandhi Maidan	3.44	1.33	13.32	10.49
Kankarbagh	4.98	2.95	11.52	8.64
Khagaul	3.31	2.45	9.08	6.49

The groundwater regime of the shallow aquifers has not shown any major change over the years. Long term water level trend of an open dugwell in the urban area (CGWB, MER data) rather shows a slightly rising trend.

Ground Water Resources & Status of Development

As per the provisional figures of the dynamic ground water resource estimation of Bihar (GWD & CGWB 2011), the replenishable ground water resource of Patna Sadar block is 43.21 MCM. The stage of development has been assessed as 74.6%. It thus indicates that the shallow aquifer system supplements only a fraction of the total drinking requirement in the urban area. As about 18% of the land use in the Patna Urban agglomeration area is under agricultural uses, shallow aquifers are mainly being tapped through shallow tube wells for vegetable farming being practised in the urban fringe areas. To meet the drinking, domestic and industrial water requirement in the urban area, the deeper aquifers are mainly being used.

Over the last 40 years, the ground water extraction in the urban area has increased from ~40 MCM to ~180 MCM; however, the contribution from aquifer storage is within 1% of the total ground water draft. The total ground water availability in the deeper aquifer within the urban area has been assessed as 1,500 MCM. The depletion in aquifer storage (15 MCM over past 40 years) attributable to the decline in piezometric level is just 1.0 % of the total resource of the deeper aquifer (Dwivedi et al., 2011). It is thus apparent that the high potential deeper aquifers of Patna urban area can sustain the future water demand.

Hydrochemistry

Ground Water from the deeper aquifer which are tapped through deep tube wells have been found suitable for drinking uses. The average EC of groundwater from the shallow aquifer (1100 μS/cm) is higher in comparison to that of the deeper aquifer (440 μS/cm). Concentration of nitrate in ground water from the shallow aquifer has been found above the permissible limit (> 45 ppm) in some parts of the urban area. The mean chloride concentration is also higher in ground water from shallow aquifers (142 ppm) in comparison to the deeper aquifer (41 ppm). Earlier studies by Ghose et al. (1986) and Ghose and Sharma (1986) have indicated high bacteriological contamination in samples from dugwells with Most Probable Number (MPN) count ranging between 1000 and 25000 per 100 ml. In areas where open channel carries sewage and waste water, faecal tests have been found positive in samples from dugwells (Maitra & Ghose, 1992).

Major Ground Water Related Problems

Some of the major ground water related problems pertaining to the urban area are:-

- The water quality of the phreatic aquifers in the urban area exhibits signs of contamination from the surface sources. The contamination is higher in the water logged area, along the open sewage lines and towards the southern part along the Patna bye pass road. Unplanned disposal of solid and sewage wastes is the main reason causing contamination to the phreatic aquifer.
- Threats of contamination of the phreatic aquifer from biomedical wastes (TOI, dated 10/2/2011)
- Decline in the piezometric head of the deeper aquifer (13 cm/year) during the previous 2 decades is another concern.
- The distribution of the high discharge municipal supply wells is concentrated in the eastern and central parts of the city. In this part of the city, the thickness of the deeper aquifer which is presently being tapped is also less as compared to the western and the southern parts.

Feasibility of Rainwater Harvesting and Artificial Recharge

Rain water harvesting and artificial recharge are suitable only for the deeper aquifers of Patna urban area. The area suitable for recharge with minimum depth of the recharge well is indicated in Fig. 7. As the shallow aquifers are barely used and the deeper aquifers are extensively exploited, artificial recharge through combination well may be a feasible option. However, recharge through combination well is to be carefully planned before attempting this option as quality of ground water from the phreatic aquifer is of sub-potable quality at many places. Such combination well is based on Siphon principle (NPRL, 1977) as the piezometric level of the deeper aquifer is lower than the water level of the shallow aquifers in the Patna urban area. A combination well consists of a dugwell section tapping the phreatic zone and a tubewell section screened in the deeper aquifer to be recharged

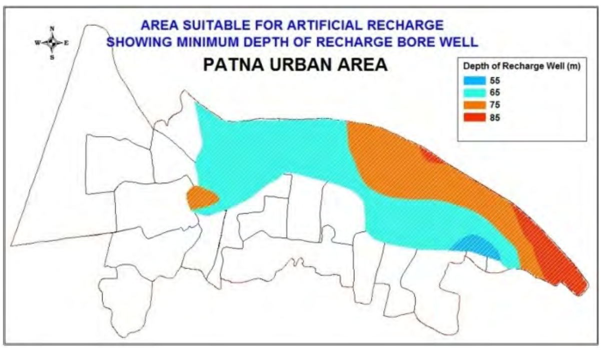


Fig 7 Area suitable for recharge with minimum depth of the recharge well

(Karanth, 1997). The design of the dugwell portion should be such as to sustain full, continuous flow through the tube well section ensuring that the water is naturally filtered. The design of the combination well is shown in Fig 8. The recharge capacity of a well is the maximum rate at which it can take in and dispose of the water admitted at or near its upper end and is approximately equal to the product of the specific capacity and the available pressure head (Meinzer, 1923). The specific capacity of the wells in the Patna urban area has been found varying between 50 and 80 m^3/hr/m. The available pressure head (the difference in the hydraulic head of the shallow and the deeper aquifer) may be considered as 4 m. Thus, the recharge capacity has been worked out as ~1000 m^3/day.

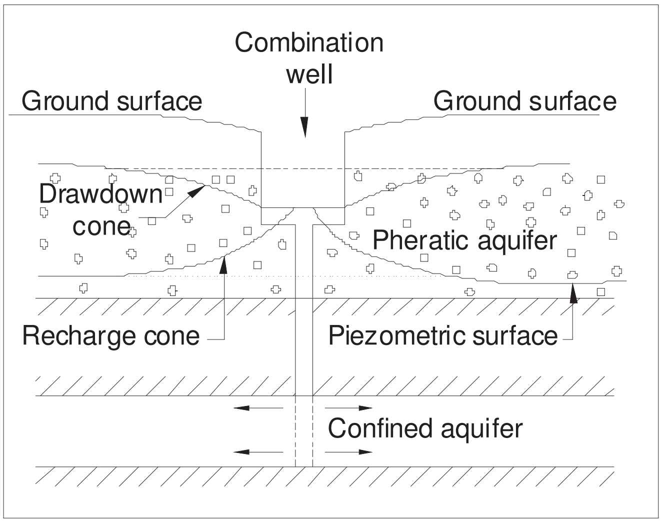


Fig. 8 Design of combination well

GROUND WATER DEVELOPMENT STRATEGY

The Highly prolific aquifer system is capable of long term water supply of the Patna Urban area by adopting a sustainable management plan which should address the following key concerns:-

- There is substantial water loss as well as threats of contamination during transmission through the old distribution pipelines. The unaccounted flow of water (UFW) has been estimated as 40% (JNNURUM 2006) in Patna urban area. Steps should be taken on priority to reduce the UFW to 10% through rehabilitation of the old pipeline network and providing a mechanism for proper water monitoring (i.e bulk metering and consumer metering system).
- The storage capacity in Patna urban area (~ 6% of the total supply) is much below the Central Public Health and Environmental Engineering Organisation (CPHEEO) norms of 1/3rd of the total supply. Owing to insufficient storage capacity, direct supply in the distribution pipelines is made through continuous pumping for long hours leading to high frictional losses (Maitra & Ghose, 1992). Continuous pumping for long hours also causes interference of the drawdown cones in the eastern and the central part of the urban areas which has higher concentration of the water supply wells. There is also uneven supply in different parts of the city which is presumably due to low pressure head at the tail end of the distribution network.
- The installed capacity of the municipal water supply wells range from 136 to 454 m^3/hr. As the municipal supply wells in general are high discharge wells, it is essential that they be located in areas with higher transmissivity so as to have minimum drawdown, thereby indirectly saving the energy cost of pumping. As the natural growth of the city is taking towards the western part, high discharge wells can be installed in this part of the city to meet the projected water requirement as these areas are better suited for groundwater development from hydrogeological standpoint.
- Artificial recharge of the deeper aquifer in Patna urban area should also be taken as a key component of the sustainable ground water management plan. The intended benefit from artificial recharge is to maintain the piezometric level so as to save the energy cost of pumping in the urban area. The areas suitable for artificial recharge are in the eastern and the central parts of the city. Recharge to the deeper aquifer can be attempted through roof top water harvesting and recharge through wells as well as through combination wells.
- To prevent the shallow aquifer system from the threats of pollution from sewage, solid and biomedical wastes along with other anthropogenic sources, proper arrangements for their safe disposal is essential. It is suggested to dispose of waste as treated effluents in the sewage streams or nalas. Sites for land fills must be selected away from habitations and should be provided by impervious lining. Sewage nalas which are flowing in the city should have both lateral and bottom lining to prevent horizontal and vertical seepage. Sanitary protection around tubewells and dugwells must be made.

- Steps should be taken to generate a reliable data base on the quantum of ground water withdrawal in the urban area. Co-ordination amongst the different agencies dealing with the water supply aspect is desirable to manage the ground water resources in an effective manner.
- To ascertain the detailed configuration of the multi-aquifer system underlying the urban area and account for the inter-aquifer interaction upto the inferred depth of ~ 700 m, deep drilling upto the basement and installation of piezometers in each aquifer system is essential.

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PANAJI CITY, GOA

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INTRODUCTION

Goa is the smallest state of India and is located on the West Coast of India. Panaji is capital city of Goa state. The early administration of Panaji was carried out by the Kadamba Kings. Panaji was often referred to as Pahajani Khali-Pahajani from which Panaji supposedly got its name and khali probably refers to the creeks and backwaters abounding in this area. The Portuguese, soon after the conquest of Goa, refer to Panjim as Panaji or Ponji, which is said to mean '**the land that never gets flooded'**. It is also said that the word Ponji is derived from Panch Yma Afsumgary or five wonderful castle where the Muslim king-Ismail-Adil Shah and his wives used to live. Its name was later changed by the Portuguese into Panjim.

In 1510, when Portuguese occupied Goa, Panaji was a small ward in Taleigao village. The only prominent construction in Panaji was the 15th century castle built by Adil Shah on the Southern bank of the Mandovi River. In 1759, when the abode of the Viceroy Count of Ega was shifted to Panaji, the old castle build by Adil Shah was completely remodeled and a palace was built. This palace, which was used as the Government Secretariat during the Portuguese period, initiated some kind of growth spurt in the city.

On March 22nd 1843, Panaji was officially declared as the capital of Portuguese Goa. Portais, Fontainhas and Boca da Vaca are the oldest settlements which developed around two freshwater springs. These old residential areas are characterized by narrow streets edged by low rise houses and bungalows. Several important buildings were constructed in Panaji between 1826 and 1870. The residential areas of Altinho and Campal were opened for development in 1893 but actual growth took place between the years 1929 and 1940. Development spread along the seafront towards Cabo and Dona Paula during later period. Portuguese Viceroy, Dom Manuel De Portugal E Castro carried out extensive works of reclamation and leveling of sand dunes of the area and starting from Old GMC hospital Complex and covering the whole of Campal and Miramar till Tonca. Post 1961 after Goa became part of Indian Union, the area around Miramar beach was opened to development. The new Patto complex which is a high rise commercial complex was designed and executed after the year 1985.

GENERAL FEATURES

Area / Administrative Divisions

Panaji is located on the Southern bank of the Mandovi River and Northern bank of the Zuari River. It lies between the 15^0 27' 00'' - 15^0 30'00'' North latitude and 73^0 47' 00" - 74^0 50' 00" East longitude. The geographical area of the Panaji city is 8.21 sq.kms falling in Survey of India toposheet No 48E/15. (Fig.1). Panaji city has a mixed economic base, the, more significant amongst them are Trade & Commerce, Tourism, Hospitality / Hotel & Restaurants. Being a state & District Head Quarter, the role of administrative activities in the economy became important.

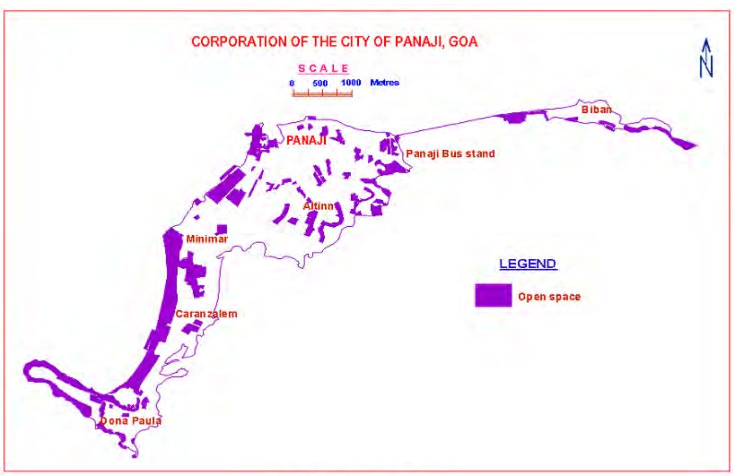

Fig.1. Panaji City, Goa

There are small parks and gardens along a traditional street and square pattern, beaches at its western tip and large open maidans. These are well conceived public open spaces strategically located to enhance the entire structure of Panaji city. Some of those are the Municipal Garden, the Azad Maidan, the Menezes Braganza and the Campal gardens. These small parks and gardens, which were once an integral part of the city, functioned as the city's lungs. The municipal gardens used to play bands to entertain visitors in the evening.

Connectivity: Panaji city is well connected with Highways (No.17 and 4A) with the rest of the nation and it has about 77 kms. of road network within the city with arterial, collector and local level of roads The prominent movement patterns are located towards the central areas of Panaji which houses the prominent natural and built heritage, carnival and festival areas and commercial and accommodation areas along with the administrative, institutional and other departmental offices. This central zone has maximum concentration of pedestrian and vehicular movement.

The D B Road is the most frequented road as it is a scenic route that leads not only to the western tip of Dona Paula which has viewing point, but also to Ribander and further to Old Goa. It is the widest road in Panaji and is designed as a promenade. Several buildings in the central area of Panaji are arcaded and hence provide shaded pathways for the movement of pedestrians. Most pedestrian movement is seen on all the main roads in the central area,which includes Dada Vaidya Marg, A B Road, 18th June Road, M G Road and other which lead to the Kadamba bus station via church square and foot bridge over ourem creek.

Demography

As per the 2001 census, Panaji city has a population of 59,066 (Male: 29,911 and Female: 29,155) and Panaji (Urban Agglomeration) has a population of about one lakhs (Actual figure is 99,677). The population has grown from 35 thousand populations in 1971 to 60 thousand in 2001 (Table.1). Panaji city contributes 4.38% of population of Goa State. It has 13,581 households and an impressive sex ratio of 975 female per 1000 male. The projected population figures are shown in Table.2.

Table : 1 Population of Panaji from 1971 to 2001

Year	Persons	Male	Female	Decadal growth
1971	34953	18577	16376	1.45
1981	43165	22798	20367	+23.49
1991	43349	22542	20807	+00.43
2001	59066	29911	29155	+36.26

Source: Panaji CDP (Primary Source: Census of India)

Table 2: Projected population of Panaji City

Sl.No	Year	Population	Density (per/Sq.kms
1	2001	59066	7211
2	2006	61171	7553
3	2010	69002	8498
4	2015	76415	9411
5	2020	85181	10490
6	2025	95300	11736
7	2030	106772	13149

Source: CDP, Panaji

Hydrometeorology

Panaji city falls in the tropical zone and due in proximity to Arabian Sea has a moderate climate. For most of the year the city experience warm and humid climate. The hottest month is May, during which the temperatures goes as high as 35^0C.The summer season prevails from March to June. Panaji receives rainfall from June to September. The annual rainfall in the year 2010 was 3862.6mm. The winter season prevails from November to February.

Climate : Due to proximity to the Arabian Sea, the city is generally humid with further rise during the monsoon season. During summer months the relative humidity is generally about 60%.

Rainfall : Panaji receives its rainfall mainly during the southwest monsoon (June to September). One rain gauge station located in the city, is maintained by Indian meteorological Department (IMD). The detail of annual rainfall for the period from 2001 to 2010 is presented in the Table 3. The 30 years normal rainfall of Panaji is 2766.9 mm (1971-2000).

Table.3 : Annual rainfall of Panaji city

Year	**Actual Rain fall mm**
2001	2128.1
2002	2270.4
2003	2682.9
2004	2156.0
2005	3345.1
2006	2968.3
2007	3689.0
2008	2829.8
2009	3114.5
2010	3862.6

Source:IMD, Panaji, Goa

Physiography and drainage

Goa is located on the slope of the Western Ghats. Some peaks of Sahyadri Ranges of Western Ghats are located in the Eastern Part of the State. There are three main physical divisions which are the mountainous region of the Sahyadris in the east, the middle level plateaus in the centre and the low-lying river basins, and the coastal plains. Panaji is located on dissected table land characterized by thick lateritic cover followed by low lying coastal plains. It has marine land form towards the west with the elevation ranging from 0 to 57 m amsl. Generally elevation ranges from 0 to 10 m amsl.

Goa has an extensive network of river systems. Important rivers among them are Terekhol, Mandovi, Zuari and Talpona. Among all the rivers Mandovi is considered the most important. Panaji city has one small drainage which originates from Altino hills and joins in the Mandovi river near Champal area.

Soil Type

Soils of the city can be grouped into two classes namely Lateritic soils which are confined to Altiho hills and foothill areas and also in Donapaula area. Remaining area is covered by coastal alluvial sand and clay. Beach sand is occurring on Miramar beach area.

STATUS OF WATER SUPPLY AND DEMAND

As per data of the Public Work Department (Water supply), presently, the town is supplied with **11** MLD of water at the rate of 180 liters per capita per day from OPA water works, Ponda. There is no shortage of water to the city.

WATER PROFILE

As mentioned above, The city is fed by surface water source from OPA water works. Duwells and few bore wells in the area also cater the needs of domestic water to some extent.

GROUND WATER SCENARIO

Goa state is dominantly covered by the rocks of the Goa Group belonging to Dharwar Super Group of Archaean to Proterozoic age, except for a narrow strip along the north eastern corner which is occupied by Deccan Trap of Upper Cretaceous to Lower Eocene age. The Goa group is consisting of green schist facies and is divided into Barcem, Sanvordem, Bicholim and Vageri formations in the ascending order of super position.

Panaji town is underlain by metagreywacks and argillites of Savordem Formation of Goa Group. The metagreywacks is fine to medium grained, hard compact, faintly schistose in nature and dark green to greenish black in colour. During Sub-Recent and Recent times, the rocks have been lateritised capping the older country rocks . The thickness of laterites varies between 18 to 40 m bgl, followed by lithomargic clays at the bottom. The laterite on the top of Althno and Donupaule areas is very hard.

Recent marine deposits consist of sands, gravels, pebbles having intercalatuions of clays and silts. Aeolian sand also occurs on the top of the marine deposits and Beach sand deposits occur along the coast (Miramare).

Potential Aquifers

Ground water occurs under phreatic condition in beach sand. laterites and weathered crystalline rocks in shallow zones. The occurrence and movement of groundwater in the crystalline rock is along the weathered and fractured zones.

Laterite is the most important water-bearing formation in and around the Panaji town, which covers over 60 percent of the city area. The lower section of the pallied zone, i.e., lithomarge, serves as an effective aquiclude. Secondary laterite of detrital origin is good groundwater repository because of its opening and loosely cemented zones. Besides the inherent porosity, the laterites are highly jointed and fractured, which further enhances their water-bearing capacity. Like other formations, the degrees of weathering and topographical setting of laterites have a definite role to play in deciphering ground water potential.

The thickness of laterites in the Panaji town area varies from 18 m to 40 m bgl and most of the dug wells are tapping laterites aquifers. Depth of the dugwells range from 6.00 m to 10.00m bgl. Depth to water table ranges between 1.50 and 6.70 m bgl. The diameter of the dug wells ranges from 2.00 m to 5.00 m. Specific capacities varies from 1.73 to 3205 m^3/day/m.

Bore wells have been drilled in the Althino platean, Panaji by PWD(PHE), Govt of Goa to a depth of 48 mbgl at the foot hills which indicated that the thickness of the over burden (laterites, lithomargic clay and highly weathered argillites) is up to 50m bgl. The moderate weathered/fractured zones constitute aquifer zone in argillites and reported yield from the bore well is 3.6m3/hr.

Three deposit wells have been drilled by CGWB in the Panaji town area i.e in Donapaule area during 1985 for augmentation of water supply for irrigation and other purposes. The depth of wells ranges from 22.05 m to 79.0m bgl. The static water level ranges from 1.44 m to 18.0 m bgl. Details of the bore wells are presented in the Table.4.

Table.4. Hydrogeological details of Panaji town

Sl No	Location	Drilled by	Total depth (mbgl)	SWL (mbgl)	Discharge (lps)	Aquifer
1	Caboraj-I,	CGWB	40.0	1.66	1.0	Lateritic gravel
2	Caboraj-II,	CGWB	79.0	18.0	1.0	Lateritic gravel
3	Caboraj-III,	CGWB	22.05	1.44	1.0	Sand
4	Western part of	PWD	3.37	1.99	-	Coastal Alluvium
5	VelisBhat st.inez	PWD	28.00	-	-	Coastal Alluvium
6	Bhatlem	PWD	48.0	-	-	Argillite
7	PWD Office Dn.IX	PWD	29.0	-	-	Coastal Alluvium

The beach sands along the coast are characterised by their primary porosity. The groundwater occurs in the inter-granular pore spaces of sands, gravels and pebbles with intercalated clays muds and silts serving as limited aquicludes. The gravel beds occurring at different depths varying from 1 to 8 m bgl in the beach sand deposit and these are the most important water bearing horizons of the beach area. The aquifer zone consisting of sand gravel and pebble occur at depth range of 1.00 to 18.00 m bgl. The depth to water levels rests around 2.00 m to 4.00m bgl. Specific capacities varies from 27.10 to 200.78 m^3/day/m.

Long-Term Water Level Analysis

Karanjhalen Network Hydrograph Station is situated in Panaji town area. The data for this station shows a rising trend in ground water levels for the period from 1994 to 2010 (Fig.2).

Springs

Panaji has two fresh water springs namely Fonte Phoenix and Boca da Vaca. On the eastern side of Altinho Hill is the Fonte Phoenix or the Fontainhas spring and on the western side of the hill and close to Mahalakshmi temple is Boca da Vaca. Initially Boca da Vaca spring served as the major source of water supply for the city. The discharge of these springs ranges from 0.02 to 0.53 lps.

Hydrochemistry

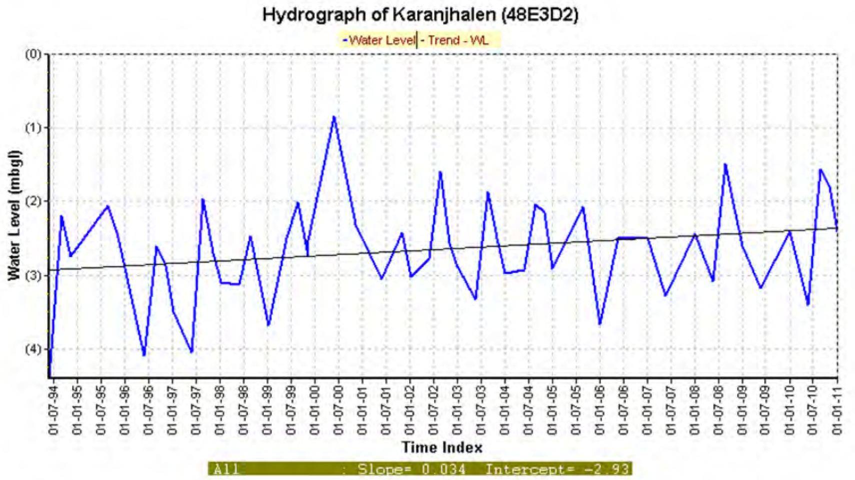

Fig.2 Long term hydrograph of Karanjhalen network hydrograph Station

Seven dug well water samples collected from Directorate of Health services, Govt of Goa and have been analyzed for assessment of suitability of water quality given in Table 5. The ground water is used for drinking and domestic purpose. It is observed that concentration of all the chemical constituents ground water are within desirable to permissible limit in water sample drawn from Chaitanya Appts area in Caranzalem. However, ground water occurring in dug wells as well as bore wells is brackish to saline in areas adjacent to the coast and tidal areas due to seawater. Salinity is more pronounced during May when fresh water flow is minimum and maximum seawater ingress takes place.

Table 5 Hydro chemical parameters of ground water in Panaji town

Sl No	Location	Source	PH	TDS Mg/L	TH Mg/L	Ca Mg/L	Mg Mg/L	Total Alkalinity Mg/L	Cl Mg/L	SO_4 Mg/L	NO_3 Mg/L
1	Sequerira petrol pump area	Dug well	7.1	115.0	62.0	20.0	2.9	50.0	24.9	7.3	7.8
2	St.Inez area	Dug well	6.9	205	125.0	3.6	18.2	105.0	32.0	17.2	5.5
3	Miramare ara	Dug well	6.8	278.0	188.0	60.8	8.7	150.0	29.0	25.0	Nil
4	Campal area	Dug well	6.5	361.0	180.0	52.0	12.2	50.0	92.3	22.5	18.7
5	Caranzelem area big well	Dug well	6.5	330.0	202.0	54.5	16.0	115.0	57.0	34.0	Nil
6	Caranzelem area small well	Dug well	6.6	375.0	168.0	54.0	8.0	135.0	50.0	29.0	Nil
7	Chaitanya appts, Carnzalem	Dug well	2.8	1155.0	320.0	32.0	58.3	Nil	490.0	310.0	Nil

Bacteriological Analysis:- To know the bacteriological organism of ground water in Panaji town, 13 dug well samples data have been collected from Directorate of Health services, Govt of Goa. The results of the bacteriological organism are furnished in Table 6. The perusal of table 6 shows that 7 dug well samples are having high concentration of coliform organisms and acid and gas formation in lactose groth at 37°C is positive as per standard proposed by BIS-1991 and is indicating non potable. Rests of six samples are having concentration of coliform organism within permissible limit.

Table 6 Bacteriological Parameters

Sl No	Location	Source	Bacteriological organism		Status
			Coliform	Acid and Gas formation in Lactose broth at 37°C	
1	Sequeira petrol pump area	Dug well	Nil	Negative	Potable
2	St.Inez area	Dug well	Nil	Negative	Potable
3	Mahalaxmi temple	Dug well	Nil	Negative	Potable
4	Cama Pinto road	Dug well	Nil	Negative	Potable
5	Chaitanya Appts, Caranzelem	Dug well	Nil	Negative	Potable
6	Fontainhas, Mala	Bore well	Nil	Negative	Potable
7	Campo Verde Agl Caranzelm	Dug well	14	Positive	Non-Potable
8	Campal area	Dug well	14	Positive	Non Potable
9	Miramare area	Dug well	11	Positive	Non-Potable
10	J.B.Store, Mala	Dug well	14	Positive	Non Potable
11	Souza Towers	Dug well	14	Positive	Non Potable
12	Ribander	Dug well	12	Positive	Non Potable
13	Dona Paula	Dug well	14	Positive	Non Potable

Stage of Ground Water Development

Stage of ground water development is 55% (as on March 2009 for Tiswadi block) and the area as a whole falls in **SAFE** category. There is scope for further development of ground water resource.

GROUND WATER DEVELOPMENT STRATEGY

Deeper ground water abstraction structures should be at least 0.5 km away from creeks and 400m away from coastline in low-lying areas to avoid quality problems. Due to complexities of formations, structure and morphological control, ground water development through shallow dug wells is ideal for the area. Caution is to be exercised while ground water is developed through bore wells. Deeper ground water abstraction structures should be at least 0.5 kms away from coast line in low lying areas to avoid quality problems.

Ground water occurring in dug wells as well as bore wells is brackish to saline in areas adjacent to the coast and tidal areas due to seawater ingress in inland aquifers. Salinity is more pronounced during May when fresh water flow is minimum and maximum seawater ingress takes place. Investigations have revealed that ground water adjacent to stream course in the north east of Panaji is also polluted due to domestic sewage in addition to salinity problem. Hence, periodical ground quality monitoring is a must for the area to use the ground water for potable purpose.

PORTBLAIR TOWN, ANDAMAN & NICOBAR ISLANDS

Amlanjyoti Kar, CGWB, Kolkata

INTRODUCTION

The town of Port Blair named after the British Marine Surveyor Mr.Archibald Bair. At the behest of the then East India company, he discovered it in the year 1774 for Penal Settlement. Because of several difficulties including availability of water, the settlement could not properly flourish. However, from 1859, immediately after the Sepoy Mutiny, penal settlement started with the establishment of the office of Chief Commissioner of British colonial govt at Ross Island (Fig-1). The population of Port Blair also started accruing with the settlement of the banished convicts in the small islands(i.e in Chatham, Viper , Hopetown etc.) and in small patches in and around Port Blair.

Fig-1 View of Ross Island

To cater the drinking water need for the population, the British rulers constructed few dug wells and number of ponds to harvest copious rainfall in the settlement areas and observed the problem of insufficient potable water availability right from the beginning. Many such ponds still exist in Port Blair and at Viper and Ross Islands. At Ross Island they even used to utilize the pond water for potable Mineral water production as early as in the eighteenth century.

Earlier water requirement was somehow managed because of less population. But after indendence severe water scarcity felt due to exodus of people. The Mega earthquake and Tsunami on 26th December, 2004 made an appreciable impact on civil structures and water sources in and around Port Blair Town. The tourism industry, the backbone of the economy was hit hard in the Post-tsunami which was also coupled with water scarcity situation. For the full-fledged growth of tourism industry which is one of the main source of economy for the people, judicious planning in the water sector would be vital for a sustainable development and growth of Port Blair town .

GENERAL FEATURES

Area / Administrative Divisions of Port Blair Town

The Port Blair town,the capital town of the Union Territory of Andaman &Nicobar Islands, falls in the south Andaman Island (Fig-2). The A&N Islands have 572 small, medium and large islands of which 36 are inhabited. Port Blair is located at a distance of 1255 Kms from Kolkata,1190 Kms from Chennai and 1200 Kms from Visakhapatnam in sea route and connected to Kolkata and Chennai through regular air services.

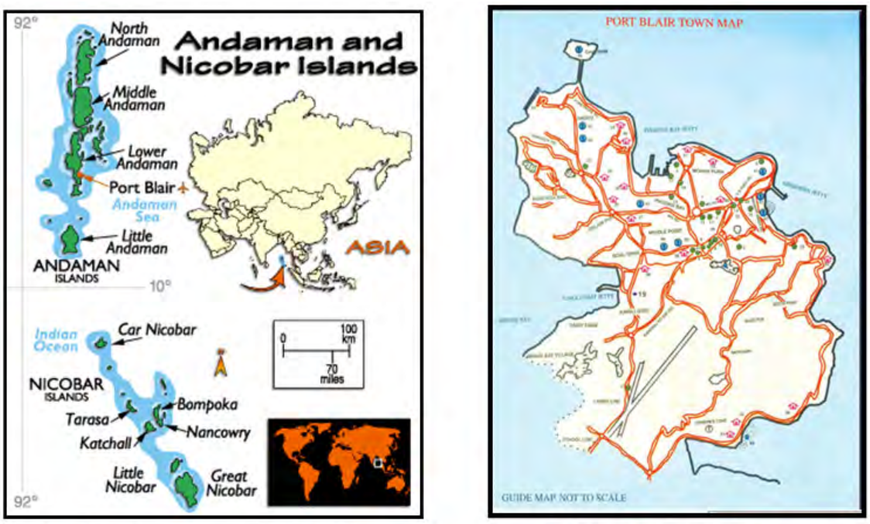

Fig-2 a. Location map of Port Blair b. Map of Port Blair Town

The town of Port Blair (Fig-2b) has grown slowly since its inception. However the town area expanded considerably with the population explosion in Post nineties. The urban centre of Port Blair is run by Port Blair

Municipal council which is having a current jurisdiction area of 16.64 sq.km., incorporated in 18 Municipal wards. During 1991 census the ward numbers under the Municipal council was only 11 which was expanded to 18 before the 2001 census .

Demography

The population of Andaman till 1951 includes only the population of Port Blair, population of the penal settlements in parts of South Andaman and Maya Bunder in North Andaman. Noticeable rise in the population observed in sixties, early seventies, as also from nineties. This happened due to two factors: i) Rehabilitation of displaced persons from East Pakistan now Bangla Desh ii) Exodus of people especially from South India and West Bengal in search of Livelihood. With rapid changes in demographic pattern, the water sources have disappeared at many places with the destruction of hills and rain water recharge areas. Many perennial springs either vanished or ceased to flow. Random encroachment in and around the Port blair town has caused constriction of the reservoir capacity of many ponds and pollution of the water sources. As per 2001 census, the population of Port Blair urban area was 99984,consisting of 55373 males and 44611 females.

Hydrometeorology

The relative humidity in Port Blair varies from 79% to 89% ,while the wind speed varies from 7 km/hr to 10km/hr. The maximum and minimum ambient temperature fluctuates between 27 to 33^{0}c and 21 to 25^{0}c. Daily evaporation rate in Port Blair is fairly high which cumulatively ranges from 1500-1800 mm. per annum . The effect of global warming and climate changes are also influencing the rainfall pattern in the Archipelago. This can be quite evident from the rainfall record in the islands. In the current decade the rainfall distribution has become highly erratic and dwindling. Prior to 1990 the rainfall used to commence from 1st week of April every year, while now it has been receded to the end part of May to 1st week of June as happened in 2001, 2002 and 2003. In 2002 the situation was so worse that Dhanikhari dam got dried up and the Port Blair town water supply was totally shattered. Barring 2004 which recorded a rainfall close to normal, in the last few years in the Post-tsunami the same vagaries of rainfall continues. Occasionally there was excessive rainfall as observed in 2008 (4152.6 mm) or very close to normal i.e. 2010(3016.6 mm) , otherwise in majority of the occasions, the downpour was below normal(2005,2006,2007&2009).

Physiography and drainage

The area in and around the town of Port Blair is highly undulating. Small to moderate high hills with intermontane valleys are the main topographical features. Drainage system in and around the town of Port Blair has not been developed properly rather it is almost absent. Few perennial streams can be observed i.e. the stream flowing in the east of Nayagoan - Chakragoan Diggi and the stream flowing adjacent to the Mazhar. Besides these, there are few perennial and many other non-perennial streams which carry lot of surface run-off water to the sea during rainy season.

Soil type

Mostly clayey to clayey loam soils could be observed in an around Port Blair town which has been derived from the underlying siltstone-shale-fine grained sandstone sequence of Tertiary Flysch deposits and Mithakari Formations.

STATUS OF WATER SUPPLY AND DEMAND

The distribution of water supply system for Port Blair urban area has been designed by the CPHEEO to meet the projected requirement of water up to 2011 considering 120 litres Per capita per day (lpcd). The present and future water supply requirement up to 2025 for the Municipal Council area including extended areas is given below considering 135 lpcd from 2011 onwards. Presently only 139 lakhs liters of treated water is being supplied by PBMC from various treatment units of APWD against a demand of 288 lakhs liters Thus there is a short fall of 149 lakhs liters i.e 51.75 % due to which water is supplied to the public on alternate day. Total requirement of water for present and the future up to 2025 has been given in (Table-1)

Table-1 Total requirement of water in Port Blair town.

Years	Requirement based on population (Lakh litres)	Requirement of institution (lakh litres)	Total Requirement (Lakh litres)
2001	160	44	235
2011	248	60	354
2021	338	78	478
2025	385	101	559

Source: APWD, A&N and PBMC

WATER PROFILE

The water supply to the Portblair town is mainly catered from the Dhanikhari reservoir and also from few ponds and wells. After the discovery of Rutland spring sources by CGWB(Kar,2002a), water supply through barges is also carried to the Port Blair town for supply to the ships. In the years of water scarcity, the water supply is drastically cut down by the APWD and only twice to thrice in a week the water supply is given to the urban area. The old wells in Port Blair and the successful bore wells of CGWB in the rural areas of Port Blair helps significantly in times of acute shortage. Currently a desalination plant has been installed by APWD in G.B.Pant hospital which is under operation.

GROUND WATER SCENARIO

The town of Port Blair i.e. the Port Blair Municipal Council area is underlain mostly by the Marine Sedimentary group of rocks (Fig-3) comprising shale and fine grained cemented sand stones which are seen to be exposed in small laminations Only in parts of Ward No. 17, in Brookshabad area and in Austinabad area (adjacent Ward No. 18) volcanic & intrusive rocks are available. Porous coralline formations which are available in many islands, are absent in and around the town of Port Blair barring a small patch of coralline sands occur nearby Corbyn's cove beach and Peerless Beach Resort Hotel.

Fig- 3 Bedded marine sedimentary shale with sand stone intercalations

Potential Aquifers

Detailed hydrogeological studies carried out by CGWB revealed that the Marine sedimentary rocks comprising shale and fine grained sandstone do not form good repository of ground water. (Fig4) A dug well properly sited in low topography and 4.5 to 5 m dia, 6 m deep can yield 3000 to 5000 liters per day. Where as the dug well in Peerless Beach resort (underlain by coralline formation)with lesser dia (3 metres) yielding over 15,000 litre per day. In volcanic rocks

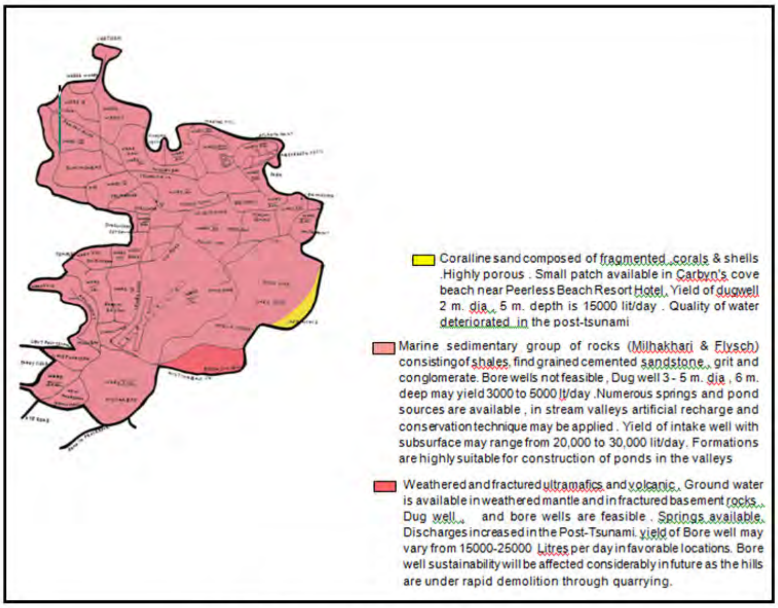

Fig-4 Hydrogeological map of Port Blair town

(Brookshabad area) groundwater development is possible through borewells. The exploratory drilling programme of CGWB revealed that the Marine sedimentary group of rocks in and around the town area did not yield even at greater depth (200 m). However, it may be opined that for ground water development, drilling is not feasible in major part of PBMC area, except in Brookshabad area in selected location.

Ground Water Level

Groundwater level always depicts the situation of topography, recharge from rainfall via-a-vis ground water development as also the potentiality of the aquifer in an area. The aquifer in major part of the town is underlain by impervious Sedimentary rocks. The aquifers have poor yield potential. Hence the water level in the town replicates the topography of the area. In the lower topographical places it is close to ground level where as in higher topographic locales it is more. The water table in the Town is monitored twice in a year from the established Hydrograph Network Stations. Average long term water level trend shows rise in water level in and around the town. The depth to water level and long term trend are shown in table 2 and 3.

Table2 Depth to water level (mbgl) of Network Hydrograph stations in Port Blair Town during 2009-10)

Well Type	Locality	M.P.	Depth	Dia	Water Level	
					May-09	Dec-09
Dug Well	Portblair(Sampat Lodge)	0.67	10.56	3.17	3.92	1.88
Dug Well	South Point(port Blair)	0.49	5.85	1.03	0.2	0.51
Dug Well	Corbyn's Cove(port Blair)	0.68	4.40	2.46	2	2.65
Dug Well	Shadipur(port Blair)	0.60	7.57	1.85	1.35	1.52
Dug Well	Brookshabad (Port Blair)	0.40	2.60	2.70	1.13	0.17
Dug Well	Junglighat (V I P Road)	0.00	4.50	1.50	0.56	8.44
Dug Well	Marina Park	0.56	3.30	1.06	0.73	0.67
Dug Well	Port Blair (Dobhi Well)	0.61	3.85	2.34	1.78	1.51
Dug Well	Light House	0.25	4.74	3.17	0.92	0.79

Table-3 Water level trend from the Hydrograph Stations in Port Blair Town (1999-2008)

Village	No of data	Rise (m/yr)	Fall (m/yr)
Austinabad(port Blair)	17	-	0.010
Brookshabad (Port Blair)	20	0.155	-
Corbyn's Cove(port Blair)	19	0.076	-
Junglighat (V I P Road)	16	-	0.225
Light House	12	0.378	-
Marina Park	13	0.193	-
Port Blair (Dobhi Well)	12	0.182	-
Portblair	17	-	0.118
Shadipur(port Blair)	18	0.126	-
South Point(port Blair)	17	0.177	-

Changes in Ground Water Scenario in and around Port Blair in the Post Tsunami Period

After the Mega Earthquake (M=9.3) and tsunami on 26.12.04, ground water resources in and around the Port Blair town were affected significantly. The surface water sources in the low-lying areas were contaminated by the sea wave having a height of nearly 1.2-1.5m in and around the town area adjoining sea coast. Due to plate collision, the urban area was also subsided for a depth of 1.0 to 1.2m which facilitate regular ingress of sea water in the town and its periphery through the creeks, sewer drains and the valley areas. To stop the ingress, the strategic areas were immediately raised through earth and rockfills by the A&N Administration and Port Blair Municipal Council (PBMC) and currently the inundation problem is stopped. Change in Aquifer characteristics shown in Table-4

The potential earthquake had influenced the ground water table. Ground Water level in higher topographical areas was declined while new springs were generated in the lower topographical locales and water level in the wells located in the valleys and coasts were increased . The rise of water level observed near Light House

Cinema &Gandhi Bhawan, Port Blair (Table 5). Here the water level is still remaining in elevated condition. New fractures also changed the aquifer characteristics .However, at many places the water level situation has been bounced back to the pre-tsunami condition while at places the change is still persistent. Both the qualitative and quantitative changes in the Post-tsunami was monitored continuously by CGWB (Kar et. al,2005,2006).

Table- 4 Change in aquifer characteristics of a select well in low altitude of Port Blair, Post-tsunami

Island name	Location	SWL(m) Pre-tsunami With date	SWL(m) Post-tsunami With date	Yield , Duration of pumping,Pump capacity, drawdown, Recuperation, **(Pre-tsunami)**	Yield ,Pump capacity, drawdown,Recuperation, **(Post-tsunami)**	Remarks
1.South Andaman, Port Blair	Peerless Beach Resort Hotel	Depth-6.3m Dia-2.65m S.W.L-4.76m(07.2.04)	S.W.L-1)G.L(26.12.04) 2)1.89m(4.1.05) 2)3.69m(22.4.05) 3)2.8m (22.2.06)	1.Yield(Per day)-7000 litres/day(290 lit/hr) 2.Duration of pumping per day-2 hrs 3.Pump capacity-5 hp(diesel) 4.Drawdown- 1.3m 5.Recuperation-1.3m in 24 hrs	1.Yield(Per day)-40500 lit/day(1690 lit/hr) 2.Duration of pumping per day-3.Pump capacity-5 hp(diesel) 4.Drawdown-3.24m 5.Recuperation-2.15m in 7 hrs.	S.W.L&Yield increased

Table-5 Rise in water level in Select dug wells in low altitude in Andaman District

Island name	Well location	Depth (m)	S.W.L(Pre-tsunami with date)	S.W.L(Post-tsunami with date)	Remarks
S.Andaman Port Blair	Near Gandhi Bhawan	4.74	4.39(03.5..04) 2.99(6.12.04)	1.14(9.1.05) 1.32(11.3.05) 1.30(23.2.06) 0.54(10.8.06)	Rise in Water level Continuing
S.Andaman Port Blair	Sampath Lodge	10.56	8.06(3.5.04) 5.56(9.12.04)	6.55(9.1.05) 1.28(11.3.05) 1.18(10.8.05) 1.64(12.12.05) 3.55(23.2.06) 4.10(10.8.06)	Well showed peculiarity in W.L.change. First no change after e.q. Then sudden rise. Continuation for some time again attaining old situation
S.Andaman Port Blair	Dhobigat Near Power Hose	3.85	3.35(3.5.04) 2.69(9.12.04)	1.55(9.1.05) 2.23(11.3.05) 1.60(10.8.05) 2.70(23.2.06) 0.58(10.8.06)	Rise in Water level continuing

Hydrochemistry

Analysis of ground water samples collected from the dugwells and also from exploratory borewells constructed in the area, revealed that the quality of water is fresh and fit for all purposes. However, in view of plate collision and subsidence after the earthquake and Tsunami on 26.12.04, a qualitative change has been noticed in the groundwater samples collected from parts of the affected areas in the town. The qualitative change is still persisting.

Major Ground Water Related Problems

The geologic formations in and around Port Blair town are highly varied and major parts are occupied by impervious sedimentary rocks where ground water development possibility is low . These rocks are not suitable for construction of borewells/tubewells. Dugwells are feasible in such formations but yield is restricted. A dug well of 2-3m diameter and 5m depth can only yield 2000-3000 litres per day. However in select locations especially near the drainage it may discharge in much higher tune. In Port Blair municipal area only in Brookshabad the igneous rocks in area of bore wells can be drilled in specific areas. In a small patch near Corbin's Cove adjacent to Peerless Beach Resort where moderate quantity of water could be available from shallow and porous Coralline limestone Formations through dug wells, where the quality of groundwater has been slightly deteriorated in the post-tsunami period.

Feasibility of Rain Water and Artificial Recharge

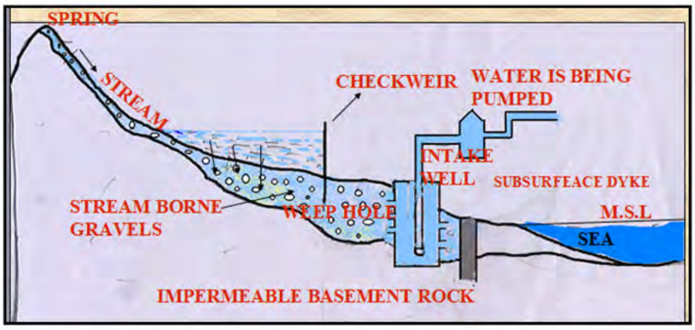

Fig-5 Model of Artificial recharge and conservation structure applied in pockets of Port Blair town

While the impervious sedimentary formations are unfit for groundwater development, these formations are highly suitable for construction of ponds especially feasible in the valleys and topographic lows where it get ground water and alsoact as a very good rainwater harvesting structure. Consequently the low-lying areas as opined by CGWB(Kar,2003,2005,2006,2007) can be developed for construction of ponds as also reservoirs. Artificial recharge techniques also could be applied (Fig.5) only in small pockets which were suggested by CGWB (Kar,2001,2003). Many of these recommendations are already implemented by PBMC (Port Blair Municipal Council) and APWD (Andaman Public Works Department).

GROUNDWATER DEVELOPMENT STRATEGY

During Pre-Tsunami Period

To overcome the shortage of water supply to the Port Blair town as also in view of severe water scarcity in 2002, the following short, medium and long term options were adopted by APWD in the pre tsunami period. The Short term options included i) Carrying water from Chain Nallah(Rutland island) through barges for supply to the ships at Port Blair by Port Management Board and Ii) Taping the ground water sources(dug wells) and Ponds in Port Blair town suggested by CGWB. Medium term options included Carrying water from Rutland through pipe lines, raising of Dhanikhari dam, water from Chouldari project & Indranala project. The only long term option which was planned in the Pre-tsunami was completion of Flat bay project. This project was designed for augmentation of water supply to the tune of 67 MLD, keeping in view of projected demand up to 2050. In this project there was a proposal to make an earthen dam in between Minnie Bay and Mithakhari village where Flat Bay is constricted. The project was abandoned after tsunami.

Post-Tsunami Period

It is already mentioned that the water scarcity in Port Blair town water supply was aggravated in the Post-tsunami. To tide over the crisis, various short, medium and long term options were adopted.

The short term options included to increase the water availability of Port Blair town from the Springs of Rutland through Barges, Urgent installation of Desalination plants in turn key basis to increase the immediate potable water availability at Port Blair and use of Dug well Sources. Medium term options include Fresh water lake Project near Sippi-Ghat and augmentation from Pond sources, while the Long term options include Raising of Dhanikhari Dam, Inter-island transfer of Spring water from Rutland island and water supply from Indranala project.

Besides the above, the following three options may also be considered for better management of water supply in the town:-

Water sources for catering raw water need in Port Blair town:- In connection with the ongoing constructional work huge quantity of fresh raw water is daily required in Port Blair town. For this purpose the use of Dhanikhari water should be stopped if it is under utilization. For this purpose small reservoirs or sources may be created to cater water for the said purpose. The Pond water also can be supplemented to the requirement.

Large Scale Roof top rainwater harvesting in all houses and institutions:-Rainwater harvesting in each house and Government and Private institutions may be introduced. The rain water may be conserved in over surface or sub-surface cisterns and should be regularly utilized for household uses, gardening, car washing etc.

From the preceding chapters it is clear that a good amount of fresh water can be generated for sustainable water supply in Port Blair town. The options can augment a volume of 50.23 Million Litres of additional fresh water supply per day to the town. The approximate water availability from various sources are given below (Table-6).

Table-6 Augmentation of water supply to Port Blair town from Short, Medium and Long term options in the Post- tsunami Period

Options	Name of the sources	Tentative water availability (lakh litres/day)	Remarks
Short term option	Water carriage from Rutland through barges.	0.5 mld	*Among the Long term option Flat Bay project was most important in the Pre-tsunami having a tentative yield of 67 mld which was abandoned due to land subsidence in the post-tsunami.
	From desalination Plant.	14 mld	
	New well sources in Port Blair.	0.39 mld	
Medium term option	Sippighat fresh water lake.	5.6 mld	
	Pond sources.	0.34 mld	
	Creation of new reservoirs in and around Port Blair.	2.9 mld	
Long term option (*)	Raising of Dhanikhari dam.	13.5 mld	
	Inter Island transfer of Rutland spring water.	12 mld	
	Indra Nallah Project.	1.0 mld	
Total water availability Million Lakh litres(mld)		50.23 mld	

Source: APWD,A&N Admn.

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PUDUCHERRY CITY, U.T.

D. Dayamalar, CGWB, Chennai

INTRODUCTION

Historical researches go to show that trade contact existed between the Romans and the inhabitants of the Puducherry area in the long centuries of Christian era. The French like the British, the Dutch and the Portuguese who had established their markets at Surat on the west coast in the 17^{th} century were officially invited by Sherkhan Lody, the then Bijapur commandant of Valikondapuram (near Perambalur, in erstwhile composite Trichirapalli district) to settle down in his government. The French landed at Pondicherry (Poudicheri) on 4^{th} February 1673 and began their occupation. In course of time they expanded their colonial and trade activities and the subsequent recorded history unfolds how the French supremacy held sway over a great part of India, south of the Deccan and underwent rises and falls in fortunes. In 1701, the French Government at Paris recognised the importance of Puducherry town and established a sovereign counsel to aid and advise in the administration of the colony. During 1793, there was internal disturbance in Puducherry and the Britishers utilised this opportunity to gain Puducherry under their control upto 1815.Consequent upon the Treaty of Paris, 1814, the French got back Puducherry, Karaikal, Mahe and Yanam regions during 1816 for governance of the administration by them and since then ruled continuously till 1954.

The French government transferred the above said four enclaves (Viz:-Puducherry, Karaikal, Mahe and Yanam) to the Indian Union on 1st November 1954 under a de facto treaty. Of these Puducherry and Karaikal is in Tamil Nadu coast Whereas Mahe is in Kerala coast and Yanam in Andhra Pradesh coast. But the registration of the treaty of Cession was delayed and ultimately the de jure transfer took place on 16^{th} August 1962. The erstwhile French establishments were constituted into Union Territory of Pondicherry under the constitution (Fourteenth Amendment) Act, 1962. For the proper administration of the territory, the parliament enacted the Pondicherry (Administration) Act, 1962. As the people aspired for a popular government, the parliament enacted the Government of Union Territories Act 1963 and it came into force on 1^{st} July 1963. The territory was given a popular government with elected legislature and responsible government through the council of ministers. The pattern of government prevailing in other parts of India was introduced in this territory subject to certain limitations.

Puducherry of U.T. of Puducherry being agrarian region, special attention needs to be paid for the development of irrigation potential. Due to rapid development of ground water in the region, problems like over-exploitation in entire Puducherry and degradation of quality due to sea water intrusion in the coastal areas have led to problems forcing water managers to adopt suitable strategies for proper management of available ground water resources.

The Head quarter of U.T.of Puducherry is located in Puducherry.

GENERAL FEATURES

Area/Administrative Divisions

Puducherry is situated on the Coromandel coast as scattered isolated patches between $11^{o}45'$ and $12^{o}03'$ N latitudes and $79^{o}37'$ and $79^{o}53'$ E longitudes. It is bounded on the east by the Bay of Bengal, on the north and west by Villupuram and on south by Cuddalore districts of Tamil Nadu state. It is not a contiguous area and is interspersed with enclaves of territory of Tamil Nadu. The region is 293 sq. km. in areal extent and is divided into seven communes namely Puducherry, Ozhukarai (Oulgaret), Bahour, Ariyankuppam, Villianur, Nettapakkam and Mannadipet. Location of Puducherry is presented in Fig. 1. Besides Puducherry municipal town, there are two more towns in the region namely Kurumbapet and Ozhukarai. There are 164 inhabited villages in this region. It represents a picture of scattered parts enclaves within Villupuram and Cuddalore districts of Tamil Nadu. The layout of Puducherry enclaved within Tamil Nadu, presents a peculiar picture of territorial jurisdiction perhaps the only one of its kind in the world. This region has several places of religious, historical or archaeological importance and tourist interest.

Demography

The total population of the Union Territory of Puducherry as per the Census 2001 is 974345 consisting of 486961 males and 487384 females. Out of this the rural and urban populations constitute 33 and 67 percent respectively. The density of population is 2510/sq.km.

Hydrometeorology

The normal annual rainfall is 1205 mm, which is received in four different seasons. The maximum rainfall is during north-east monsoon (Oct to Dec), which brings about 65% of the total annual rainfall, which accounts for about 650 mm. The southwest monsoon rainfall, which occurs between June and September, brings about 350mm rainfall. The rainfall in winter period (Jan & Feb) and hot weather period (March to May) is collectively accounts about 200 mm. The climate of Puducherry is tropical. Both winter and summer are not very severe. The temperature ranges from a minimum of 17^{0}C to a maximum of 42^{0}C. The humidity is comparatively higher, becoming as high as 83% at times.

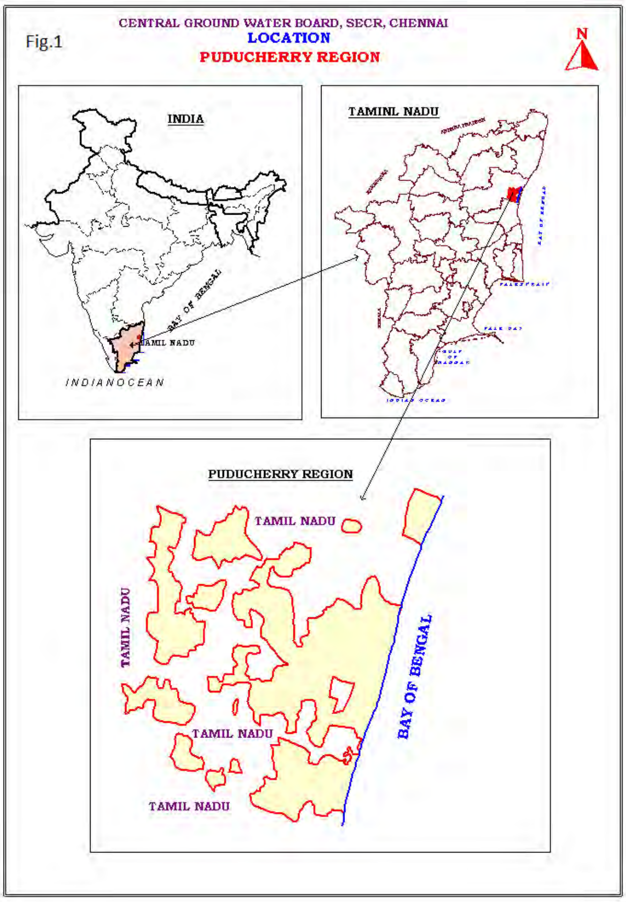


Fig.1

Physiography & Drainage

The Puducherry in general is a flat peneplain with an average elevation of 15 m above mean sea level. The terrain becomes a little undulating with prominent high grounds varying from 30 to 100m above mean sea level towards northwest and northeastern parts of the region. Three major physiographic units are generally observed namely (i) Coastal plain, (ii) Alluvial plain and (iii) Uplands.

The coastal plain extends as a narrow stretch for about 22 km and of four to six hundred meters width on the eastern part of the region along the Bay of Bengal. The major part of the coastal plain comprises gently sloping land with a chain of sand dunes extending all along the coast. Other physiographic units which are characteristic of the coastal plains such as spit bars, mud flats, lagoons and tidal inlets also occur.

The alluvial plain formed due to two major rivers namely Gingee and Ponnaiyar that pass through the area occupies major portion of Puducherry covering the Bahour, Nettapakkam, Ariyankuppam, southern half of Mannadipet and Villiyanur and part of Ozhukarai communes. The alluvial plain in this part in general is a monotonous plain with slope ranging from 1 to 3 percent. The lands in this region are intensively cultivated throughout the year. Besides the rivers and major canals, there are depressions acting as storage tanks, which are spread all over the terrain, to serve as surface water reservoirs. The high grounds known as Uplands with elevations of about 30 to 100m above mean sea level are seen in the north-western and north-eastern sectors of Puducherry covering northern part of Mannadipet, Villiyanur and Ozhukarai communes. These uplands which are popularly known as “Les Montagnes Rouges” or the “Red Hills of Puducherry” are intersected by a number of gullies and deep ravines which give rise to bad land topography. A patch of gently sloping fossiliferrous limestone terrain also exists in the north-western part.

There are two major drainage basins in this region 1) the Gingee river, which traverses the region diagonally from north-west to south-east and 2) the Ponnaiyar (Penniyar) river, which forms the southern border of the region. The river Gingee also known as the Varahanadi or Sankaraparani which has its source in the hills of Malayanur of Villupuram district, Tamil Nadu has a course of 34 km in this region before it confluences with the Bay of Bengal. At a distance of 7 km. from its mouth, it shoots into two branches knowns as Ariyankuppam river in the north and Chunnambar river in the south. The affluents of Gingee river, are the Vikravandi, the Pambaiyar and the Kuduvaiyar. The river Ponnaiyar originates from the hills of Karnataka and enters the Puducherry after flowing through the districts of Dharmapuri, Salem, Vellore and Cuddalore of Tamil Nadu. The Malattar is the distributary of the Ponnaiyar and drains the southern part of the region and finally discharges into the Bay of Bengal near Aladimedu and Pannithittu. All the rivers are ephemeral in nature.

Soil Type

Various soil types found in Puducherry are red loamy, coastal alluvium, red laterite, deep black and red sandy.

STATUS OF WATER SUPPLY AND DEMAND

The water supply and the projected scenario up to 2040 are presented in Table 1. The analysis of the water supply position gives the real magnitude of the problem even after all the possible measures taken by the government so far. A perusal of the table-2 shows that the demand would be around 90.46 MLD (2025) & 114.25 MLD (2040). Presently 60 MLD water is supplied for Puducherry Municipality and oulgaret Municipality. Water supply details are given in Table 2.

Table-1: Present and Projected Population and Demand Details for Water Supply Schemes.

Sewarage zone	Area in Ha	Population in lakhs					Demand in MLD @135 lpcd excluding the loss			
		2001	2007	2020	2025	2040	2007	2020	2025	2040
I	203	0.62	0.67	0.92	1.00	1.25	9.05	12.42	13.5	16.89
II	200	0.45	0.48	0.67	0.73	0.91	6.48	9.05	9.86	12.29
III	440	0.78	0.84	1.15	1.26	1.59	11.34	15.53	17.01	21.47
IV	570	0.84	0.91	1.25	1.36	1.77	12.29	16.88	18.36	23.89
V	640	0.52	0.56	0.77	0.84	1.05	7.56	10.39	11.34	14.18
VI	350	0.39	0.42	0.58	0.63	0.79	5.67	7.83	8.51	10.67
VII	250	0.22	0.24	0.33	0.36	0.45	3.24	4.46	4.86	6.08
VIII	360	0.22	0.24	0.33	0.36	0.45	3.24	4.46	4.86	6.08
IX	236	0.10	0.11	0.15	0.16	0.2	1.49	2.03	2.16	2.7
Total	3249	4.14	4.47	6.15	6.7	8.46	60.36	83.05	90.46	114.25

Table-2: Present water supply in Puducherry urban area

Water supply	*Coverage*
Percentage of house holds covered by protected water supply	100%
Percapita domestic water supply	120 – 135 lpcd
Average number of hours of water	10 hours per day
Quantity of water supply	60 MLD
Percentage of water loss due to leakage	15 to 20%

WATER PROFILE

Surface Water

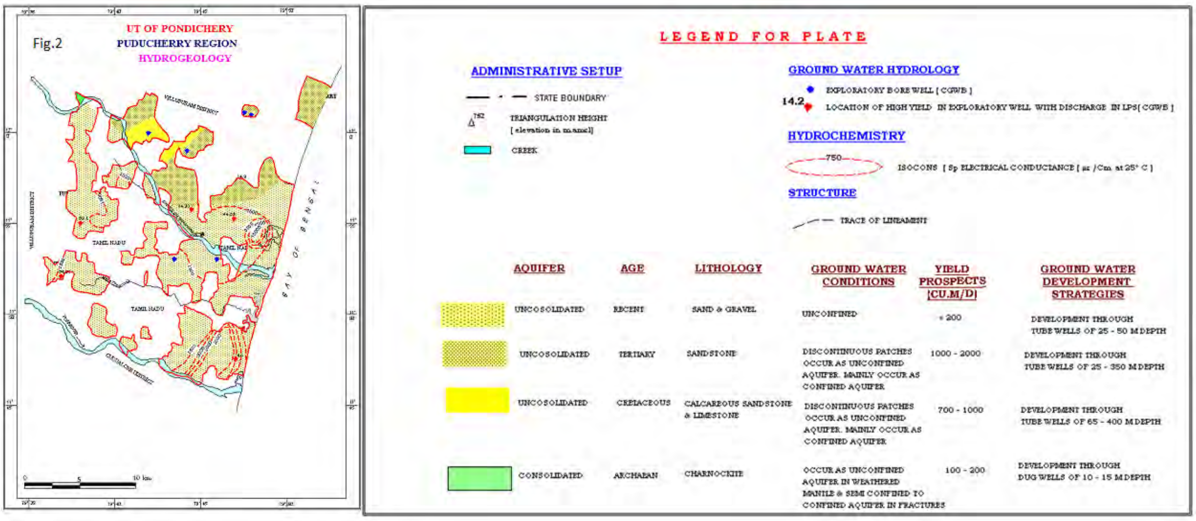
About 140 small and two big tanks viz. Usteri and Bahour lakes, the other important lakes are Oustery lake, Olandai and Murungapakkam lakes. Besides these, there are number of tanks and spring ponds in this region. These tanks are interlinked and act as water storage for agricultural purposes as well as to recharge the ground water.

Ground Water

Ground water occurs in all the geological formations ranging in age from the Achaeans to Recent which can be broadly classified into two hydrogeological units viz., (i) Fissured and fractured crystalline formations and (ii) Porous sedimentary formations.

GROUND WATER SCENARIO

The ground water occurrences can be broadly classified into two hydrogeological units viz., (i) Fissured and fractured crystalline formations and (ii) Sedimentary formations. The yield of dug wells depends on the topography, geology, rainfall and prevailing ground water extraction pattern. There are number of dug wells and dug cum bore wells in the hard rock terrain while tube wells are common in sedimentary terrain. The dug wells yield 20,000 to 50,000 liters/day in summer months and few wells remain dry. The yield of the well is adequate for irrigation for one or two crops in the monsoon period. The yield of bore wells, in favourable locations, varies from 0.2 to 3 lps and sustainable sources are limited to few pockets. The river valley and intersection of lineaments are reported to have potential pockets suitable for dug wells and bore wells. The contact between crystalline and sedimentary tract has variable yield prospects. The cretaceous formations are very compact and yield prospects are low. In the regions, shallow unconfined aquifers are tapped by dug wells and deeper semi confined to confined aquifers are tapped by dug-cum-borewells or tube wells. The Hydrogeology of Puducherry is shown in Fig. 2.



Potential Aquifers

Fissured and fractured formations : The crystalline rocks of Archaean age, consisting of mainly charnockite and gneissic rocks represents the fissured and fractured formations which are confined in the northwestern corner of the Puducherry. These rocks are devoid of primary porosity. The secondary porosity in the weathered, fissured and fractured zones forms the avenues for ground water occurrence and movement. The thickness of weathered zone varies from less than a metre to more than 15 m. below ground level (m bgl) at places. Ground water in this terrain is developed by means of dug wells and dug-cum-borewells. Ground water occurs under water table conditions in the shallow weathered zones and under phreatic to semi-confined conditions in the fissures occurring at depths. The depth of dug wells varies from 4 to 22 m bgl. The yield of dug wells tapping this aquifer ranges between 250 to 400 lpm.

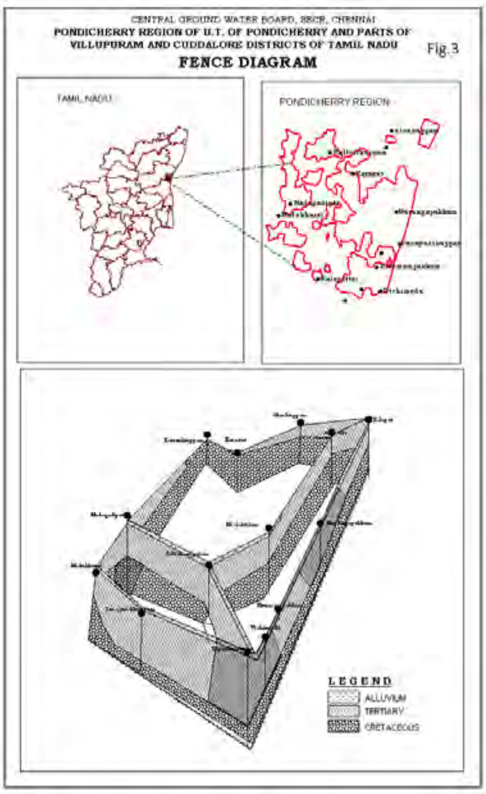
Sedimentary formations : The porous sedimentary formations occur in almost the entire region and are represented by the semi consolidated formations of Cretaceous and Tertiary age and the unconsolidated Quaternary formations of Recent age. Among the sedimentary aquifers, the Vanur-Ramanathapuram Sandstone (Cretaceous) and the deep Cuddalore sandstone (Tertiary) aquifers and the recent alluvial (Quaternary) aquifers constitute the three major potential aquifer systems, in the region. Ground water occurs in these formations both under water table as well as under confined conditions and is being developed by means of dug wells, dug-cum-borewells and tube wells.

Cretaceous Aquifers : Among the various water bearing formations of Cretaceous age, the Ramanathapuram and Vanur formations form potential aquifers. They occur in the north-western part of Puducherry and are encountered in the boreholes drilled in the major part of the region. The aquifers of the above formations include sands and calcareous sandstones. They are coarse grained in the western part and grade into finer facies towards east and northeast. The thickness of these aquifers ranges from 38 to 92 m. The yields of the tube wells with depths between 65 and 400 m, tapping these aquifers vary between 800 and 1500 lpm. The transmissivity and storativity of these aquifers as computed varies between 92 and 1925 m^2/day and 2.93×10^{-5} to 1.36×10^{-4} respectively. The thickness of the aquifers in upper Cretaceous Ottai formations varies between 42 and 56 m and the water bearing property is mainly dependant on the few bands of fine grained sandstones and lime stones. The yields of the wells tapping these aquifers vary between 1015 and 2210 lpm for draw down ranging from 6.6 to 25 m.

Tertiary Aquifers : Cuddalore sandstone, Kadapperikuppam formation and Manaveli formation are the three stratigraphic units of Tertiary aquifers. Out of three, the Manaveli formation of Paleocene is mainly an aquitard and the localised granular zones do not provide any appreciable yield. Another unit of this group namely the Kadapperikuppam formation contains some productive aquifers. The thickness of the aquifer shows wide lateral and vertical variations.

The Cuddalore sandstones of Mio-Pliocene age constitute the most potential aquifers. The Cuddalore sandstones comprising sandstones, sands and gravels occupy an extensive area. The thickness of these aquifers ranges between 20 and 245 m. Ground water occurs in this aquifer mainly under confined conditions and is developed by means of tubewells ranging in depths between 27 and 366 m. The yields of the tube wells range between 200 and 3000 lpm for drawdown varying from 5 to 10 m. The average transmissivity of these aquifes is around 2000 m^2/day. Storativity values range between 9.583×10^{-5} and 8.9×10^{-4}.

The Kadapperikuppam aquifers are constituted by the fine grained sandstones and give moderate to good supplies of water as seen around Sedarapalli, Pillaiyarkuppam and further northeast, of the area. The thickness of aquifer ranges between 52 and 90 m south of Gingee river, whereas in the area north of Gingee river, it is between 13 and 37 m. Gorund water occurs under confined conditions.



Recent Aquifers : Sands and gravels constitute the alluvial aquifers. Alluvial deposits occupy nearly threefourth of the region. These aquifers form the most potential shallow aquifer system in the area. The thickness of these aquifers ranges between 5 and 34 m. Thick alluvial aquifers occur in the area bordered by Thirukanji, Odiyampet, Tavalapet, Villiyanur, Mangalam and Satyamangalam. In these, ground water occurs under water table or semi-confined conditions. The depth of tubewells tapping these aquifers range between 25 and 50 mbgl. The studies indicated that the Transmissivity of the aquifers in the west is in the order of 275 m^2/day at Madukkarai whereas at Tirukanji in the east is in the order of 770 m^2/day.

Subsurface Geology

A fence diagram (Fig.3) has been prepared based on the results of ground water exploration to obtain a comprehensive picture of the disposition of the aquifers.

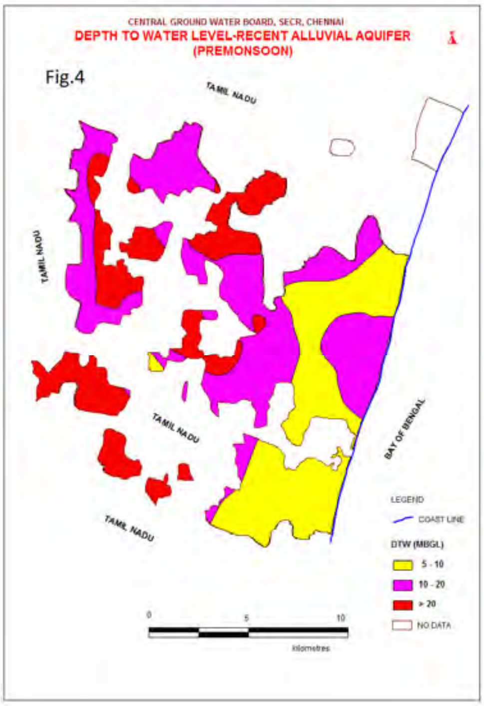
The boreholes pierced through alluvium and lateritic soils with gravels of Recent followed by unconsolidated and semi-consolidated sediments of Tertiary and Mesozoic periods which in turn are underlain by the crystalline rocks of Archaean age. Sands and gravels constitute the alluvial formations. The alluvial formation exhibits maximum thickness of 51 m in the middle part of the region which gradually pinches out towards north-east.

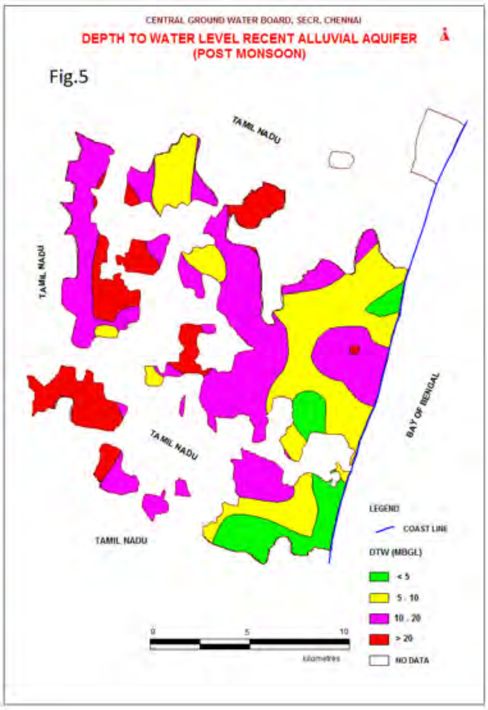
Upper Tertiary period comprises Cuddalore sandstones whereas Mesozoic period comprises clays, claystones, siltstones, shales, calcareous sandstones and lime stones. The individual aquifer in this multiple aquifer system is separated by the argillaceous sediments. The shallow alluvial aquifers and the deep aquifers in Cuddalore sandstones (Tertiary) and the aquifers of Vanur-Ramanathapuram sandstones (Cretaceous) constitute three major potential aquifer systems. The sandstones of Cuddalore formations form the principal aquifer in the region. The thickness of the sediments shows a wide variation at different places both laterally and vertically depending upon the depositional conditions and basement topography. In the northern part of the region (i.e.) to the north of Gingee or Varahanadhi river, the thickness of the sediments is comparatively less and it increases towards south and south-east. The thickness of the sediments which is 193m in the northern part of the region as observed at Katterikuppam increases to 500 m at Kalapettai falling in the northeastern part of the region and over 1200 m in the south east near the mouth of Ponnaiyar river. Basement has been encountered at Kalarpettai at 500 m bgl. The absence of potential aquifers within the depth of 227 m bgl at Kalapettai is a conspicuous feature.

The Ramanathapuram and Vanur formations are both clastic and coarse grained in nature in the north-west whereas in the down dip direction, they are finer clastic type with limestone bands. These formations have a maximum thickness of about 500 m in the north-east, to about 700 m in the south. The thickness of alluvium is maximum (i.e,) around 50 m at the central part of the region as observed at Sattamangalam. Sands of varying grades constitute the aquifers. The maximum cumulative thickness of saturated granular zones met with in the Cretaceous and Palaceocene sediments was of the order of 144 m near Madukkarai whereas in the Cuddalore formations it is of the order of 265 m near Manapattu and about 34 m in alluvium near Sattamangalam.

Broken shell pieces and limestone have been encountered at different depth ranges in the region and the presence of these materials suggests these might have been deposited under marine/fluvio-marine conditions during the transgressional / regressional periods of the sea.

Ground Water Level





State Ground Water Unit of Agriculture Department, Puducherry has constructed about 100 observation tube wells, piercing different aquifer system and the water level data are periodically collected from these observation tube wells. While perusal of the water level data, shows that the water level in the alluvial aquifer during premonsson (july 2009) ranges from 5.75 to 35.9 m bgl. Whereas during post monsoon the water level ranges from 3.2 to 34.7 m bgl. In tertiary formation, the water level is in the range of 6.1 to 34 m bgl during premosoon and 4.8 to 33.75 m bgl during post-monsoon. In cretaceous aquifer, the water level is 12.5 to 39.85 m bgl during pre-monsoon and 12.2 to 50.75 during post-monsoon. Depth to water level maps for alluvium aquifers are presented in fig. 4 & 5.

Ground Water Resources and Development

The ground water resources have been computed jointly by Central Ground Water Board and Ground water division, Department of Agriculture, U.T.of Puducherry as on 31st March 2009. The salient features of the computations are furnished in Table-3.

Table-3 Ground Water Resources and Status of Development (As on March 2009) in Ha m								
District	Net Annual Ground Water Availability	Existing Gross Ground Water Draft for Irrigation	Existing Gross Ground Water Draft for domestic and industrial water supply	Existing Gross Ground Water Draft for All uses	Requirement for domestic and industrial requirement supply to 2025	Net Ground Water Availability for future irrigation development	Stage of Ground Water Development %	Category
Puducherry	9322.17	11600	2401.63	14001.63	2621.99	Nil	153%	Over Exploited

Hydrochemistry

The groundwater of alluvial aquifer is almost neutral to alkaline in nature with pH values ranging from 7 to 8.5. The water is generally bicarbonate chloride type, the bicarbonate is predominating over chloride. Carbonate is generally absent or occurs in traces. Chloride content is generally below the permissible limit except in few places along the coast. The electrical conductivity ranges from 1500 to 2000 micromhos/cm at 25^{0}C. The quality of groundwater being tapped from Tertiary aquifer is alkaline with pH ranging from 7.4 to 8.5. Carbonate is almost nil and the groundwater is generally calcium – Magnesium – bicarbonate type. The quality of groundwater in the Cretaceous aquifer is slightly alkaline with pH ranging from 7.7 to 8.5. The concentration of chloride is generally within 150ppm. The electrical conductivity values are less than 1500 micromhos/cm at 25^{0}C. Groundwater from all the aquifer system is, in general, suitable for both domestic and irrigational purpose. However, water with high salinity and medium sodium hazard are reported from both alluvial and Tertiary aquifers in the coastal areas of Puducherry. High salinity and high sodium are reported from select wells along the coast due to sea water intrusion.

Major Ground Water Related Problems

Industrial pollution : Many water based industries have been established in the Puducherry during early eighties because of availability of ground water and electricity in plenty. Some of the chemical industries started dumping the chemicals, both used and unused, in open yards and releasing untreated effluents on open ground/unlined channels. As a result, in Puducherry, ground water has been polluted in the industrial estates, particularly in Mettupalayam area, leading to environmental degradation.

In order to study the industrial pollution, Central Ground Water Board, along with State Ground Water Department and State Pollution Control Board, Government of Puducherry, carried out a study at Mettupalayam Industrial Estate during July 2001. Ground water samples from the tube wells in and around the PIPDIC Estate area, Mettupalayam were collected and analysed. Mettupalayam Industrial Estate is situated on the elevated lateritic terrain with a maximum elevation of 27 m with the steep slope dipping towards southeast. There are eight deep tube wells in the PIPDIC Estate area to cater to the need of in house industries. A couple of industries are having their own tube wells.

The study revealed that quality of ground water in and around the Mettupalayam Industrial area is slightly acidic in nature as pH varied from 6.13 to 7.81, except for two samples. The electrical conductivity ranged from 256 to 2040 µS/cm at 25°C, except from Saradha Castings and Guru Papers (opposite) where it recorded 9750 and 12510 µS/cm at 25°C respectively. Sulphate was found to be 1670 and 5203 mg/L and also, Fluoride contents were 1.5 and 1.65 mg/L in those tube wells, which may be due to the effect of chemicals used in those industries. It was also noticed that Arsenic content (20.15 µg/L) in Gurupaper Mill, which may be due to leaching effect of dyes used in this paper industry, which is below permissible limit.

The previous records of the Government of Puducherry for Mettupalayam Industrial Estate reveals that one of the tubewells, constructed in 1992 by PIPDIC, had pH value of 7.7, which turned into acidic nature with pH value of 3.5 during 1993. Similarly, Fluoride value had also increased from 2.5 to 6 ppm as against permissible limit of 1 ppm. The tubewell has since been abandoned.

Another tube well constructed in this Industrial Estate during 1983 had a fresh ground water in the beginning, which is at present abandoned since the pH was found to be 3.8 and the sulphate content increased to 1800 ppm. Also, another deep tube well, constructed in 1997 near the industrial estate at Shanmugapuram, was abandoned due to the presence of high sulphate and high electrical conductivity.

A study by the Government of Puducherry in Mettupalayam Industrial Estate revealed that ground water extracted from the tube wells is found degraded widely in and around Mettupalayam Industrial Estate area, with Sulphate to the limit of 2714 ppm and more acidic nature near the Electricity staff quarters.

The main cause for the total deterioration of ground water in and around Mettupalayam Industrial Estate is the reported dumping of chemicals by some chemical industries and discharging of untreated effluents in the open drains. It has been found that effluents of certain units are having pH in the range of 1.2, 3.2, 3.5 and 12.8 and total dissolved solids in the range of 11500, 14000 and 29300. To identify the source of ground water pollution in the aquifer system of Mettupalayam industrial Estate and to take remedial measures, the Government of Puducherry has taken up a detailed study in that area.

Sea water intrusion : The United Nations Development Project in Tamil Nadu had studied the effects of sea water intrusion due to ground water development during 1968-70 in the Puducherry. A tube well was constructed at Krishnapuram in southeast corner of Puducherry near the coast tapping the zones between 152 and 226 m bgl. The static pressure head was 4.6 m agl at that time and the studies indicated that strong dynamic hydrostatic equilibrium existed between fresh water and salt water due to high transmissivity of the deeper confined aquifer in this area. The recent static pressure head at this well was around 8.5 m bgl recording a drop of about 13 m within a period of 25 years, which may be due to intensive development of ground water in the area over the years. The large scale development of ground water in the area caused reversal of gradient of piezometric head and increasing the salinity of water of deeper tube wells in villages like Kirumambakkam, Manapattu, Narambi, Murungapakkam etc. on the coast indicate sea water intrusion in recent years.

In the northeastern part of the region lying north of Puducherry near Kalapettai, a borewell constructed tapping the deeper aquifers (Vanur and Ramanathapuram) has turned to be saline due to sea water intrusion indicating that interface exists beyond a depth of 465 m bgl. The intensive ground water development in the area has resulted in sea water intrusion due to the up coning of salt water.

The State Ground Water Department has constructed a battery of tube wells tapping both shallow and deep aquifers along the coast to monitor the sea water intrusion and the salt-fresh water interface movement due to large scale development of ground water in recent years. Water levels and water samples are collected once in every one or two months. Effects of sea water intrusion and interface movement are noticed in some of the above observation wells.

The Geophysical logging done by the State Ground Water Department in the tube wells drilled along the coastal belt during 1993-97 reveals the intrusion of sea water from Kalapet to Cuddalore area at depths ranging from 40 to 140 m bgl. It has moved inland by about a kilometre at Kalapet and 8 kms at Bahour areas.

In Puducherry, the coastal aquifers can be broadly divided into three groups, viz., Alluvial, Tertiary & Cretaceous. The thickness of alluvial aquifers range from 5 – 34 m tapped by wells in the depth range of 25- 50 m, while it varies from 20 to 245 m in Tertiary formations and are tapped by tube wells in the range of 27-366 m depth. In Cretaceous aquifers, the thickness varies from 38 – 92 m and the depth of the wells tapping this aquifer varies from 65 – 400 m bgl. The groundwater exploration has revealed that in general, the groundwater encountered down to 300 m bgl was of good quality with EC less than 600 μS/cm, while the zones beyond 300 had EC about 1500 μS/cm.

In general, the quality of the formation water in alluvial aquifers is good and has EC <750 μS/cm except at Murungapakkam, Kirumampakkam, Kizparikelpet & Uchimedu along the coast. It has also been reported that the deterioration in quality at these places may be due to seawater intrusion, which needs to be ascertained.

The quality of groundwater in Tertiary aquifer is good and has EC <750 μS/cm except along the coast at Murungapakkam (8280 μS/cm), Kizparikelpet (6800 μS/cm) & Uchimedu (5100 μS/cm). Similarly, the quality of groundwater in Cretaceous aquifer is also good and has EC <750 µS/cm except at Madagadipet where EC was recorded as 7280 µS/cm.

A perusal of the figure shows that from Marungapakkam to Kizparikalpet, along the coast, the formation water has turned brackish in both Recent Alluvium and Tertiary aquifers in recent years probably due to seawater ingress. The poor quality of the formation water in Madagadipattu in Cretaceous may be due to insitu salinity.

GROUND WATER DEVELOPMENT STRATEGY

The studies carried out in the regions reveals that the development of ground water has assumed rapid strides in recent years. As on 31st March, 2009, the level of ground water development is 153% in Puducherry. It is therefore imperative that there should be regulations over the development of ground water in the regions for efficient functioning of the wells without interference between wells and over-development of aquifers. Any perspective planning and judicious management of ground water resources should envisage proper design and rational spacing of abstraction structures for the regions.

Design of Ground Water Abstraction Structures

The design of ground water abstraction structures should be made on a rational basis depending on the potentialities of the aquifers and hazards of either over-capitalisation or under-financing by institutional agencies. The available saturated thickness of the aquifer especially during the peak period of requirement of crops, the required discharge and the estimated aquifer parameters were considered for determining the diameter and average depth of the wells. In case of tube wells in sedimentary terrain, the provision of housing is to be provided for accommodating pumping equipment which in turn depends on the i) average depth to water level below ground level during peak period of requirement, ii) delivery head above ground level, iii) the maximum pumping water level attained during the required discharge and iv) possible decline in water in course of time. The length of the slotted pipe depends on i) thickness of aquifer ii) nature of aquifer and iii) sorting of aquifer material.

Spacing between Wells

Regulation on ground water development can be effected for efficient performance of neighbouring ground water abstraction structures using spacing between wells. The spacing between wells has to be evolved based on the following norms:

- The spacing should be two times the radius of influence estimated by pump tests.
- The spacing should be such that the pumpage works out to be economically viable.
- In the ayacut areas of tanks and other surface bodies, the ground water development is meant only for supplemental purpose during water shortage period for sustaining the crops. 75% of the spacing recommended in the non-command area is considered realistic in command areas.

Accordingly, the recommended spacing between pumping wells in non-ayacut area is given in Table-3.

Table - 3 : Minimum Spacing Recommended between Ground Water Abstraction Structures

Type of Unit	Irrigated Area (ha.)	Average Spacing recommended (m)	Typical Annual Withdrawal (m3)
FISSURED FORMATION			
Dug wells	1	150	5000 to 6000
Dug-cum-bore wells	2	175	10000 to 12000
POROUS FORMATION			
Shallow Tubewells	3	175	15000 to 25000
Medium Tubewells	8	600	75000 to 100000
Deep Tubewells	10	600	300000 to 400000

Artificial Recharge Structures

The topography of Puducherry, in general, is suited for construction of various artificial recharge structures such as percolation ponds, check dams and recharge shaft/well. However, detailed studies are necessary to formulate a comprehensive scheme for artificial recharge of phreatic ground water in the district in view of the variations in the geomorphic set-up and the complex hydrological and hydrogeological conditions. Since there are a large number of irrigation tanks in the regions suitable measures for increasing the quantum of storage like desilting, raising of bunds etc have to be taken up immediately which will facilitate recharge of the shallow water table aquifer to a considerable extent. For recharging deeper aquifers and to prevent sea water intrusion, recharge wells in all favourable tanks and coastal areas is recommended. Sub-surface dykes, percolation ponds and small check weirs to hold rain water can be planned in the fissured hard rock areas. Roof top rain water harvesting made mandatory by the State Government has improved the water level condition but due to lack of periodical maintenance, the effect has reduced over the period of time.

The ongoing large scale of development of ground water for ever increasing demands has caused considerable impact on the ground water regime of the region. The region, which had many flowing wells in the past, has witnessed termination of free flow over the years and continued declining trend of water levels. Artificial Recharge Programme for augmentation of the ground water resources can be used to arrest the declining trend.

The availability of the water source with good quality in the vicinity of favourable site for the aquifer to be recharged is the most important factor for any artificial recharge programme. The selection of site for artificial recharge depends on several factors like topography, nature and infiltration capacity of soils, lithology, permeability and thickness of aquifer to be recharged etc. Specific studies together with a sound knowledge of hydrological and hydrogeological parameters and identifying appropriate technique or the methodology to be adopted at each site is essential for selecting site for artificial recharge programme. Recharge can be augmented through 1) contour bunding, 2) nala bunding, 3) check dams, 4) contour trenching, 5) construction of percolation ponds, 6) surface channels, trenches and subsurface dykes in hydrogeological favourable locations.

Poor recharge conditions and over draft of available groundwater resources are mainly responsible for the high-level ground water development in the regions. There is an urgent need to replenish the ground water resources through construction of appropriate ground water conservation/artificial recharge structures.

Steps Taken for Augmentation of Ground Water Resources

Steps taken by Central Ground Water Board include a) Implementation of Pilot Schemes for Recharge Augmentation / Ground Water Conservation in areas of over-exploitation of Ground Water Resources/ Long Term Water Level Decline for popularising cost-effective technologies for Augmentation Of Ground Water Resources & b) Initiatives for Creating Mass Awareness on the importance of Conservation, Protection and sustainable management of available Ground Water Resources & for creation of trained manpower to implement strategies for Sustainable Ground Water Management at Community Level.

Measures taken by Government of Puducherry are schemes for augmentation of ground water resources in Puducherry since 1990. Implementation of such schemes has been geared up since 2001. Various campaigns aimed at creating public awareness on the importance of ground water augmentation and conservation are also being taken up regularly in the regions by the concerned Govt. agencies and NGOs.

RAIPUR CITY, CHATTISGARH

Rumi Mukherjee, Mausumi Sahoo, K.C. Naik, CGWB, Raipur

INTRODUCTION

Raipur, the capital city of Chhattisgarh along with its outgrowths lies between 21° 10'and 21° 21' N latitudes and 81° 32' to 81° 44'E longitudes and falls under Survey of India toposheets no. 64G/11 & 64G/12 .The town of Raipur has been in existence since the 9th century. As per one story, King Ramachandra's son Brahmdeo Rai established Raipur and named it after himself in around 1402 A.D. He belonged to the Kalchuri Dynasty of Tumman. Chhattisgarh was declared a separate commissionary in 1854 by the British Government with its headquarters at Raipur. Raipur attained municipal status in early 1867 and was upgraded to Municipal Corporation in 1967. After independence, Raipur district was included in the Central Provinces and Berar. Chhattisgarh was carved out of Madhya Pradesh and became a separate state in the year 2000.

GENERAL FEATURES

Area/Administrative Divisions

Raipur urban area spans over more than193 sq. km. It is an important urban centre of Raipur district and comes under Dharsiwa block. For administrative purpose, it is divided into 67 wards. The location map is given in Fig. 1.

Fig. 1: Location map of Raipur Urban Area

Demography

As per 2001 census, the total population of Raipur Urban Area (Municipal corporations and outgrowths) was 670042. The total population of Raipur Municipal Corporation alone is 605747. Apart from Municipal Corporation, the outgrowths have also been brought under urban area. Considering an increase of about 49% per decade (the average growth rate in the last three decades), the projected population for the year 2011 for Raipur Urban Area works out to be 998363 i.e. approximately 10 lakhs.

Hydrometeorology

Sub-tropical climatic condition prevails in Raipur Urban Area. The area experiences a very hot long summer from March to mid June followed by rainy season which lasts for almost four months from mid June to September. The winter season commences from December and lasts till end of February. The mean maximum temperature in May is 45.2°C, whereas the mean minimum temperature in January is 9.2°C (for the period1951 to 2008,IMD).The average (1980-2007) potential evapo-transpiration varies from 104mm. in December to 258mm in April.

South west monsoon contributes more than 85% of the annual rainfall. The annual normal rainfall of the area is 1288.8 mm. On an average there are 63 rainy days in a year. Table 1 contains the monthly rainfall data of year 2005-2009 of the area.

Table 1: Monthly rainfall (im mm) in Raipur Urban Area (IMD)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2005	68.6	25	0.9	2.4	25.9	155.9	493.5	255.3	229.3	91.2	0	0	**1348**
2006	0	0	35.6	31.2	72	59.6	384.5	430.5	177.5	14.4	1.4	0	**1206.7**
2007	0	19.5	0.2	0.2	4.1	525.2	320.1	284.6	238	28.3	14	0	**1434.2**
2008	6.5	10.1	2.6	1	5.8	262.8	233.1	279.5	289.7	23.4	0	0	**1114.5**
2009	0	0	0	2.1	4.9	25.8	571.8	246.4	66.4	20.1	10.5	0.3	**948.3**
Average	**15.02**	**10.92**	**7.86**	**7.38**	**22.54**	**205.9**	**400.6**	**299.3**	**200.18**	**35.48**	**5.18**	**0.06**	**1210.34**
Normal*	**6.7**	**12.3**	**24.6**	**15.7**	**18.8**	**189.8**	**381**	**344.7**	**230.2**	**53.9**	**7.4**	**3.7**	**1288.8**

* Based on data from 1951 to 1980.

Physiography & Drainage

Physiographically Raipur is situated in the south central part of Chhattisgarh basin having gentle undulating topography. The maximum elevation is 304 m. amsl whereas lowest elevation is 268m amsl. The center of area forms an elongated ridge like structure, generating a radial pattern of drainage of lower order streams flowing towards the north-south and west, and joining the Kharun River. The Karun River joins Seonath River (a tributary of Mahanadi River). Kharun along with Chhokra Nallah and other small nallah systems drain the area. Drainage density is moderate in the area due to flat terrain and underlying layers of laterite and sandstone which have moderate permeability.

Soil Types

Mainly two soil categories are present in Raipur Urban Area-ultisol and vertisols.

Vertisols-Under this category, only one soil type is found in Raipur namely deep black soil. It is characterized by a high content of expanding and shrinking clay known as montmorillonite having high level of plant nutrients. Owing to the high clay content, it is not well suited to cultivation. This type of soil has developed mostly over limestone covered areas.

Ultisols- Under this category, only one soil type is found in Raipur namely lateritic soil. This is a highly weathered and leached acid soil with high levels of clay below top layer. This soil has variety of clay minerals but in many cases the dominant mineral is Kaolinite. They are red to yellow in colour and are quite acidic having pH less than 5.The red and yellow colour results from the accumulation of iron oxide which is highly insoluble in water. It has developed mostly over the sandstone and shale covered areas.

STATUS OF WATER SUPPLY AND DEMAND

The demand of water for municipal and industrial uses has been worked out. The water demand for municipal use has been worked out @170 lit/capita/day (lpcd). In the year 2011 the water requirement for Raipur Urban Area worked out to be 62.05 MCM.

This requirement is met through surface and ground water resources. As per the data of Raipur Municipal Corporation (RMC Water Works Department, 2011)), total water supply by RMC is 150 MLD, i.e. 54.75 MCM. Out of it 127 MLD (i.e. 46.35 MCM) is supplied from surface water sources. The rest 23 MLD (i.e. 8.4 MCM) is supplied met from ground water.

RMC supplies a total of 54.75 MCM against a demand of 62.05 MCM. Remaining 7.3 MCM is met entirely through private borewells. Thus the total annual ground water draft is estimated as 15.7 MCM.

GROUND WATER SCENARIO

Major Geological Formations

Raipur is situated on Proterozoic Chandi Formation of Raipur group (Chhattisgarh Super Group) comprising of limestone, shale and sandstone which is at places intruded by dolerite intrusives. 0 Chandi Formation comprises of horizontal to gently dipping Niwari stromatlitic limestone and Deodongar shale and sandstone member. The limestone is generally massive to jointed, karstic in nature showing fractures, solution cavities and sink holes is exposed at Mahadevghat and Purena section. Deodongar Member overlies the limestone. Deondonger Member consists of khaki to purple colored shale, inter-bedded with layers of sandstone. The shales are thinly laminated, compact and impervious. The sandstones are orthoquartzite with siliceous cement and ferruginous coating, compact, thinly to thickly bedded. The sandstones are generally covered with lateritic soil and the shales are covered by soil.

The sub surface geology of the area prepared on the basis of lithologs of boreholes data and dugwell sections reveals that Deodongar Member is forming an uneven capping of impervious layer over limestone. The maximum thickness of shale is recorded in Telibandha area and which is thinning towards Raipura and Labhandi area forming a prismatic cover on limestone (Fig. 2). A subsurface dolerite dyke is running roughly E-W to NE to SW in Kota – Samta colony area. A borehole drilled down to 300-mbgl shows that the thickness of Chandi Limestone is 136 m and overlies the Gunderdehi Shale. The exploratory data in the Daldal Seoni indicates presence of Chandi Shale from the top to 72 m bgl after which limestone is encountered. Water bearing zone is encountered at the contact of shale and limestone of Chandi Formation.

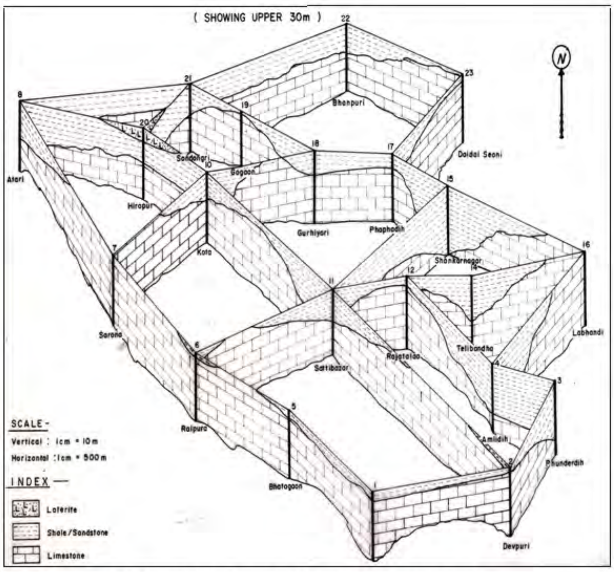


Fig 2: Fence diagram showing the lithology of Raipur Urban Area

Potential Aquifers

Limestone, shale and sandstone of Chandi Formation comprise the major aquifers in the area. The major aquifers can be grouped into three - an unconfined (shallow) aquifer, a discontinuos semiconfined (deeper) aquifer and a perched aquifer. The perched aquifer is characterized by very shallow water table condition throughout the year and is encountered in the central part of Raipur town covering Ashram-Amapara-Rajatalab, Shankarnagar,Telibandha,Rawabhata areas due to the presence of impermeable shale layer above the unconfined aquifer. Ground water in Chandi Formation occurs both under phreatic and semi-confined to confined condition. The dug wells in the area tap the upper part of the shale or limestone. The depth of the dug wells varies from 7 to 21 m bgl with diameter ranging from 2 to 6 meter. The deeper aquifer in the form of fractures and solution cavities are being tapped by means of bore wells, where the ground water remains under semiconfined to confined condition. The deeper fractured zones between 30 and 70 mbgl are the major aquifer zones in the Chandi Limestone and Gunderdhi Shale underlying the city. In some areas, like Shyamnagar, Telibandha, Sundernagar, cavernous limestone has been encountered in a depth range of 20 to 70 mbgl. In general the water bearing horizons are encountered in depth ranges of 13 to 45m bgl and 65 to 85m bgl. The depth of the borewells in the area ranges from 30 to 120m bgl. The yield of the bore wells tapping these horizons ranges from 1 lps to 12.5 lps and the drawdown varies from 7 to 60m It has been observed that low yielding wells tapping limestone aquifer show increase in discharge up to 2 lps after blasting through explosive by crude method (RMCWD, 1998-99). At present, aquifers ranging in depth from 20.00 to 60.00m bgl are not yielding because of heavy ground water withdrawal due to rapid urbanization. This aquifer zone was earlier capable of catering to the ground water needs of the city. The Transmissivity(T) & Storativity (S) calculated for Chandi Formation varies from 1 to 120 m^2/day and $2*10^{-3}$ to $8.3*10^{-5}$ respectively (Shobnath et.al, 2000).

In general the ground water flow direction is perpendicular to ground water divide. Towards the Kharun River in the south of Dumartalab the ground water flow direction is south to south-west with gentle gradient. Ground water plateau is formed in the central part of the city having flow direction towards Daldal Seoni and Labhandi. The detailed hydrogeological map is shown in Fig. 3.

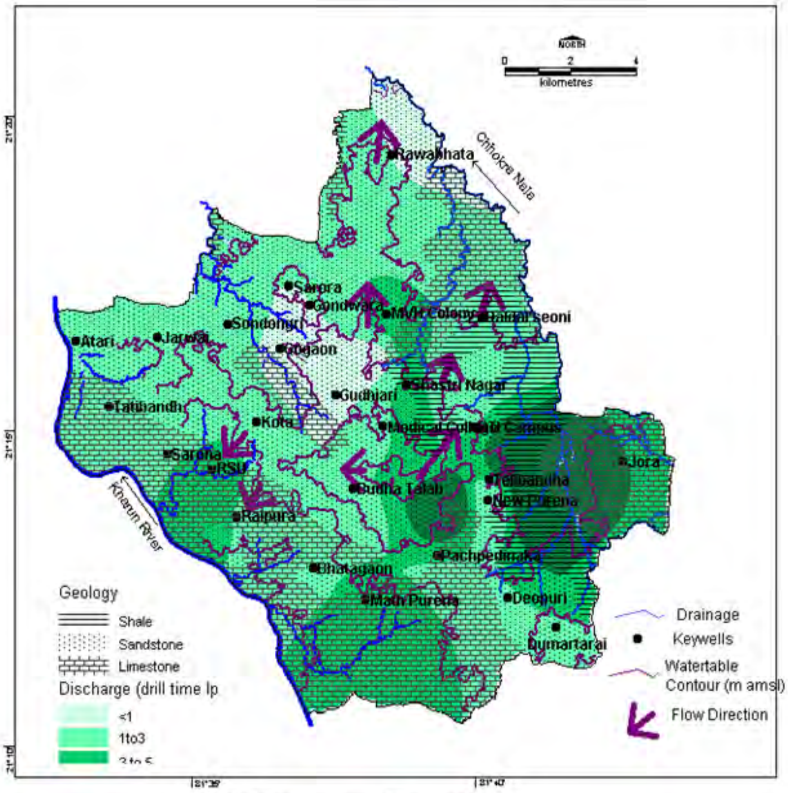


Fig. 3: Hydrogeology of Raipur Urban Area

Water Level Conditions

The phreatic aquifer depth to water level ranges from 4 to 15m bgl during pre-monsoon period(**Fig.** 4) and 1.3 to 9 m bgl.during post monsoon period (Fig 5)**.**In many areas like Daldal Seoni, Bhatagaon, Sadu etc. , the phreatic aquifer dries up during pre-monsoon period leading to acute water shortage.

For the deeper aquifer, the depth to water level varies from 4 to 55 m bgl during pre-monsoon period **(**Fig.6).Whereas during the post-monsoon period, the depth to water level varies from <3m to 35m bgl. (Fig. 7). From the map it is seen that the depth to water level of the deeper aquifer remains at more than 15m bgl in the northern areas (Rawabhatta-Gogaon-Gudhiari) during the post-monsoon period. This area is adjacent to the Urla industrial belt located in the northern western outskirts of Raipur. So there may be excessive ground water withdrawal from deeper aquifer which is under stress.

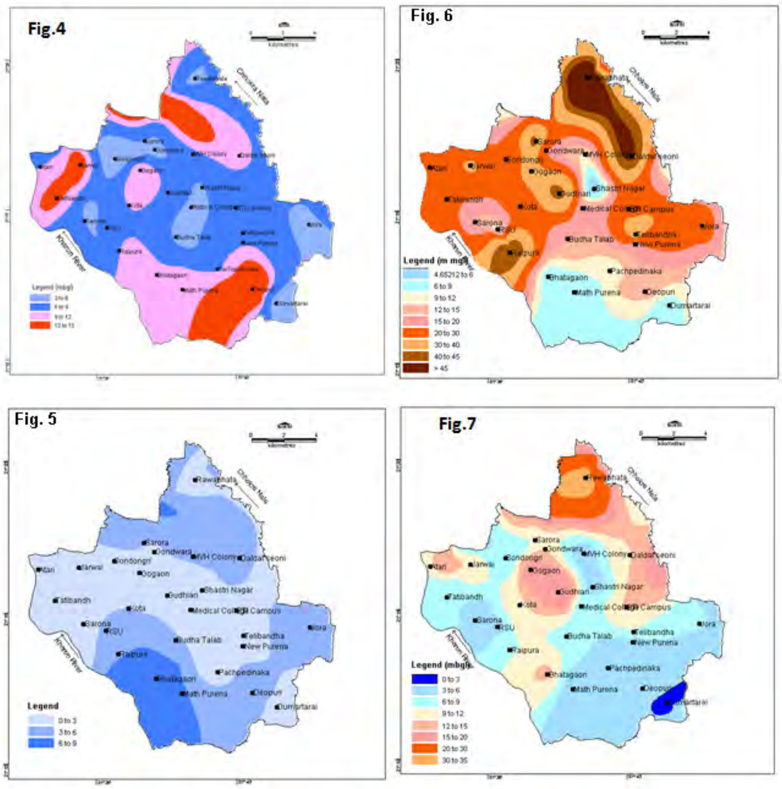


Fig. 4: Pre-mosoon (May. 2010) depth to water table (m bgl) in shallow aquifers.
Fig. 5: Post-mosoon (May. 2010) depth to water table (m bgl) in shallow aquifers.
Fig. 6: Pre-monsoon water level (m bgl) variations in deeper aquifers in May 2010.
Fig. 7: Post-monsoon water level (m bgl) variations in deeper aquifers in November 2010.

The Fig. 8 shows the water level-rainfall relationship for shallow, deeper and perched aquifers in Raipur Urban Area. Water level behaviours in most of the cases are sympathetic with rainfall. At some points in the deeper aquifer, delayed recharge is apparent.

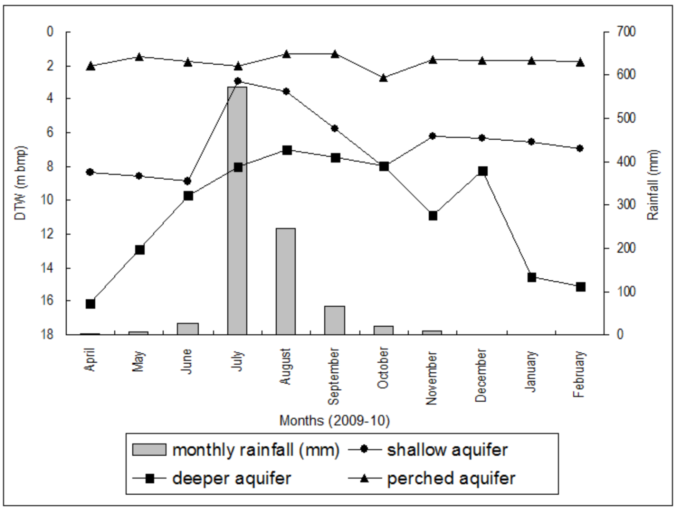


Fig. 8 **Depth to Water Level –Rainfall relationship for different aquifer systems in Raipur**

Ground Water Resources

Ground water resource of Raipur Urban Area has been estimated using water table fluctuations and specific yield of different rock types (Table 2). The rainfall infiltration method was not considered because it was difficult to estimate recharge worthy areas in an urban environment. Many parts of the urban areas are rendered impermeable because of roads and other constructions. Further, there are many additional sources of ground water recharge in an urban area (Lerner 2002), which are difficult to identify and quantify. Water level fluctuations reflect the resultant ground water recharge from all the possible sources. Though the shallowest water levels are attained during the month of August, the water levels deplete very fast and usually stabilize by the month of November. So the available ground water resource was estimated considering water table fluctuations between from May and Nov. 2010. The estimate was based on water level fluctuations in the phreatic aquifer multiplied with area and and the specific yield for the aquifer (GEC'97). The total annual available resource was estimated to be 19.80 MCM.

Total annual ground water draft was estimated earlier as 15.7 MCM. The stage of ground water development calculated as a ratio of total annual ground water draft to total annual available ground water resource (15.7/19.8) is nearly 80% for Raipur Urban Area. With the stage of ground water development more than 70% and pre-monsoon water levels in most of the wells showing falling trends, Hence, the Raipur Urban Area can be categorized as semi-critical.

Table 2: Ground water resource estimation using water level fluctuation method

Geology	Fluctuation (m)	Area (Km^2)	Sp. Yield	Resources (MCM)
Limestone	1.21	25.05	0.03	0.91
	3.00	7.94	0.03	0.71
	5.00	28.58	0.03	4.29
	7.00	17.68	0.03	3.71
	8.85	1.57	0.03	0.42
Shale	1.21	0.30	0.02	0.01
	3.00	8.77	0.02	0.39
	5.00	11.11	0.02	0.83
	7.00	1.67	0.02	0.18
	8.85	0.00	0.02	0.00
Sst	1.21	4.32	0.02	0.10
	3.00	28.06	0.02	1.68
	5.00	43.39	0.02	4.34
	7.00	10.89	0.02	1.52
	8.85	3.98	0.02	0.70
			Total	19.8

Hydrochemistry

Water samples of wells in and around Raipur were analysed for the basic parameter. pH (laboratory measurements) in ground water samples of Raipur varies from 7.04 to 8.7 with an average of 8.03,which shows that water is mostly alkaline in nature. pH is within the permissible limits.

Electrical conductivity (EC) is a measure of the dissolved solids in water. The relation between dissolved solids and EC is EC*K=S, where EC is in microsiemens/cm. S is the total dissolved solids(TDS) in milligrams per litre and K is the proportionality constant which remains mostly between 0.55 and0.75,higher values are associated with water high in Sulphate concentration(Hem,1985).EC values of ground water in Raipur vary from 349 to2690 micro siemens/cm. which are equivalent to 209.4mg/l(K=0.6)and 2017.5 mg/l(K= 0.75) of total dissolved solids. The desirable and permissible limits for TDS (IS:10500,1991) are 500 and 2000 mg/l respectively.

The desirable and permissible limit of Ca (IS: 10500,1991) are 100 and 300 mg/l respectively.Ca values from the dug wells of Raipur varies from 10 to 266 mg/l. Water sample from Math Purena shows high Ca content (266 mg/l).

The desirable and maximum permissible limits (IS: 10500, 1991) of Mg in drinking water are 30 and 100mg/l respectively. The Mg values of dug well samples vary from 9 to 75mg/l. which are well within the maximum permissible limit. The desirable and maximum permissible limits (IS: 10500,1991) of Total Hardness(TH) in drinking water are 300 and 600mg/l respectively.The TH varies from 110 to 885 .One sample from Math Purena shows TH more than the permissible limit.

The chemical analysis of dug well samples of Raipur show that the water is potable except a few isolated locations where water is contaminated mainly through anthropogenic activities.

Major Ground Water Related Problems

Declining ground water level trends
Water levels in major part of Raipur show falling trends. One representative hydrograph of deeper aquifer of Raipur (IGKV) is given in Fig.9, which shows falling trend for both pre-monsoon and post-monsoon water level. With increasing ground water draft the situation may worsen.

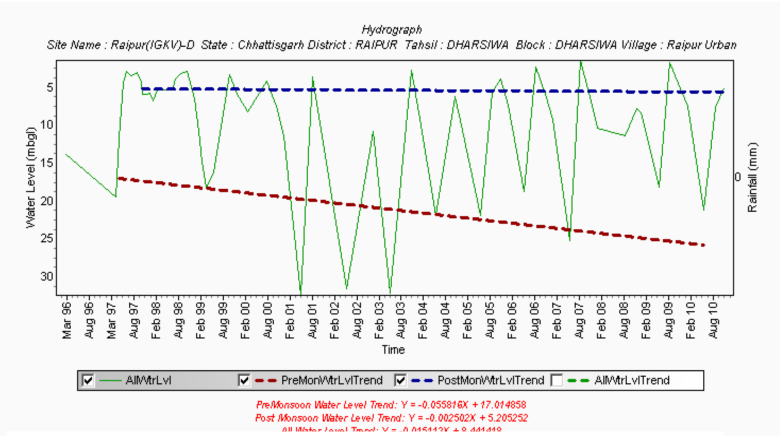


Fig.9: Hydrograph of piezometer at IGKV, Raipur

Reduction in recharge area
There is a rapid change in land use pattern of Raipur as a result of urbanization. Most of the area which was earlier occupied by agricultural land and water bodies have been converted into industrial and residential colonies. So there is significant reduction of area suitable for recharge.

Pollution due to urbanisation
The growing urban agglomerates generate large quantities of waste both liquid and solid. The city has not been provided with facilities for proper treatment/disposal of the wastes. Abandoned quarries and local depressions are converted into waste disposal sites which contaminate the aquifers. Some residential colonies have come up on the old land fill sites which pose serious health hazards.

GROUND WATER MANAGEMENT STRATEGY

As discussed earlier Raipur Urban Area is categorized as semi critical from ground water development point of view and the stage of development has already attained 80%. The dependence on ground water is bound to increase in the future. Thus it is imperative to plan for augmentation of ground water resource in the city area. Keeping in view the land availability and feasibility, the following interventions are recommended

Renovation of ponds

Raipur Urban Area has nearly 190 ponds with a total area of 3810000 m^2, which is nearly 2% of the total geographical area of the city. Out of these, about 51 (with a total area of 960000 m^2) are located in the limestone areas and the rest 139 (with a total area of 2850000 m^2) are located in the sandstone and shale areas. Ponds in the limestone areas are already effective recharge structures. Water in these ponds remains for nearly 180 days in a year. Desilting and deepening of these ponds will increase the water storage, which may increase in ground water recharge.

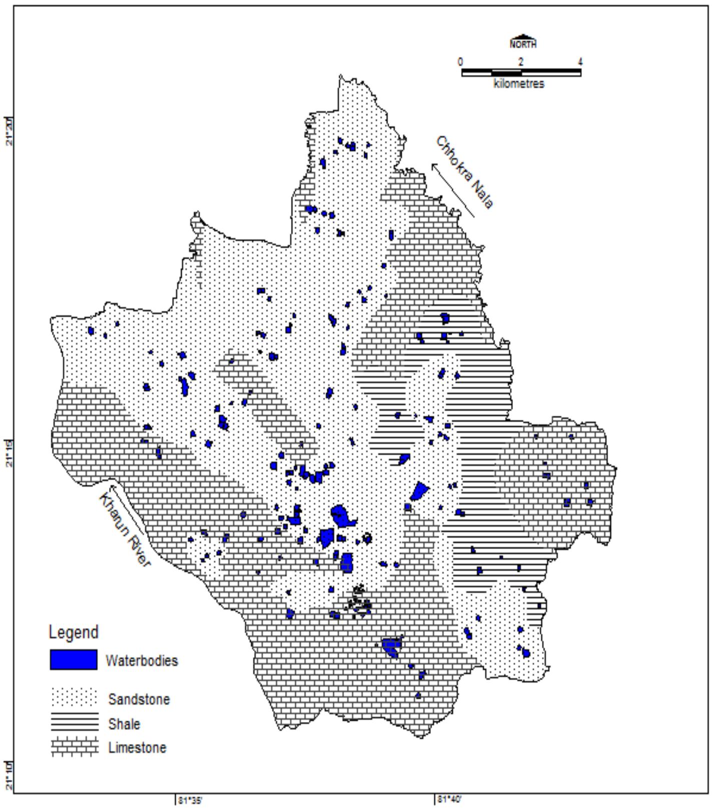


Fig. 10 Distribution of water bodies in Raipur Urban Area.

On the other hand, the ponds situated on the sandstone and shale contribute marginally to ground water recharge. Thickness of the upper sandstone is not more than 2m in most parts. The bottom of all these ponds is on shale, which does not allow percolation at faster rate. Thickness of this shale layer is up to 30 m, below which stromatolitic limestone is encountered. This stromatolitic limestone is a potential aquifer. To increase recharge efficiency, inverted wells or recharge wells may be constructed in these ponds. Ponds in the urban areas in many places are polluted by urban wastes, so special care should be taken and complete hydrochemical and biochemical assessment of water of individual ponds should be carried out, before constructing recharge wells. Out of 139 such water bodies, those water bodies which have areas more than 1000 m^2 may be considered for construction of recharge wells. The recharge wells should be constructed in such a way that a minimum storage is maintained in the pond. There are 103 (say 100) such ponds in Raipur Urban Area. Cumulative area of these ponds is 2596000 m^2. Assuming an average water column of 4m and a recharge efficiency of 50%, by the construction of recharge wells, recharge from these ponds is expected to increase by a significant 5 MCM.

Construction of Recharge Wells and Cost Estimates

It is proposed to construct two recharge wells (bore-well) in each pond of area more than 10000 m^2. This means that a total of 200 recharge wells are to be constructed. The bore wells may be constructed during the dry season, when the water levels in the ponds are at minimum level. Recharge wells may be constructed in such a manner that pond water enters the recharge structure only when water level in the pond rises above water level in the summer. Each borewell may be of 70m depth and an associated *insitu* filter is to be constructed. Average rate of construction of a bore well is around Rs. 1500 per m and the average cost of construction of the filter is 20000. Thus the unit cost of each installation will be around Rs. 125000. Total cost of construction of 200 bore wells will be Rs. 2.5 crores.

Rooftop Rainwater Harvesting

The most effective way of ground water augmentation in an urban area is rooftop rainwater harvesting. Rooftop rainwater harvesting is effective for harvesting non-monsoon rainfall. During monsoon period, the aquifers are already saturated in many parts and the recharge efficiency is greatly reduced. Normal nonmonsoon rainfall in Raipur Urban Area is 1146mm. There are nearly 200000 households in the Raipur Urban Area. Assuming a total roof area of 500.0000 m^2 and a harvesting efficiency of 20%, total volume of harvested water will be nearly 14MCM, which is a significant amount.

Construction of Subsurface Dykes

Central Ground Water board has constructed a subsurface dyke across Chhokra nala and it has shown promising results. Two additional subsurface dykes may be constructed at suitable sites to restrict subsurface flow.

Water Quality Considerations

Most important aspect of ground water development in the city is to maintain ground water quality standards. It has been pointed out in many reports (State Report 2006) that the karstic limestone terrain in Raipur Urban Area is highly vulnerable to pollutions especially when the urban waste dump sites are located above them. It is recommended that all the urban waste dump sites be relocated to low lying shale covered areas.

Demand Side Management

It is also imperative to reduce groundwater demand by adopting water efficient lifestyle. The success of any programme finally depends on people's participation. So mass awareness campaigns regarding water conservation in day-to-day activities can go a long way in ground water conservation in Raipur Urban Area. Further suitable regulatory guidelines and legislations should be adopted to control ground water draft and to promote safe ground water abstraction.

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RANCHI CITY, JHARKHAND

G.K Roy, R.A. Kujur & S. Toppo, CGWB, Ranchi

INTRODUCTION

The Ranchi district was formed in 1899. It was named after a small village. The district was earlier known as Lohardaga, which came into existence after the creation of the non-regulation South-West Frontier as a result of the Kol rising. In ancient times the district of Ranchi and the neighbouring parganas were in the possession of Munda and Oraon tribes and were known to Aryans as Jharkhand or the 'forest territory'. Ranchi urban area is capital of the state of Jharkhand and is also district Headquarter. It is known for its rich deposits of minerals, waterfalls, rivers, streams, lakes, dams and forests. Ranchi has witnessed a huge influx of people after the formation of Jharkhand State on November 15, 2000, owing to the rise in employment opportunities and opening of numerous regional and state level offices, banks, and private organisations.

Subernarekha River flows by the side of the city. Ranchi Lake is one of the major water bodies located in the heart of the city spreading over an area of 53 acres. Water demand of the city is met from three surface water reservoirs namely, Kanke Dam, Dhurwa Dam and Rukka Dam and by large numbers of dug wells of 10-15m depth tapping phreatic aquifer represented by weathered mantle and saprolite zones. These dugwells are of late replaced by large scale deep bored wells.

Fig. 1 Ward map of Ranchi Urban Area

GENERAL FEATURES

Area/ Administrative Division

Presently the capital city of Ranchi spreads over an area of about 257 km^2 which has increased from 173 sq.km in 1991. It is bounded by $23^0 15'$-$23^0 25'$N latitude and $85^0 15'$-$85^0 25'$E longitude and falls in Survey of India toposheet 73E/7. The urban area is divided into 55 wards (Fig. 1).

Demography

As per the 2001 census, the total population of the area is 10.5 Lakh. The population of the urban area has grown from 5.99 to 10.5 lakh during 1991-2001 recording 41% decadal growth rate. The population density has increased to 4086 persons/km (2001) as compared to 2330 person / Sq.Km in 1991. The present population is estimated to be 11.93 lakhs and is likely to touch around 17 lakhs in 2021 considering the same growth rate.

Hydrometeorology

Ranchi represents a sub-tropical climate. The minimum ambient temperature has been recorded as low as 4-5^o Celcius in December/January, whereas maximum temperature of 42^o Celcius has been recorded in May/June. The average annual rainfall of 1377mm (year 2004–year 2008) has been recorded in the urban area. The rain in the monsoon months of July to September varies from 117.4 to as high as 640.6 mm.

Physiography & Drainage

The area was subjected to long phase of denudation and is approaching to peneplain stage except for some residual hillocks with scattered distribution in Ranchi Urban Area. There are mainly three types of geomorphologic units, moderately pedimented weathered plateau, shallow pedimented weathered plateau, and dissected plateau. Physiographically the area can be divided into three distinct units.

1. Northern Region - Potpotto –Jhumar basin
2. Central Region - Manatu-Booty Upland
3. Southern Region - Peneplain Flat

The general ground elevation ranges from 596 to 700 m above mean sea level with the regional slope of the area towards east. Average regional slope is 1 to 3 which is indicative of flat or low slope profile. Rock types have played important role in shaping the geomorphology of the area. Granitic, khondalitic and Lateritic rocks both are common in plain and hillocks. Domal appearance of granitic hills and conical appearance of khondalite hills are result of the rock types. Exfoliations over the upper surface of such rocks are observed in the area. Typical spherical weathering is also seen. A few inselbergs standing as isolated hillocks also dot the urban area. Ranchi Hill, Tagore Hill and Bariatu Hill are prominent amongst them. The area is marked also with erosional features such as bad land topography for example in the west of the Rifle Range, Bariatu, where topographic gradient is moderated to high.

Subarnarekha River is the principle drainage of the area. Harmu nala and Jumar nala are the major tributaries of Subarnarekha River. Drainage pattern is mainly dendritic in nature. From north to south, the different nallas/rivers crossing across the urban area are Jumar Nadi, Potpoto Nadi, Pandra Nadi, Harmu Nadi, Dibdih Nala , the nala at Hinnoo, Subarnarekha river near Hatiya. All the nala/rivers flow from west to east except the Subarnarekha river which after flowing in west –east direction for a distance takes a turn near Hatya and flows in NE direction till it meets the Getalsud reservoir. The drainage pattern of the area is mainly dendritic in nature. These streams, which were previously carrying clear water and perennial in nature, though there were variation in discharges between lean and flush periods. Presently these streams are carrying a lot of sewage discharges from the urban area (Fig. 2).

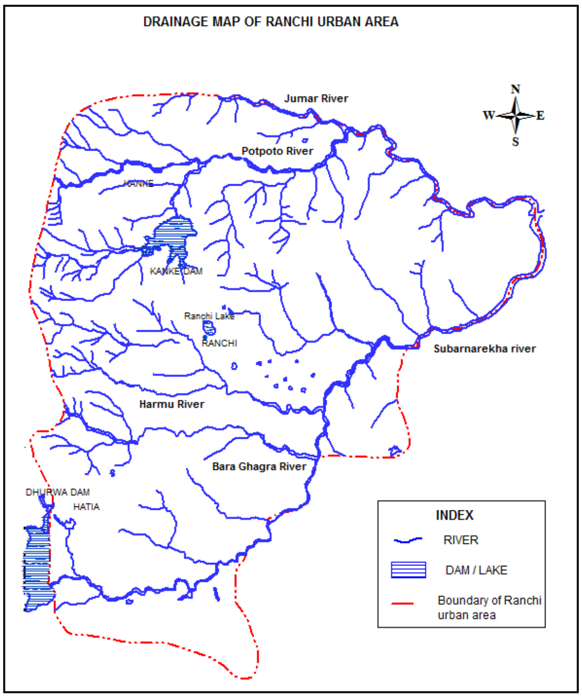

Fig.2 Drainage map of the Ranchi Urban Area.

Soil Type

The humid tropical climate has led to the formation of red soil in areas of higher elevation. This is overlain by lateritic soil. The area underlain by schistose rocks is having more deep red soil than those of granitic rocks due to the dominance of mafic minerals, particularly garnet. Soils of granitic rocks are lighter in colour due to the leaching of felsic components present in the rocks. Such variation in soil type is observed in the areas around the Ranchi Hill, Hehal Hill and Argora Hill with the Harmu River traversing the whole area.

STATUS OF WATER SUPPLY AND DEMAND

The domestic water demand is estimated to be 58.81 MCM @ 135 lpcd in 2011. The water supply to Ranchi town is being made from three surface water sources namely: Kanke Dam (19.5 mld), Hatia Dam (58.83 mld), Rukka Dam (170.48 mld) having the combined capacity of 246 mld. However, at present only 199 mld is supplied due to less water storage in the dams owing to less rainfall in 2010. It is also been worked out that about 30 % of the total water demand is met from ground water.

The present water supply covers 65% of the population. (RMC & PHED estimates it as 80%). On an average, it is stated that water is supplied to households at 100 lpcd per household. At present non-revenue water is about

92%. The other identified issues are; non-uniformity in supply (levels), high amount of distribution losses (over 40%), inefficient operations, high pollution in distribution network, and decline in ground water level.

The expected water demand will increase to about 83 mcm by 2020 and 232 mcm by the year 2051 and ground water demand will increase from 17.64 mcm at present to 69.73 mcm by 2050 taking 30% dependency on ground water in Ranchi Urban Area. The present and projected demand has been shown in Table1.

Table1 Water demand of Ranchi Urban Area

Year	Population	Expected water demand(m^3/day) @ 135 lit/person /day	Expected water demand (mcm/annum)	Ground Water Demand (mcm / annum) (30 % DEPENDENCY)
1991	599000	80865	29.52	8.85
2001	846454	114271	41.71	12.51
2011	1193500	161123	58.81	17.64
2021	1682835	227183	82.92	24.88
2031	2372798	320328	116.92	35.08
2041	3345644	451662	164.86	49.46
2051	4717359	636843	232.45	69.73

GROUND WATER SCENARIO

Potential Aquifers

Ranchi urban area is underlain by Chotanagpur Gneiss Granulite Complex of Precambrian age and exhibits a gently rolling to undulating topography. Occurrence and movement of ground water in consolidated formation is controlled by rock types and their properties related to weathering and deformation. In Ranchi urban area ground water occurs under unconfined condition in phreatic aquifer consisting of weathered mantle and saprolite zones (fractured zone in contact with weathered mantle) in confined to semi-confined conditions in deep seated fractures in the consolidated formation. Weathered zone thickness varies between 5.50 m to 37 m bgl. The hydrogeological of ranchi urban area has been given Fig.3

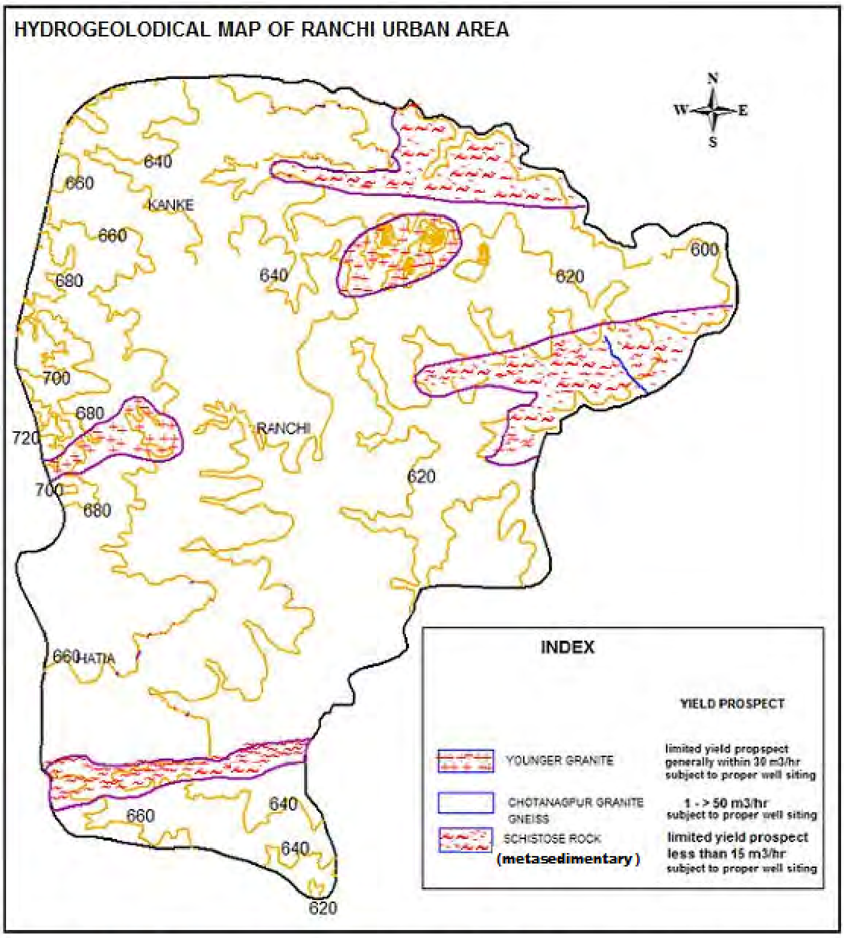

Fig.3 Hydrogeological map of Ranchi urban area

The fractures were detected up to a depth of 192 m bgl. However, the fractures occurring between 70 and 150 m depth constitute potential aquifers. The ground water occurs under semi-confined condition in these fractures. Transmissivity has been found to vary between 2.46 m^2/day (Rajbhawan campus) to 80 m^2/day (Golf ground, Dipatoli). Storativity at Doranda was observed to be 6.00 X10^{-4}.

Ground Water Level

40 dug wells and 13 peizometers are being monitored monthly in Ranchi Urban area for study if spatial and the ground water regime . The water level data of key observation wells and piezometers is given in table – 2 and 3.

In shallow aquifers during pre-monsoon period (May 2010) water levels vary between 2.04 (Dindyal Nagar) to 15.95 mbgl (Daily Market). During post-monsoon (November 2010) water levels vary between 0.25 (Tiril) to 11.81 mbgl (Church Compound). Depth to water level maps of both the period have been shown in Fig. 4.

Table 2 : Depth to water level in shallow aquifer (dug well zone)

Well No.	Village / Area	Depth (mbgl)	Diameter(m.)	DTW (mbgl) May-2010	DTW (mbgl) Nov-2010
RNC - 1	Tupudana	10.82	1.87	9.52	6.4
RNC - 2	Kachnar Toli	11.10	1.90	11.03	5.55
RNC - 3	Birsa Chowk (Check post)	6.01	2.00	4.96	2.76
RNC - 5	Hinoo	8.73	2.00	3.19	2.19
RNC - 6	Namkum	9.25	3.15	8.04	4.37
RNC - 7	Dhurwa (HEC)	7.27	2.45	3.87	2.39
RNC - 8	Tiril	13.45	4.60	8.66	5.92
RNC - 9	Pundag	8.90	3.80	8.2	5.01
RNC - 10	Ashok Nagar	6.50	2.17	5.15	3.01
RNC - 11	Lowadih	7.76	1.84	7.2	5.16
RNC - 12	Kokar	11.25	2.10	5.95	4.53
RNC - 13	Hotwar	13.60	1.50	11.51	7.11
RNC - 14	Booty(Nayak Toli)	5.41	1.22	3.98	3.41
RNC - 15	Baragai	6.34	2.50	3.51	3.04
RNC - 16	Ratu Road Bus Stand	8.75	3.10	5.05	3.49
RNC - 17	Dindayal Nagar	3.98	1.83	2.04	1.66
RNC – 18	Morabadi	12.36	1.80	Dry	7.55
RNC – 20	Chauri Basti (Kanke	8.97	1.15	3.35	4.03
RNC – 21	Bajra (Itki Road)	12.95	1.80	12.95	2.3
RNC – 22	Pandra	6.80	4.00	6.16	3.93
RNC – 23	Piska More(Hehal)	10.13	2.36	7.43	1.53
RNC – 24	Jahaj Kothi (Kanke Road)	7.56	3.38	2.68	3.42
RNC – 25	Upper Bazar (Zilla	6.70	1.55	5.35	0.28
RNC – 26	Chutia	5.78	2.44	3.89	3.59
RNC – 27	BaraGhaghra	8.44	2.80	7.63	5.85
RNC – 28	Kadru	12	2.60	13.1	4.61
RNC – 29	Balsiring	11.81	0.92	7.13	6.36
RNC – 30	Harmu	13.20	3.36	12.7	3.93
RNC – 31	Tupudana	7.95	1.47	7.98	5.95
RNC – 32	Doranda (AG Office)	11.48	1.78	9.01	2.16
RNC – 33	Doranda (Nepal House)	11.50	3.00	2.96	4.35
RNC – 34	Lalganj	11.25	2.35	7.9	1.82
RNC – 35	Kanke	5.80	1.60	3.41	4.07
RNC – 36	Sukurhutu	7.20	2.47	7.29	4.03
RNC – 38	Sainik Market	9.20	1.9	Dry	8.14
RNC – 39	Daily Market	16.25	1.9	15.93	11.04
RNC – 40	Church Compound	14.65	1.9	11.44	7.92

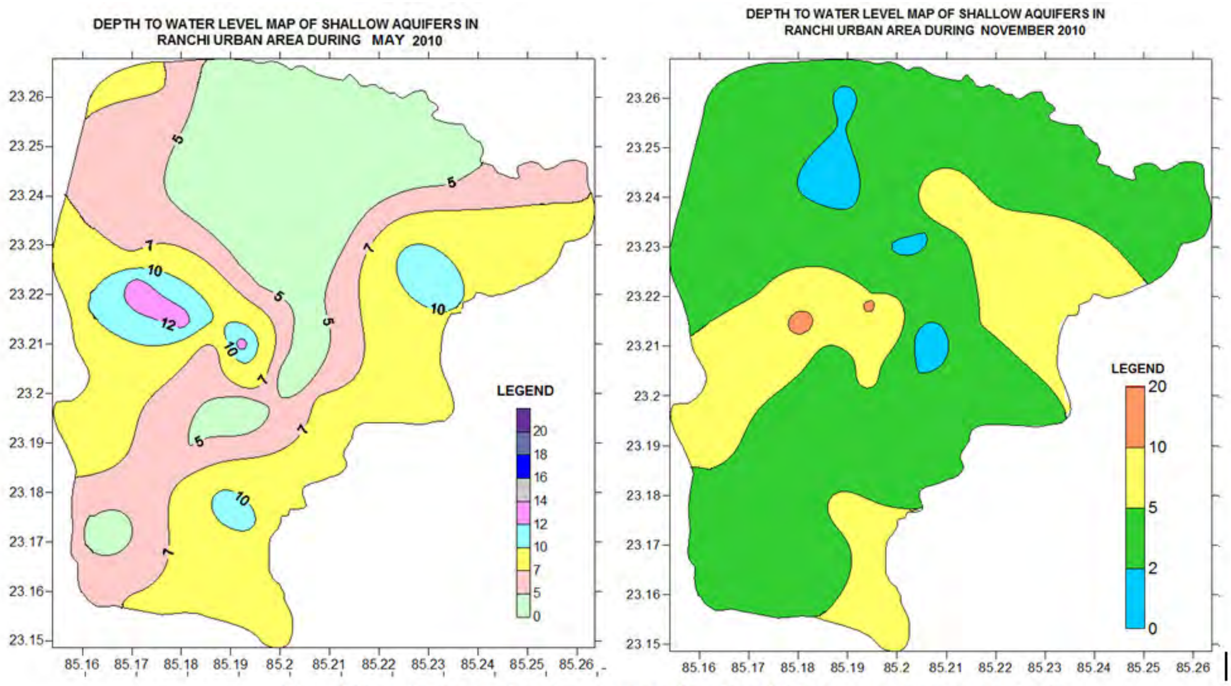

Fig:-4 Depth to water level map for Pre &Post-monsoon periods

Water Level in Deeper Aquifer

During May 2010 the depth to water level registered wide variation throughout Ranchi Urban Area. The minimum water level has been recorded as 5.49 m bgl at Bariyatu, where as maximum water level has been recorded as 22.08 m bgl at Kanke (Table 3).

During November 2010 also depth to ground water level registered wide variation throughout Ranchi Urban Area. The minimum water level has been recorded as 3.9 m bgl at Zilla School, where as maximum water level has been recorded as 19.84 m bgl at Kanke. The depth to water level map of the deeper aquifer has been shown in Fig. 5.

Table 3 Peizometric levels (m bgl) in deeper fractures

Location	Pre-monsoon (May 2010)	Post-monsoon (Nov.10)
Zilla School, Upper Bazar	5.80	3.9
RIMS, Bariyatu	5.49	4.02
DAV School, Doranda-PZ-I	22.01	15.9
DAV School, Doranda PZ-II	22.08	16.03
DAV School, Doranda PZ-III	21.92	15.93
Dipa Toli, Booti More	8.47	6.9
Khoja Toli, Namkom	8.19	5.27
Ranchi College	5.26	3.63
NIFFT Campus, Hatia	18.74	10.87
Army Aviation Mess, Hinoo	8.42	4.61
Harmu, HHC	24.57	12.35
Kanke	19.84	17.08
Harser, Dhurwa	7.13	5.58

If water level of the deeper aquifer during a month is compared with water level of the previous year is may seen that there is decline in water level in the deeper aquifers. It may be attributed to increase in stress on the deeper fractures for meeting the water demand of the population. Decline in water level has been depicted in Fig.6.

The water level data of the phreatic aquifer analysed to ascertain falling or rising trends, if any. It has been found that at some localities like Birsa Chawk , Pundag , Lowadih, Chauri basti, Chutia, BaraGhagra,Balsiring, the water level shows declining trend. The rate of decline varies from 0.017m/yr at Piska More to 1.025m/yr at Chiraundi .

The piezometers tapping different fracture zones at different depths also shows declining trend varying from 0.017 m/yr at RIMS Pz-I in and around Bariyatu area, to 0.922 m/yr DAV Shyamali PZ-I, Doranda area. This declining trend may increase in due course of time with the increase in population and other infrastructural facilities for the urban area. The piezometers with falling trend has been shown in figure:-7

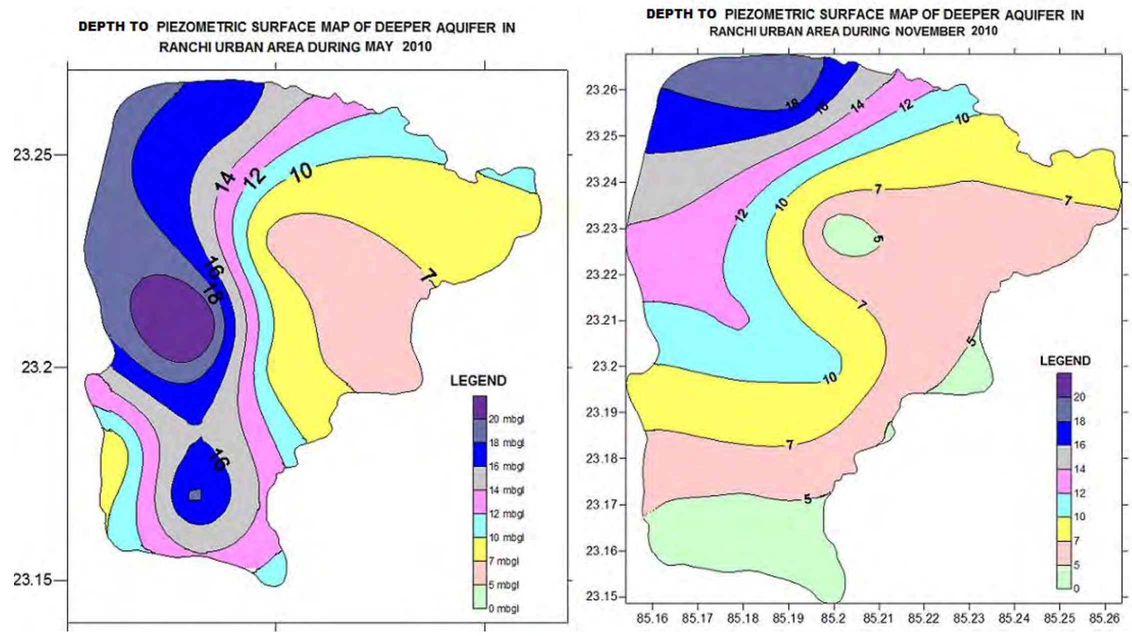

Fig.5 Depth to Piezometric Surface map (Pre & Post-monsoon periods 2010) of the deeper fractures

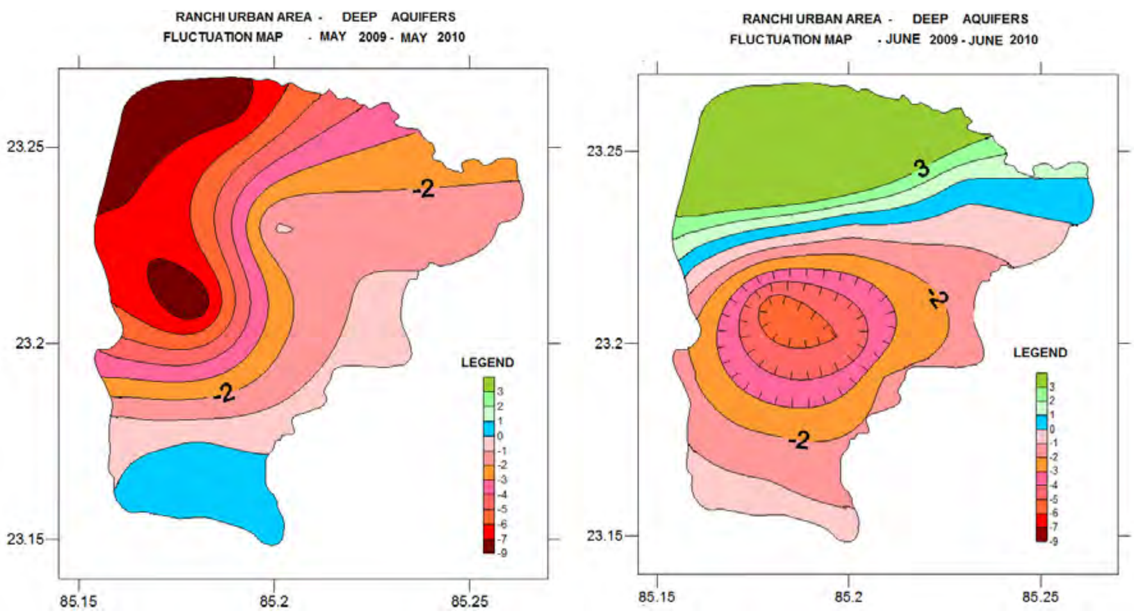

Fig.-6 Decline in water levels in two consecutive years

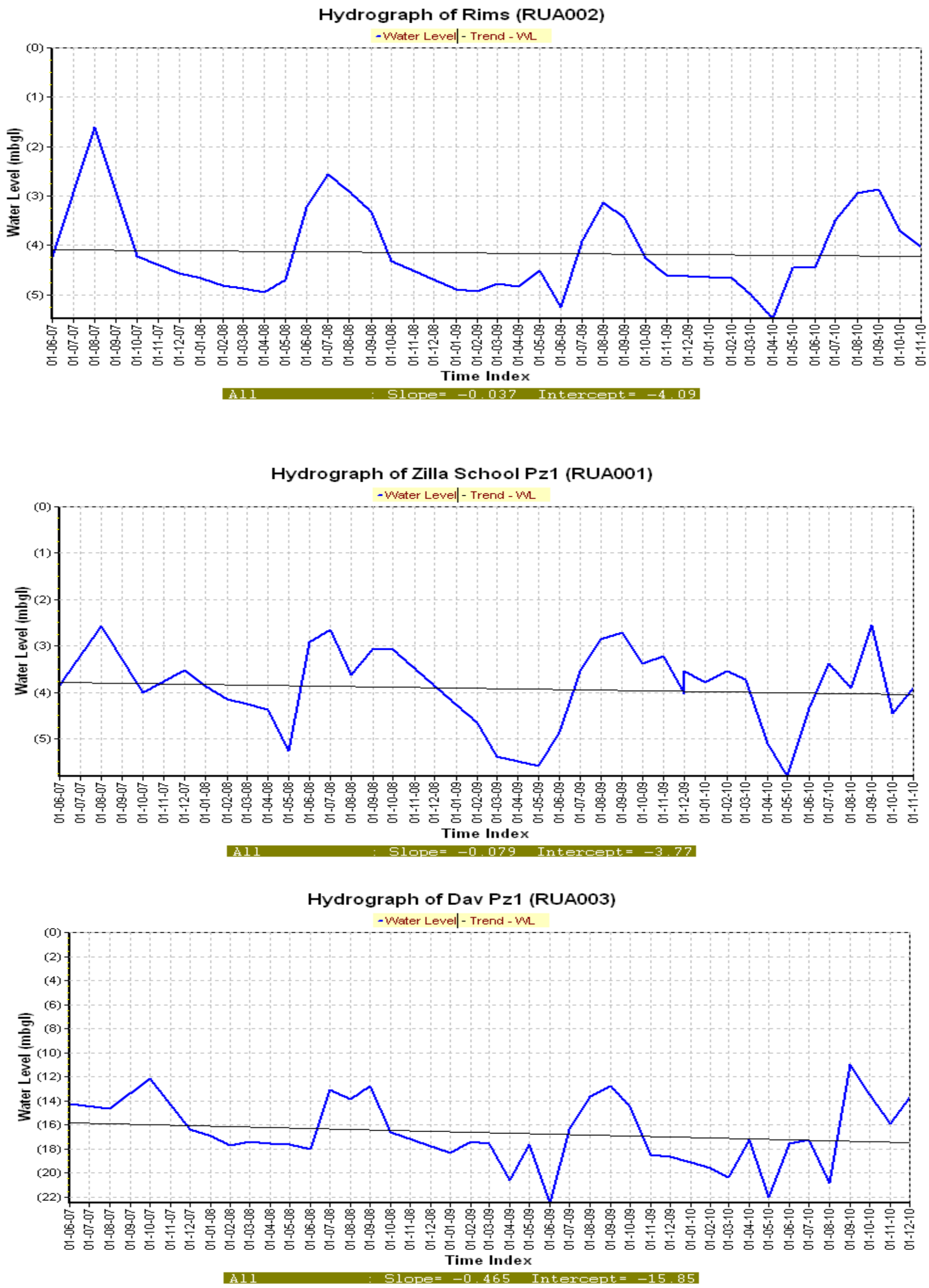

Fig. 7 Hydrographs of Piezometers with falling trend

Ground Water Resources & Status of Development (2004)

As per the provisional figures of the dynamic ground water resource estimation of Jharkhand (GWD & CGWB 2011), the replenishable ground water resource of Kanke block , Namkum block and Ratu block in which the Ranchi Urban area is situated are 36.79mcm,25.67mcm and 22.07 mcm respectively. Majority portion (70%) of Ranchi urban Area comes under Kanke block. The stage of development has been assessed to be 112.4%, 25.67%, and 22.07% respectively for Kanke, Namkum and Ratu blocks. It thus indicates that the enormous stress is being given on the shallow aquifer system which has become overexploited in Kanke block. However, due to increase in urban population and more and more apartments and high rise buildings are coming up in the city. The deeper fractures are mainly being exploited through bore wells to meet the drinking, domestic and industrial water requirement.

Hydrochemistry

In general ground water from shallow as well as deeper aquifer are found suitable for drinking uses. The EC of groundwater from the shallow aquifer(27 samples) varies from 162 µS/cm at Badghagra to 1168µS/cm at Daily market area. Whereas, in deeper fractures (14 samples) it varies from 252 µS/cm at Dipatoli area to 1319 at Mochuatoli area(central part of Ranchi Urban Area). In common market place and highly populated areas in central Ranchi, the EC values has been found on the higher side in both shallow and deeper aquifer. The chloride values in groundwater from the shallow aquifer varies from 14.2ppm at Harmu and Pandra to 192 ppm at Daily market area whereas deeper fractures it varies from 14.2 ppm at Dipatoli area to 178 ppm at Mochuatoli area (central part of Ranchi Urban Area). Concentration of iron (Fe) in ground water from the deeper aquifer has been found above the permissible limit (> 1.5 ppm) in some parts of the urban area like Sadar hospital area, Dipatoli area.

Major Ground Water Related Problem

- The Ranchi urban area is facing unique situation where water level in phreatic aquifer in some areas is rising, while water levels in deep seated fractures are showing declining trend.
- The deep seated fractures having higher discharge has witnessed higher fluctuation between pre and post-monsoon period peizometric heads.
- In the localities where population is growing fast like Doranda, Ashoknagar, Lalpur chowk, Kanke road the water level in deeper fractures rest between 20 and 25m blg during pre-monsoon period due to heavy draft.
- Iv After rainy season is over in some areas the water levels remain at deeper levels which shows higher degree of ground water withdrawal.
- Some areas with ground water quality problem (higher EC, Higher Fe than permissible limit)have been observed in the urban area.
- vi The problem with the existing distribution system is non-uniform water supply. Many areas do not receive any water while some areas receive water scantly. The some of affected areas are Doranda, Hindpiri, Harmu and isolated residential colonies.

Feasibility of Rainwater Harvesting and Artificial Recharge

Most of the areas are occupied by the hard rock, which are part of the Chotanagpur Plateau. These rocks are devoid of primary porosity and occurrence and movement of groundwater is controlled by the joints, fractures and fissures present in them. Due to the uneven topography major part of rain water flows as surface runoff resulting in less water available for percolation below the surface. The need of the day is to conserve every drop of water and use rain water for recharge of the depleted fractures. The scheme can benefit thousands of acres of barren land; if small ponds are excavated at suitable points or small check dams are build in the different rivulets. It will conserve soil moisture. The areas where artificial recharge is necessary are described in the following paragraphs.

D.A.V. Shyamli, Doranda

Geologically the area consists of granite gneiss. Weathered zone thickness is about 12 m. Piezometric surface level remains between 22.08 m bgl- 16.03m bgl during pre-monsoon and post-monsoon seasons. Fractures were encountered at different depths 36.00 - 38.00m bgl, 42.00 - 44.00m bgl, 45.00 - 46.00m bgl, and 89.00 - 91.00m bgl and 120.00 - 121.00 m bgl.

Harmu Housing Colony

Granite gneiss is the main geological formation. Weathered zone thickness is around 20 – 22 meters. Two sets of fractures were identified one at 29.00 - 32.00 mbgl and other at 102.00 - 103.00 mbgl. Discharge in different bore wells in the area varies between 2 to 7 lps. Water level observed during May was 24.57m bgl. Artificial recharge may be taken up in the fracture zones.

NIFT Campus, Hatia area

Granitic gneiss is the mainn formation over here. The depth to piezometric surface in the area varied from 18.54 mbgl during premonsoon to 12.35 during postmonsoon period. long term trend of Hatia monitoring well(dugwell) indicates falling trend. Deeper fracture zone was encountered at 152 m to 156 m with discharge of 6.34 lps. In the area recharge to shallow weathered zone as well as deeper fracture zone may be taken up.

Kanke Area

Granite gneiss is the main geological formation. The piezometer which is being monitored here is having water level of 19.84 during premonsoon and 17.08 during postmonsoon. Fracture zone was encountered at depth of 45 to 46 meter with discharge less than 1 lps. The area is suitable for recharge to deeper aquifers.

GROUND WATER DEVELOPMENT & MANAGEMENT STRATEGY

Keeping in view spatial and temporal variation of ground water levels in different localities in both phreatic and deed seated fractures, suitable ground water development strategies may be evolved to arrest further decline of the water level in the urban area and to make ground water supply sustainable.

- The localities where decline in water level of both shallow and deeper fractures has been observed artificial recharge of ground water may be made mandatory.
- The fractures occurring between 70 and 150 m bgl constitute potential aquifers and may be tapped for ground water withdrawal.
- High amounts of distribution losses (40%) due to old water supply distribution network, besides, unauthorized tapings should be checked by adopting suitable measures on priority basis. This will reduce pressure on ground water system
- The old water bodies within the urban area may be revived and renovated. This will help in recharging the shallow aquifer.
- There are a number of nalas flowing within the urban area. Suitable sites for Nala bunds and check dams may be identified and construction on priority basis.
- Roof top rainwater harvesting and artificial recharge may be taken up in the areas found suitable.

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SHILLONG, MEGHALAYA

Anu Radha Bhatia & Utpal Gogoi, CGWB, Shillong

INTRODUCTION

Shillong is the capital of Meghalaya, one of the smaller states in India. It is also the district headquarters of East Khasi Hills District. Shillong was a princely state (Hima Shillong), which was bifurcated into Mylliem State and Khyrim State in 1830. A hill town in the north eastern part of India, termed as “Scotland of the East”, Shillong is situated at an altitude of 1,496 m (4,908 ft) above sea level in the centre of the Shillong Plateau and is surrounded by hills, three of which are: Lum Sohpetbneng, Lum Diengiei and Lum Shillong or Shillong Peak. During the British Rule, Shillong consisted of only a few scattered clusters of hamlets.It is said that the rolling hills around the town with waterfalls, brooks and cool colonnades of tall pine trees reminded the European settlers of Scotland. The city was founded by Col. Henry Hopkinson, Commissioner of Assam in 1864 as a civil station of the Khasi and Jaintia Hills. In 1874, the State of Assam was created out of Bengal and Shillong became a Chief Commissioner's Province and provincial capital of the new administration. Shillong has steadily grown in size and significance since then. It remained the capital of undivided Assam until the creation of the new state of Meghalaya on January 21, 1972, when Shillong became the capital of Meghalaya and Assam moved its capital to Dispur in Guwahati.

GENERAL FEATURES

Administrative Setup

Shillong city is now an urban agglomerate known as Greater Shillong comprising Shillong Muncipality and 6 suburbs, namely Shillong Cantonment, Madanryting, Mawlai, Nongthymmai, Pynthorumkhrah and Nongmynsong. The Greater Shillong area falls under Mylliem block, East Khasi Hills district, Meghalaya covers an area of approximately 40 sq. km. The area lies between north latitudes 25°33′15″ to 25°36′ 02″ and east longitude 91°50′50″ to 91°56′17″ and falls in the survey of India toposheet No. 78 O/14. Location Map of Greater Shillong is shown in Fig. 1. Shillong is well connected by road with all major north eastern states. Two major National Highways pass through Shillong - National Highway 40 connects Shillong to Guwahati and National Highway 44 connects it to Tripura & Mizoram. There is no rail connection and the nearest Railway Station is Guwahati at a distance of about 110 Km from Shillong. Although Umroi Airport exists but there are only limited flights and connectivity. Helicopter service is also available between Shillong-Guwahati and Shillong-Tura.

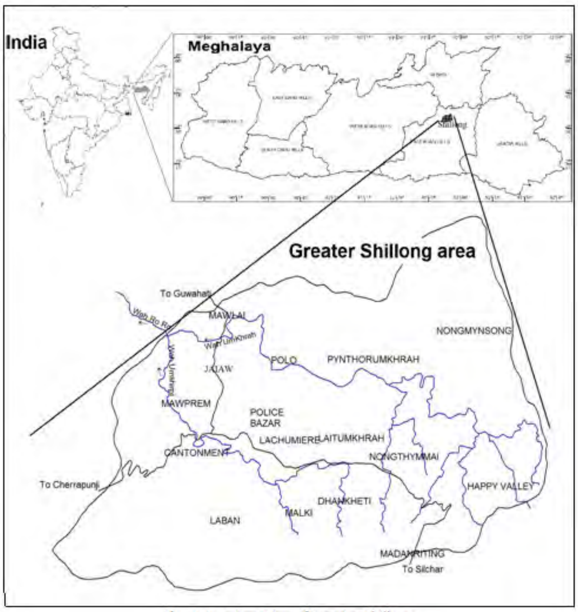


Fig. 1: Location Map of Greater Shillong

Demography

As per 2001 Census, the total population of the urban area is 267662 as against 233280 in 1991 indicating a decadal growth of about 15%. The projected population of the urban area from 2011 to 2041 is presented in Table 1. As per 2001 Census there are 134497 Males and 133165 Females. The sex ratio is 101 males to 100 females. Average literacy rate is 80%, higher than the national average of 59.5%: male literacy is 83%, and female literacy is 78%. 11% of the population is under 6 years of age.

Table 1 Population in Greater Shillong (1991, 2001 and projected population for 2011 to 2041)

Year	1991	2001	2005	2007	2010	2011	2021	2025	2031	2041
Population	233280	267662	285141	296000	313676	316000	374000	405000	439000	512000

The population of the suburban towns of Greater Shillong as per 2001 Census is given in Table 2.

Table 2: The population of the suburban towns of Greater Shillong

Suburban Town	Area in sq.km.	Population (2001 Census)	Projected Population (2010)
Shillong Muncipality	10.5	132867	133827
Shillong Cantonment	2	12396	13678
Madanryting	2.1	16318	27804
Mawlai	6.2	38303	46179
Nongthymmai	3	34292	42453
Pynthorumkhrah	2.2	22115	34015
Nongmynsong	2	11371	15720
Total	**28**	**267662**	313676

Khasi tribals make up majority of the population. All the other northeast Indian tribes are represented here as well as significant numbers of Bengali, Nepali, Assamese, Biharis and Marwaris making it a fairly cosmopolitan city. Christianity is the dominant religion in the city. A sizable proportion of the population follows the original Khasi religion, Niam Khasi and Niamtre. Other religions found in India are also represented in significant numbers in the city.

Hydrometeorology

The city features a subtropical highland climate with temperature varying from 2° to 25.0° C (Table 3). Winter usually starts from October and continues up to March. During the months of December and January ground frost in early morning is very common. Summer is rather of short duration followed by monsoons which generally starts from May and continues till September and so. 90% of the total annual rainfall takes place in this season. Rainfall is high in the area with an annual rainfall of about 2400 mm.

Table 3: Climate of Shillong

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Average high °C (°F)	15.6 (60.1)	17.9 (64.2)	21.9 (71.4)	24.3 (75.7)	24.2 (75.6)	23.8 (74.8)	24.1 (75.4)	24.3 (75.7)	23.7 (74.7)	22.1 (71.8)	19.1 (66.4)	16.5 (61.7)	21.46 (70.63)
Average low °C (°F)	3.6 (38.5)	6.1 (43)	10.5 (50.9)	14.3 (57.7)	15.9 (60.6)	17.4 (63.3)	18.2 (64.8)	17.8 (64)	16.5 (61.7)	13.1 (55.6)	7.8 (46)	4.7 (40.5)	12.16 (53.89)
Precipitation mm (inches)	15.2 (0.598)	28.5 (1.122)	59.4 (2.339)	136.4 (5.37)	325.4 (12.811)	544.6 (21.441)	394.9 (15.547)	334.6 (13.173)	314.9 (12.398)	220.2 (8.669)	34.9 (1.374)	6.3 (0.248)	2,415.3 (95.091)

(Source: Indian Meteorological Department)

A major percentage of the heavy precipitation, received in Shillong area goes as direct surface runoff because of steep hilly slopes but ground water recharge does take place in those areas that are characterized by gently undulating terra.

Physiography and Drainage

The area under Greater Shillong forms a part of the Shillong Plateau. It is located on a gently undulating area with steep slopes running in different directions. The master slope runs mainly in south-west to north-east direction. The whole area is altered by construction and other related activities, habitations and office establishments. Hence, it is difficult to decipher the original land forms of the area. The average height of the area is about 800-1400 m above msl. The highest point of Shillong is Shillong peak, which is situated at a height of 1960 m above mean sea level. The plateau is dissected by a number of streams into hills and intermontane valleys. One major intermontane valley lies to the north of the city along Wah Umkhrah river in the Polo Ground area.

The main drainage of Shillong is carried by two rivers, namely Wah Umshirpi and Wah Umkhrah, which confluence near Beadon and Bishop Falls to form the Wah Ro Ro river, a tributary to Wah Umium river. These two rivers surround the Shillong town and roughly determine the municipal limits. The numerous streams in the western and southern parts of the city are tributaries of Wah Umshirpi, whereas streams in northern and eastern parts of the city are tributaries of Wah Umkhrah which starts as Umpling River near Umpling. The drainage pattern of the area is angular to sub-angular, typical of hard rock hilly terrain. The streams are not perennial in nature. The discharge in the streams varies from season to season.

Soil Type

The soils present in and around Shillong Urban area are ultisols, colloquially known as "red clay soil". The soils are shallow to moderately deep, loamy, skeletal, fine and excessively drained, with severe to very severe erosion hazards. Ultisols vary in color from purplish-red, to a blindingly bright reddish-orange, to pale yellowish-orange and even some subdued yellowish-brown tones. They are acidic, often having pH of less than 5. The red and yellow colors result from the accumulation of iron oxide (rust) which is highly insoluble in water. Major nutrients, such as calcium and potassium, are typically deficient in ultisols, which means they generally cannot be used for sedentary agriculture without the aid of lime and other fertilizers such as superphosphate.

STATUS OF WATER SUPPLY AND DEMAND

The main source of water for Greater Shillong is water supply from the river Umiew originating from Shillong Peak (RL1964 m above mean sea level). River Umiew is one of the major rivers in the state perennially flowing throughout the year. Under the Greater Shillong Water Supply Project, a mass gravity concrete dam was constructed across the river Umiew at Mawphlang, about 20 km. from Shillong. The dam is 135m wide and about 50m high and provides 9.145 MCM of live storage. The catchment of river Umiew is about 115 sq km and a large area of the catchment is in close proximately to Cherrapunjee. As a result, the catchment receives a fairly good amount of rain in comparison to other areas. Records available indicate daily spilling of water almost 24 hrs a day despite lifting about 51.30 MLD (Million liters per day), indicating that the river has the potential to cater to the additional demand in future which may arise due to increase in population of the Greater Shillong. The responsibility of P.H.E.D. in Shillong municipal area is to lift required quantity of water from Greater Shillong Water Supply Scheme at Mawphlang Treatment Plant and release to 13 zonal overhead tanks/reservoirs located in different parts of Shillong City for distribution of water to consumers.

At present, along with the municipal water supply from 7 springs ((Table 4)) and about 7 deep tubewells and more than 25 shallow tubewells, the Greater Shillong Water Supply Project completely meets the water requirement of 42.5 Mld. However, for projected future demand, with the present water availability, there will be shortfall in water supply of 8MLD and 24MLD in the years 2026 and 2041respectively. Taking this into consideration, infrastructure for generation and distribution of additional quantity of water to meet the shortfall is required to be created without any loss of time.

Water is supplied in Shillong municipality area from (i) Municipal Sources and (ii) Greater Shillong Water Supply Scheme (G.S.W.S.S.). The Shillong Municipal Board (SMB) has the capacity to supply nearly 6.0 MLD of water every day. The springs, which are the major sources of water, are Wahrisa, Wahjalynnoh and Umjasai. Shillong Municipal Board has provided about 8851 water connection around the Shillong Municipal Area.

Table 4: Water Supply through Springs in Shillong area

Sources of Water	Amount of Water (litres)	
	Pre- monsoon period	Monsoon period
Wahrisa	454600.0	636440.0
Wahjahlynnoh	454600.0	545520.0
Umjasai	909200.0	1136500.0
Madan Laban	227300.0	363680.0
Crinoline	363680.0	454600.0
Patta Khana	113650.0	227300.0
Wahdienglieng	227300.0	295490.0
Total	2750330.0	3659530.0

Outside Shillong municipal area but within Greater Shillong, 1.5 million litres water is supplied from the following water supply schemes, which were implemented & are being maintained by PHED:(i) Mawlai Umsohlang WSS for Mawlai, (ii) Pynthorumkhrah WSS for Pynthorumkhrah, (iii) Umkhen WSS & Lum Demthring for Nongthymmai area, (iv) Nongmynsong WSS for Nongmynsong area. The water demand and supply of Greater Shillong area is shown in table -5.

Table 5 Water Demand and Supply of Greater Shillong area

Suburban Town	Area in sq.km.	Projected Population (2011)	Drinking and domestic Water Demand per day (Million Litres)	Water Supply per day from G.S.W.S.S (Million Litres)	Water Supply per day through Springs and Tubewells (Million Litres)
Shillong Muncipality	10.3	155737	21.1	19.97	Approximately 4.0 Ml (Ground Water - 7 major springs, 16 small springs, 7 deep tubewells and 25(+) shallow tubewells + 4.5 Ml (other surface water sources)
Shillong Cantonment	2	13628	1.8	3.74	
Madanryting	2.02	21118	2.8	0.75	
Mawlai	6.14	42748	5.8	2.5	
Nongthymmai	3	38085	5.1	3.9	
Pynthorumkhrah	2.11	28627	3.8	2.7	
Nongmynsong	10.3	16057	2.1	1.6	
Total	**35.87**	**316000**	**42.5**	**35.16**	**7.5**

The contribution of ground water is only 10 % of the total water supply to Shillong urban area. However, a number of private ground water sources (shallow dug wells and shallow tubewells) exist, for which no census is available.

GROUND WATER SCENARIO

Geology

The area forms a part of Shillong Group of rocks consisting of quartzite & phyllites. Exposures of crystalline rocks in the area are of quartzites belonging to Shillong Group of Pre-cambrian age are scattered all over the area. The base of Shillong Group is marked by conglomerate bed containing cobbles and boulders of earlier rocks, i.e. Archaean crystalline rocks, which formed the basement rocks over which the Shillong Group of rocks were laid down as sedimentary deposits during Pre-Cambrian age and metamorphosed over time. The rocks were intruded by epidiorite rocks known as Khasi green stone. These metabasic rocks occur mostly as sills being concordant with the formations they intruded.

The surface area is covered by red soil to mixed soil type having thickness ranging from few centimeters to 2 m. The rocks are highly weathered at shallow depth leading to the formation of thick soil cover in the low lying areas & thin veneer of soil layer at higher elevation. This weathered zone is underlain by jointed and fractured quartzite. The distribution and disposition of these joints and fractures are of complex nature due to the various tectonic and structural disturbances to which country rocks are subjected to. The depth of this zone varies from 10-60 m below ground level. This is followed by hard massive quartzites, which are generally devoid of prominent structural features. However fracture/jointed rocks are found to occur at greater depths in certain exploratory wells drilled in similar formations in the area. Broadly, there are three sets of lineaments in the area, mainly along ENE–WSW, NW–SE and E–W directions. Lineaments along NE–SW, NNW–SSE and N–S directions are also developed.

Potential Aquifers

Groundwater resources in Shillong area are highly variable, it being mountainous terrain and are mainly dependent on topography, zone of weathering, fracturing and interstices present in country rocks. The availability of ground water in hilly region is manifested in the form of springs, seepages, wells and bore well of limited/ nominal yield.

Ground water occurs in the area under water table condition in the top weathered and fractured zone of quartzite. Further below, semi-confined to confined condition exist in the interconnected joints, fractures etc. of the underlying hard quartzite. The weathered quartzite has poor to moderate yields. The depth of this weathered zone varies up to about 30 m below ground level. The underlying second zone is fissured and jointed which is the zone of saturation. The distribution and disposition of these joints and fractures are of complex nature due to the various tectonic and structural disturbances to which country rocks were subjected to. Groundwater occurs under semi-confined condition in this zone. Such zones saturated with water are likely to extend down to 60 to 180 m below ground level.

Quartzite and recent valley fills (in Polo area) constitute the major aquifer system in the area. Ground water occurs under unconfined condition in the weathered rock and residuum. Ground water development in the urban agglomeration is both by dug wells generally confining to the weathered zone & bore wells, which mainly tap, fractured zone in the hard rocks. These fractures sometime extend very deep beyond 60m bgl, but otherwise generally close before 60m depth. From the well inventory data, it has been found that during the dry period, in dug wells, depth to water level varies from 0.50m bgl (at Polo) to 5.56m bgl (at Pynther). In post-monsoon period it varies from 0.15m bgl to 5.10 m bgl at the same locations respectively. The average seasonal water level fluctuation is 1.19m with minimum fluctuation of 0.35 m at Polo and maximum 2.95m at Mawlai-Mawroh. The hydrogeological map of Greater Shillong is shown in **Fig.2.**

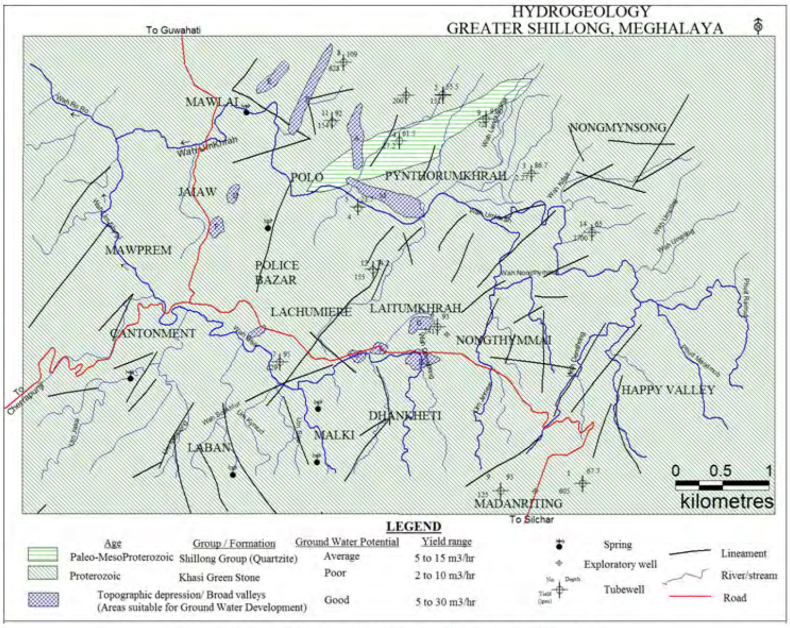


Fig. 2: Hydrogeological map of Greater Shillong

As the topography is uneven and the thickness of the weathered horizon varies considerably, open wells are restricted to the Umkhrah valley in polo ground and Pynthorumkhrah area. Inventory of these wells have indicated the following-

(a) Depth to water level is shallow in topographic depressions than in the upland areas. It varies from about 10 to 5.0 m bgl in the depressions while it is about 10.0 m bgl in the upland.
(b) Water level values are independent of lithology of the area.
(c) Wells in weathered metabasic rocks hold water throughout the year, whereas wells in weathered quartzites dry up during the lean period, indicating thereby better inflow of ground water in metabasic rocks.
(d) The seasonal water level fluctuation is about 3.0 m in topographic depressions and about 8.0 m in higher upland areas.

Yield capacity test in the near surface aquifers in the Shillong area establishes that weathered matabasic rocks have a moderately high yield potential. From the study of lithological and hydrological data of shallow borewells of Shillong area it has been observed that Pynthorumkhrah area is most productive. The wells have been drilled in quartzites and metabasic rocks to a depth ranging from 30.00 to 110.00 m below ground. The yield of the boreholes ranged from 5.0 m^3/hr to 8.0 m^3/ hr. with drawdown of about 3.5 m.

National Hydrograph Station located near Polo market fall falls in Greater Shillong. The piezometric head in dry period varies from 2.63 (at Lapalang) to 17.2m bgl (at Raj Bhawan complex). In post-monsoon period it varies from 1.97 to 14.32m bgl at the same locations respectively. Two tubewells, located at Nongmensong &

Kench's Trace, have artesian condition with a free flow discharge ranging from 0.13 to 3.6 m^3 /hour respectively.

Yield of bore wells in Greater Shillong : The yield from bore wells drilled in urban agglomerate area ranges from 0.9 to 50 m^3/hr. The total depth of the tube wells varies from 31.08 to 126 m bgl. The summarized details of yield ranges in bore wells are given in Table 6**.** After analysis of the data it is observed that the yield in most of the bore wells lies between 5 and10m^3/hr (in 35% of the bore wells). The yield of about 78% of the bore wells is less than 20m^3/hr. It has been observed that most high yielding bore wells are generally associated with NE-SW trending lineaments and the intersection of NE-SW & NW-SE lineaments.

Table 6 Summarised details of bore wells drilled in Shillong Urban Agglomerate.

S. No	Location	Depth of well (m)	Static Water level (mbgl)	Discharge (m^3/hr)
1	NEHU -I	67.78	1.52	36.30
2	NEHU -II	90.99	10.05	11.34
3	NEHU -III	56.00	6.09	76.68
4	Pynthorbah-I	55.54	5.18	9.06
5	Pynthorbah-II	84.84	15.24	29.40
6	Pynthorbah-III	56.36	-	19.02
7	Nongmynsong	86.66	-	13.62
8	Pythorumkhrah	61.51	21.33	16.32
9	Post & Telegraph, Polo	97.87	0.30	25.38
10	Industrial Estate	109.00	1.52	37.68
11	Lady Hydari park	91.51	6.70	19.14
12	AIR, Polo	102.00	12.19	27.24
13	AMD Complex, Lalchandbasti	90.00	6.09	8.4
14	A.G. Colony, Motinagar I	93.00	36.57	7.44
15	A.G. Colony, Motinagar II	92.00	6.70	3.30
16	St. Edmunds School I	93.00	6.09	14.46
17	St. Edmunds School I	93.00	6.09	16.20
18	Lyndhurst Estate, Upper New Colony	93.00	10.05	11.22
19	Assembly hostel	108.00	12.98	63.72
20	Jaiaw Thangbriew	80.00	3.05	42.12
21	BSF Complex Lachanbasti I	56.00	-	9.18
22	BSF Complex, Lachanbasti II	74.00	6.70	9.18
23	MSEB Meter Factory	92.00	12.19	9.30
24	Raj Bhawan	74.24	1.82	12.00
25	MPRO Complex Golf link	72.00	12.19	9.50
26	Umpling I	53.00	4.00	27.00
27	Umpling II	65.00	-	5.68
28	East of Pinewood Hotel	31.00	-	9.00

N.B. : Discharge of Tubewells not verified by C.G.W.B.

Occurrence of Ground Water as Springs : Spring plays a major role in domestic water supply to the people in Shillong. Spring discharge is controlled by rainfall, land use, vegetation, and geomorphology of the recharge zone. Geologically, the springs monitored in the study area are of gravity type. The study of springs in Shillong area was taken up as a part of urban hydrogeological surveys in 2004-05. The average annual rainfall (average of 1991-2002) worked out to be 2241.85mm. Springs' discharge monitored during the survey showed higher discharge in May-June compared to January-March. This may be due to high rainfall during April-June. Hence the discharge measured in the month of Jan-Mar has been taken as the discharge in dry period (summer) and in Nov-Dec as wet period (post-monsoon). The discharge of the springs in dry period varies from 8100 lpd (at Laban) to 51,840 lpd (at Umkdait) and in wet period from 11293 lpd (at Mawpat) to 187488 lpd (at Umkdait). Further, it was observed that 89% of the springs confine their discharge to 50,000 lpd during dry period. The same was 66% during the wet period. The percentage of spring with discharge more than 50,000 lpd in wet period was 22, which came down to 11 in dry period. It reveals that only low yielding springs are least affected by rainfall in the study area. Looking at the hydrogeological behavior of these springs it can be inferred that each spring has its own character, which is influenced by a combination of factors, operated in the recharge zone.

Ground Water Resources and Status of Development

The estimated annual recharge of ground water in Shillong is to the tune of 4.19 MCM. As against this the present withdrawal is about 2 MCM. The balance of 2.19 MCM can very well supplement the shortfall of water supply, especially during five months of lean period between December and April.

Hydrochemistry

The water quality analysis results of some of the samples collected in Greater Shillong area are given in Table 7.

Table 7 Details of chemical analysis results of ground water samples

S. No.	Location in Shillong	Source	pH	EC	CO_3	HCO_3	Cl	TH	Ca	Mg	Fe
1	Golf Link Ground	Spring	5.70	17	Nil	4.9	2.1	6.0	1.6	0.49	-
2	Bara Bazar	Dugwell	5.4	280	Nil	11.0	6.0	52.0	11.0	5.8	-
3	Pynthormukhra-I	Dugwell	6.45	87	Nil	9.8	5.7	9.0	1.6	1.2	0.3
4	Pynthormukhra-II	Dugwell	6.50	55	Nil	12.0	10.0	14.0	2.4	1.9	-
5	Buddhist Temple	Dugwell	6.80	148	Nil	89.0	7.0	62.0	22.0	2.0	0.2
6	Sacred Heart Church	Dugwell	6.01	-	Nil	103.7	14.2	30.0	4.0	5.0	-
7	Polo Ground	Spring	5.4	-	Nil	18.3	21.3	55.0	8.0	9.0	0.2
8	Dremland Cinema	Dugwell	6.5	90	Nil	12.0	18.0	45.0	10.0	5.0	0.15
9	Lower Lachumiere	Dug well	7.1	120	Nil	18	25	45	14	2.4	0.11
10	Kench's Trace	Tube well	5.7	52	Nil	18	7.1	10	2	1.2	0.14
11	12^{th} mile Mylliem	CGWB EW	6.78	96	Nil	49	7.1	30	10	1.2	0.02

All Units are in mg/l except E.C., which is expressed in at microsiemens/cm at 25°c

A perusal of the above chemical data indicates that groundwater around the area of investigation is slightly acidic to alkaline with pH values ranging from 5.4 to 8.2. The electrical conductivity values vary from 17 to 280 microsiemens/cm at 25^oC indicating that the water is potable. The carbonate content is nil. Total hardness (Ca+Mg) expressed as $CaCO_3$ in ppm is small indicating that the water is soft in quality. The other chemical constituents of ground water namely HCO_3, Cl, Ca, Mg, Fe etc. all are within permissible limit as per Bureau of Indian Standard (IS: 10500-91). The iron concentration in ground water varies from 0.02 to 0.30 ppm. The highest iron content of 0.30 ppm is observed in a dug well while lowest occurs in spring water. Thus it can be concluded that the ground water in the area is generally good and potable which can be used for domestic and industrial use.

Major Ground Water Related Problems

In spite of the availability of ground water, the ground water development in the city is poor. The physiography of the rugged hilly terrain restricts development of groundwater. Many areas are unapproachable for truck-mounted rigs and there is need for In-well Drilling Rigs. Another problem is concentration of borewell in some pockets. Regulatory measures should be taken up to regulate ground water development. The matter is under consideration by the State authorities.

Although, ground water in the area is generally good and potable for drinking, domestic and industrial uses, concentrations of iron > 1mg/l in some pockets have been reported from Greater Shillong. The presence of iron in drinking water supplies is objectionable for a number of reasons related to health. Ferrous salts are unstable and precipitate as insoluble ferric hydroxide when water is brought in contact with air, and settle down as rust coloured silt. Ground water having high iron content tastes unpalatable and stains laundry and plumbing fixtures.

Feasibility of Rainwater Harvesting

Rainwater harvesting is an important aspect of water conservation and management as it provides a cost effective means of collection and storage of water for use during the water deficit period. Bestowed with high rainfall, some areas of Greater Shillong face water scarcity during the lean period. It is not always feasible to construct ponds/lakes/reservoirs in the city due to the cost of land and urban development pressures. However, roof-top rainwater can be conserved, thus bringing much needed relief to the water scarcity areas of the city. Central Ground Water Board implemented pilot project studies of roof-top rainwater harvesting in Shillong under Central Sector Scheme during IX Plan. The scheme was implemented in the locations shown in Table 8, at a total cost of 20.32 lakhs.

Table 8 Details of roof-top rainwater harvesting in Shillong

Sl. No.	Location	Roof-top area (sq.m)	Gutter Length (m)	Drop Pipe (m)	Conveyance Pipe (m)	Carrying Pipe (m)	Water harvested (cu.m)
1	State Guest House Barik	186.2	53.4	12.0	85.0	40.0	357.5
2	Circuit House Laban	137.6	42.4	10.0	60.0	60.0	264.19
3	State Central Library, IGP	1103.2	162.6	42.0	90.0	45.0	2118.4
4	Auxilium Convent Nongthymmai	520.5	123.0	15.0	60.0	45.0	999.36
5	Pine Mount School in Barik	973.3	176.1	24.0	140.0	40.0	1868.73
6	All Saints School, IGP	613.4	106.0	15.0	120.0	48.0	1177.73

GROUND WATER DEVELOPMENT STRATEGY

Development of ground water by construction of borewells is suggested in the following locations-

(A) European Ward – Laban – Malki area
1. South of Pine Mount School, near the confluence of Umkyrud, Umshan Show and Wah Risa River.
2. Adjacent to Umkdait River, North of Cromeen's House.
3. NE of Pine Wood Hotel and south of Bishop Cotton Road and Polo Road.
4. Malki play ground on east of Survey of India office.

(B) Police Bazar – Mawlai – Mankhar – Kench's Trace area
1. SW of the confluence of Umkhrah river and Umsoh-sun stream.
2. East of Mawlai and north of the right angled bend of the Umkhrah River.
3. At the confluence of Umjasai and Ummawlong rivers, west of Kench's Trace.

(C) Nongthymmai – Umpling – Happy Valley area
1. East of Nongthymmai and SW of Rynjah in the valley of Wah Demthring nalla.
2. Located between Umpling and Nongmynsong at the confluence of Wahkdent and Umpling rivers.
3. NNW of the bridge on NH-44 on Wah Nongthymmai rivers western bank.

In the above mentioned sites drilling with a DTH rig down to a depth of about 60.00 m from the surface can be taken up. As the rocks of the shilling area are sometimes highly weathered with the deep situated water bearing zones, it is suggested that such unstable formations may be cased and assembly lowered and annular space gravel packed, to facilitate entry of ground water and at the same time preventing collapse of the tubewell wall. The potential ground water zones are not uniform in characteristics as the aquifer material, fracture density, its' distribution and hydrogeological characteristics vary widely over short distances. Consequently, water yielding capabilities vary considerably. In hard rock terrain, selection of site with the highest potential on the basis of geomorphology, relative relief, gentle gradient, thick top weathered mantle and occurrence of fractured zone for getting a productive borehole is necessary and reduces chances of striking a dry hole.

Further, there is ample scope for the construction of large diameter open wells in a few selected intermontane valleys of Greater Shillong area, which can considerably help in augmenting the water supply system. The favourable areas are as follows-

- In the linear valley on the eastern side of the meter factory of MESB, marked in **Fig. 2** as A.
- In the linear valley on the eastern side of the Sacred Church Convent in Mawlai area marked in **Fig. 2** as C.
- In the small valley adjacent to and NNW of Bara Bazar, south of District Council Office, at the junction of G.S. Road and Cantonment road, marked in **Fig. 2** as F.
- A broad valley on the southern side of NH-40 near Fire brigade ground, marked in **Fig. 2** as H.
- The main Polo river valley, marked in **Fig. 2** as M.
- Broad flat valley of Wah Yblam river between CPRS and Government Agriculture Farm. The valley extends for about a km and has an average width of about 100 m, marked in **Fig. 2** as L.

Though ground water has the possibility to further augment the drinking water supply of the city, conjunctive use of surface and ground water sources is highly recommended. For better utilization of the surface sources like springs, streams, it is recommended that effort should be make to tap the springs right at the source of emergence and water be conducted through large diameter pipes to avoid pollution and other losses. Groundwater development may be regulated by permitting development only in needy areas and new colonies. Further, rainwater harvesting techniques should be universally educated and brought to practice with immediate effect.

SHIMLA, HIMACHAL PRADESH

Sunil Kumar & Vidya Nand, CGWB Dharamshala

INTRODUCTION

Shimla is the Capital Town of Himachal Pradesh. The name Shimla was derived from **'Shyamalaya'** meaning blue house said to be the name of house built of blue slate by a faqir on Jakhu. According to another version, Shimla takes it name from 'Shamla' meaning a blue female another name for Goddess Kali. The place was on the Jakhu Hillside and there was a temple of Goddess Kali. During the British period, the image of the Goddess was shifted to a new place, now famous Kali Bari Temple. Shimla remained unnoticed during the Anglo-Gorkha War. It was only in 1819 A.D. that the then Assistant Political Agent of hill states Lt. Ross set up first British residence, a mere wood cottage. His successor Lt. Charles Patt Kennedy' erected the first pucca house in 1822 named after Lt. Kennedy as 'Kennedy House'. The land of present Shimla town originally belonged to the Maharaja of Patiala and Rana of Keonthal and was acquired by British regime in 1930. Thereafter Shimla became summer capital of India. After independence of India, it continued to be the summer capital of Punjab Government till 1948 when Himachal Pradesh was formed by merger of erstwhile princely state on 15th April, 1948.

GENERAL FEATURES

Area and Administrative Divisions

Shimla city is located between North latitudes 31^{o}04'and 31^{o}07' and East longitudes 77^{o}06' and 77^{o}13'. The city falls in survey of India toposheet no. 53 E/4 and covers an area of about 28.53 sq km. The city is well connected by roads and railways. The Hindustan Tibet road i.e. National Highway No. 22 passes through the city and connects Delhi, Chandigarh and other major part of India by all season motorable road. The narrow gauge railway lines connect Shimla town with Kalka. The city consists of the Shimla Municipal Corporation and Shimla Planning Areas (SPA). The SPAs are Dhalli, Tutu and New Shimla urban agglomerations.

Demography

As per the 2001 India Census, the city has a population of 1,44,555 spread over an area of 28.53 km. A floating population of 75,000 is attributed to service industries such as tourism. 84% of the population of Shimla city is literate, compared to 80% in Shimla district and 77% in the entire state. The majority of Shimla's population consists of natives of Himachal Pradesh. Hindi and Punjabi are the main languages. The major religion is Hinduism (93.5%), followed by Sikhism (2.5%) and small minorities of Buddhists, Christians, and Muslims.

Hydrometeorology

The climate of the city is cold and tends to be temperate. There are four major seasons. The winter season commences from October to February and ends in March. Summer season extends from March to June followed by the monsoon period extending from July to September. Maximum precipitation occurs during the months from July to September. The normal annual rainfall of the Shimla city is 1340 mm. The southwest monsoon sets in last week of June, withdraws towards the middle of September, and contributes about 75% of annual rainfall. The July and August are the wettest months of the year. The rest of the annual rainfall, i. e. 25% occurs during non-monsoon period, in the form of thunderstorm and western disturbances. In the winter season precipitation as snowfall also occurs. The city remained under a cold spell from mid December to February and during the period the town experiences occasional snowfalls. Mean maximum and minimum temperature ranges between 33.3°C and –3.1°C. The relative humidity varies from 51% in December to 89% in August.

Physiography & Drainage

Shimla is situated on a range of hills which forms the last traverse of the Central Himalayas to the south of river Satluj with an average elevation of 2205 m amsl. The city is situated in a seismic belt (seismic zone IV) as per IS-1983. Shimla is spread over seven hills spurs with average elevation above mean sea level from 2073 to 2454 m amsl. The phsiographic and drainage map is depited in Fig. 1. The important character of the road network circumscribing these hills is that it is connected to the Mall road from Boileaugang in west to Chhota Shimla in the east. Shimla town is situated on the rocks of Shimla group comprising shale, slates, greywacke, quartzite, local conglomerates and dolomites of Jutogh group with carbonaceous phyllite and local land of quartzite and limestone. The rocks have undergone three distinct generations of deformations resulting in the variation in altitude of formations structurally the area forms a synform whose main axis trends WNW-ESE. The springs and seepage points are generally located between 1660 m and 1950 m on the southern slopes and on the eastern elevation at 2060 and 2180 m. The presence of subsurface water in sheared and fractured zone is also revealed by the existence of several springs around the periphery of Jakhu hills. The Shimla town is situated on water divide separating Indus basin with Ganga basin. A number of nala originates along the southern slopes and meets Aswani khad, which is tributary of Giri river of Yamuna sub basin of Ganga basin. Similarly, various khad originating from hill slopes forms Nayaser ki Khad which meets Satluj river of Indus basin.

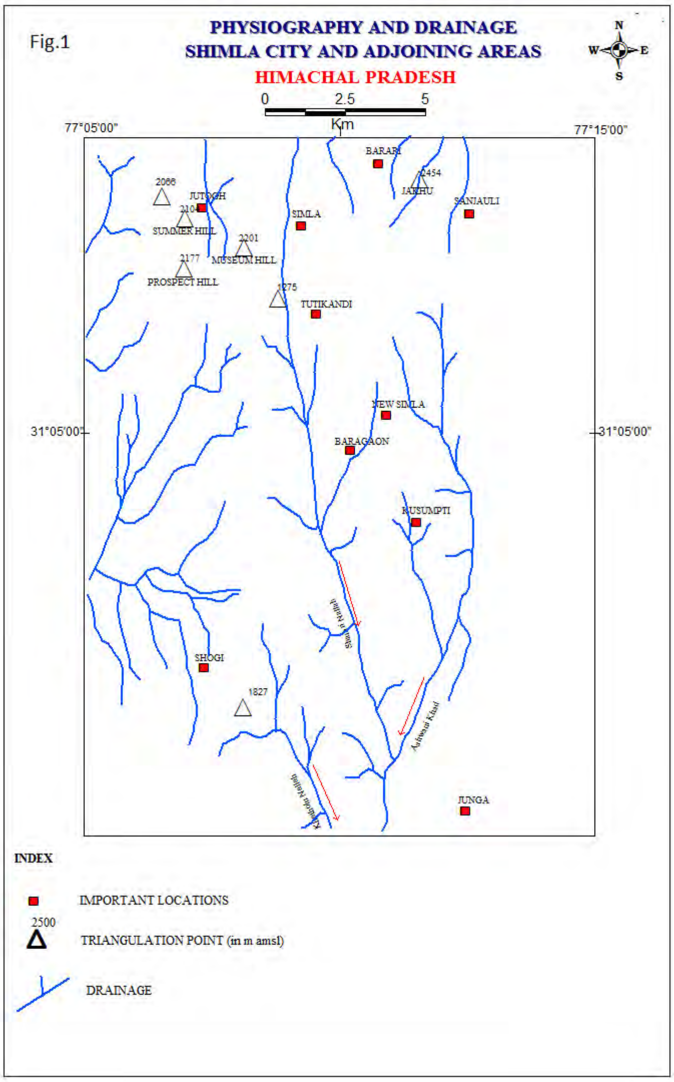


Fig.1

STATUS OF WATER SUPPLY AND DEMAND

The major water supply to the Shimla city is based on surface water sources made through trough track mains emerging from various existing reservoir located at different locations. The present water supply networks system has become inadequate to cater the water supply demand in most of the area of city due to increase in water demand and leakage. The first systematic water supply was executed in the year 1875 for a small population of 16,000 persons. With the increase in demand of water supply has been augmented several times i.e. during the year 1889, 1914, 1923, 1974, 1982, 1992 and 2008. At present water has been tapped from the following six sources (Table 1).

Table 1 : Status of water supply schemes, Shimla

S. No.	Name of source	Year of installation	System design capacity in MLD	Present average supply in MLD	Present status during May 2010
1	Upper gravity line in Dhalli catchments area	1875	4.54	0.45	0
2	Cherot Nallah	1889	4.80	3.50	2.48
3	Chair Nallah	1914	2.50	1.20	0.55
4	Gumma	1923, 1982 2008	7.72 16.34 } 28.60 4.54	16.75	16.44
5	Ashwani Khad	1992	10.80	7.60	4.96
6	LWSS Shimla town from River Giri	2008	20.00	12.00	10.69
	Total		**71.24**	**41.50**	**35.12**

In addition to tapping of surface water from above six sources, raw water requirement is further supplemented at following sources by installing tube wells.

i) Gumma 4 Nos.
ii) Ashwani khad 4 Nos.
iii) Cherot 2 Nos.

The projected population of Shimla town up to 2042 is 604,044 and the ultimate water demand @135 liter per capita per day works out 99MLD. As such a shotfall of 41 MLD is to be met out by constructing additional water supply schemes. Following two proposals are under consideration:

Construction of water supply scheme to Shimla from River Pabbar : This scheme has been proposed as a gravity scheme of 41 MLD capacity. The distance of the proposed source from Shimla up to Dhalli filter is 139 km and the total estimated cost is Rs. 1417 crores. This scheme has submitted to the Govt. of India for approval and funding.

Construction of Lift Water Supply Scheme to Shimla from KOL Dam Reservoir on River Satluj near Sunni, district Shimla : This scheme has been proposed as a lift water supply scheme of 11 MLD capacity. The distance of the proposed source from Shimla up to Ridge is only 22 km and the total estimated cost is Rs.324 crores. This scheme has submitted to the Govt. of India for approval and funding.

WATER PROFILE

Shimla city is situated on hilly terrain and area is underlain by hard rock formations, which are devoid of primary porosity. The occurrence and movement of ground water are controlled by secondary porosity. The aquifer of the area have low yield prospect as inferred from ground water development in the city by construction of the various ground water structures. The large scale development of ground water resource is limited. In the low lying areas on the banks of perennial rivers/khads, where river terrace deposits are found are the favorable locations for ground water development. Due to non availability of ground water in the area only perennial rivers are tapped so far for domestic as well as industrial uses.

GROUND WATER SCENARIO

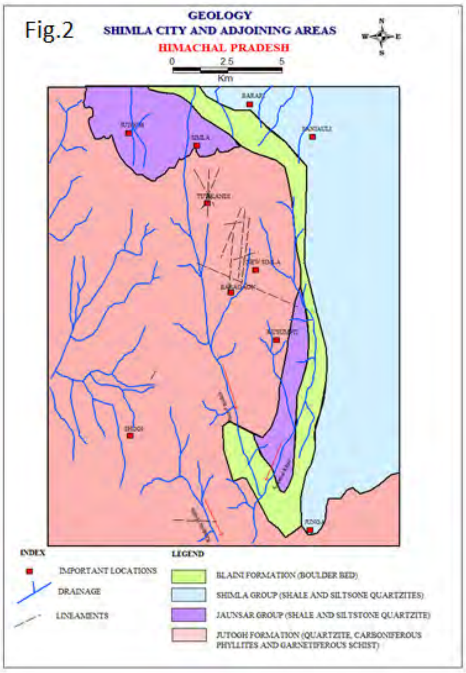
Potential Aquifers

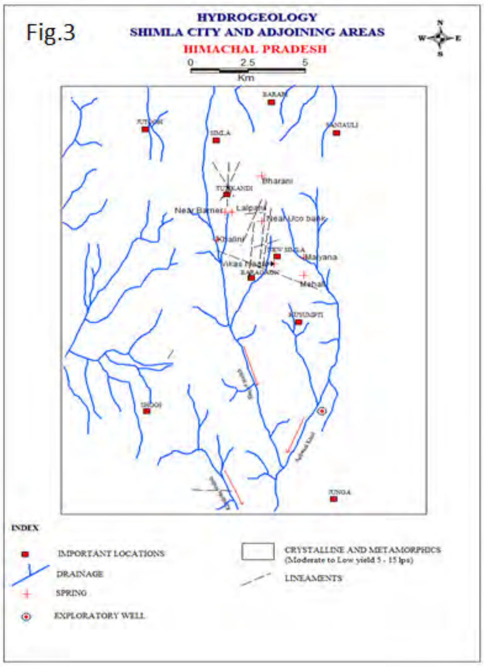
The area is situated on rocks of Shimla Group and Jutogh formation comprising of shale, slates, phyllites, quartzite, dolomite and limestone and structurally it forms a synform with main axis trending in WNE-ESE direction (Fig. 2). The Shimla hills mainly comprises of metamorphic rocks that are devoid of primary porosity. However, when adequate secondary porosity is available in the form of fractures, fissures, joins and shear planes, this may facilitate storage and transmission of ground water. The availability of satellite images has made possible the delineation of secondary porosity zones even if they are covered by diverse land cover. The following sets of lineament have been delineated from satellite images. The hydrogeological map of the area is depicted in Fig. 3.

(i) NE-SW to ENE-WSW
(ii) N-S to NNE-SSW
(iii) WNW-ESE

Secondary porosity (fracture & fissure) in these rocks, topographical set up coupled with precipitation in the form of rain and snow, mainly govern occurrence and movement of ground water. The area is underlained mostly by hard rocks which form aquifer of low yield prospect. Ground water potential in such areas is very low due to its hydro-geomorphic set up. Springs are the main ground water structures that provide water for domestic use.

Springs in the area are mainly gravity, contact or fracture type and located along major thrust/faults or structurally weak planes are high yielding. The discharge of springs, locally called C*hasma*, varies from seepages to as high as 18 lpm. *Bowries*, a type of dug well, are another structure constructed in the hill slopes to tap the seepages. Such *Bowries* are very common and observed all over the city.





Ground Water Level

There are no dug wells in the area because of hilly nature of the terrain as such no water level record is available. Irrigation and Public Health (I&PH) department, Govt. of Himachal Pradesh have drilled shallow bore wells (hand pumps) to provide water for domestic use. These hand pumps have been drilled between the depth ranges of 50-90 m. The static watr level (SWL) of hand pump constructed in the city varies between 10 to 30 m bgl and discharge varies from 0.14 lps to 1.37 lps. To know the aquifer system of the hard rock, Central Ground Water Board, NHR, Dharamshala has drilled a tube wells up to the depth of 302 m. The tube well was constructed up 74 m and yielded 1173 lpm with drawdown of 26.62 m. The SWL of this tube well was 1.60 m and transmissivity is 70.39 m^2/day.

Ground Water Resources and Status of Development

The ground water resources of the city have not been computed because the entire area is hilly and having slope more than 20%.

Hydrochemistry

In order to ascertain the variation in chemical quality of ground water, data of ground water samples collected from spring, hand pumps and tube wells have been analyzed. The result of chemical analysis of ground water samples is given in Table-2. The chemical analysis of ground water samples indicates ground water is generally alkaline in nature and fresh and is within permissible limit as prescribed BIS, 1991 except at few places where nitrate concentration have been found slightly higher. In general, ground water is suitable for drinking and domestic. Though contamination of ground water have not been reported in the city so far, however, the fast increase in population/tourist population in the major towns, mainly Shimla city is highly vulnerable to pollution from Municipal effluent and small industries. There is thus need to have proper ETPs and waste disposal system with all the industries and major towns. Proper monitoring is very much required.

Major Ground Water Related Problems

Most of the ground water issues and problems in the district are localized and need to be treated independently by taking the micro level studies in a particular area. In hilly and mountainous parts, the most common issues relate to scarcity of water particularly in low precipitation year during non-monsoon period when dwindling levels and spring discharges are seen. Rainwater harvesting and awareness for water conservation, protection and water harvesting are measures that need to be taken.

Table 2: Result of chemical analysis of water sample collected from Shimla City.

S. No.	Location	Source	pH	EC µS/cm at 25°C	CO_3	HCO_3	Cl	SO_4	NO_3	F	Ca	Mg	Na	K	TH as CaCo3
					mg/l										
1	Siva temple	Hand Pump	7.08	402	Nil	90	24	Nil	8.3	0.40	42	12	16	6.7	157
2	Uco bank	Hand Pump	7.35	308	Nil	54	21	Nil	16	0.27	38	8.5	9.8	6.6	116
3	Lalpani	Hand Pump	7.40	318	Nil	107	31	Nil	3.5	0.31	34	4.9	16	5.5	106
4	Saint Beeds Collage	Hand Pump	7.65	222	Nil	84	7.1	Nil	3.3	0.18	30	4.9	5.1	3	96
5	Sanjauli	Hand Pump	7.40	400	Nil	156	21	Nil	1.8	0.40	36	25	7.6	2.6	192
6	Khalini	Hand Pump	7.55	242	Nil	77	14	Nil	5	0.33	34	3.6	5.4	8	101
7	Lakkar Bazar	Hand Pump	7.75	377	Nil	118	28	Nil	24	1.60	51	12	12	1	179
8	Bharari	Hand Pump	7.43	134	Nil	18	10	Nil	8.6	0.40	15	2.3	4.8	0.6	48
9	Khalini	Spring	6.85	345	Nil	84	24	Nil	28	0.27	34	9.8	14	6.6	127
10	Banahlog	Spring	7.50	255	Nil	96	7.1	Nil	3	0.40	32	7.3	6	12	111
11	Mehali	Spring	7.55	407	Nil	42	54	Nil	36	0.57	23	10	33	3	100
12	HSEB (Central Store)	Spring	8.40	374	Traces	84	17	Nil	7	nd	44	12	12	2.8	157
13	Bharari	Spring	7.93	362	Nil	48	31	Nil	46	nd	34	8	16	6	119
14	Uco bank	Spring	7.42	435	Nil	72	42	Nil	105	0.21	40	9.8	22	8.8	142
15	Vikas Nagar	Spring	7.00	542	Nil	90	52	Nil	70	0.28	53	15	26	6	192
16	lalpani	Spring	7.60	503	Nil	102	42	Nil	50	0.26	55	7.3	30	2	165
17	Motar barrier	Spring	7.60	443	Nil	101	45	Nil	34	0.02	47	12	33	12	169
20	Ashwani Khad	Tube well	8.00	947	Nil	348	14	Nil	8.8	3.25	2	1.1	22	8.8	95
18	Kiyana river	River	7.32	212	Nil	60	14	Nil	12	nd	21	6.9	9.2	2.1	81
19	Nayasera	River	7.85	519	Nil	115	18	Nil	2.7	0.40	73	22	12	4.3	220
	Minimum		**6.85**	**134**	**Nil**	**18**	**7.1**	**Nil**	**1.8**	**nd**	**2**	**1.1**	**4.8**	**1**	**48**
	Maximum		**8.40**	**947**	**Nil**	**348**	**54**	**Nil**	**105**	**1.60**	**73**	**25**	**33**	**12**	**192**

n.d. denoted not detected

Feasibility of Rainwater Harvesting and Artificial Recharge

Shimla city is entirely hilly terrain with steep slope. These hills comprise of metamorphic rocks and devoid of primary porosity and have rugged topography. These formation are having only secondary porosity. Due to steep slopes and non availability primary porosity coupled with space problem in the hills, the rainwater harvesting structures are feasible.

GROUND WATER DEVELOPMENT STRATEGY

In the city area, emergence of ground water through the traditional sources viz. Springs *(chasmas*), *Bowries* occurs*.* The banks of perennial streams are the only possible development of ground water resources at favorable locations. Proper development of springs is essential as it is observed that most of the spring does not have collection chamber or tanks from where water can be distributed under gravity. Similarly, *seepage springs* along hill sides also need to develop for harnessing ground water in such areas*.* In the last decade number of shallow bore wells fitted with hand pumps has been constructed in these areas serving as the source of water supply for domestic uses in the city. Due to hilly terrain only shallow bore wells at favorable locations are feasible. However, looking to the fragile eco-system drilling activity should be minimum.

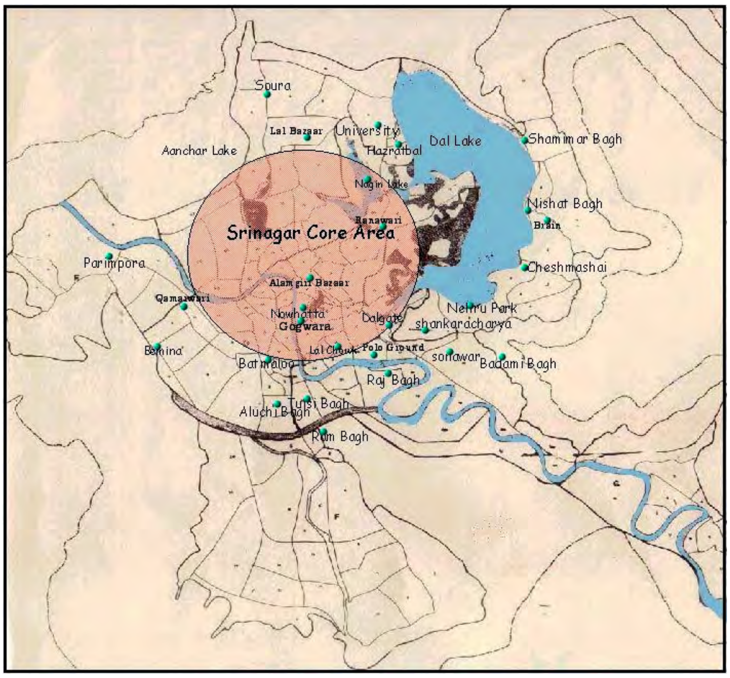
Perennial khads are the major source for domestic water supply in city areas. In most parts the availability of water during summer is limited particularly in drought/ low precipitation. There is thus immediate need to conserve and augment water resource. Based upon the climatic conditions, topography, hydro-geology of the area, suitable structure for rain water harvesting and artificial recharge to ground water body need to be planned and implemented. Roof top rainwater harvesting in urban areas and water harvesting in rural area need to be adopted and proper scientific intervention for spring development and revival of traditional water storage is required in water scarce hilly upland areas. The hilly areas receive fair amount of rainfall & ample scope exist for implementing roof top rain water harvesting by constructing appropriate harvesting structures. Such structures should be replicated to conserve and augment water resources. There should be mandatory provision under law to construct roof top rainwater harvesting structures in all schools, colleges, offices and *pucca* buildings. In similar way, the defense establishments can also have such water harvesting provisions.

SRINAGAR, J&K

Priya Kanwar, CGWB, Jammu

INTRODUCTION

Srinagar is the summer capital of the state of Jammu and Kashmir and is the pride of the beautiful valley of Kashmir. Famous for its excellent landscapes- lakes, gardens and the charming rows of houseboats floating on them and abundant natural beauty, the city is also called *Heaven on Earth*. Founded by the King Pravarasena II over 2,000 years ago, Srinagar owes its name to two Sanskrit words, Sri (meaning profusion and wealth) and Nagar, (meaning a city). Dating back to the 3rd century BC, the city was formerly a part of the Mauryan Empire. This region prospered quite well under the rule of the Kushans in the 1st century AD. During this period, it used to be an important Buddhist pilgrimage site. In the 6th century, however, it became a part of the kingdom of Vikramaditya, Local Hindu rulers ruled it until the 14th century, when Muslims captured it. In 1814, it went to the Sikhs. However, ultimately the British defeated Ranjit Singh and appointed Gulab Singh as the autonomous ruler of Kashmir. Later, Hari Singh, the great grandson of Gulab Singh, united this huge state into India.



GENERAL FEATURES

Area / Administrative Divisions

Srinagar city is located in the heart of the oval shaped Valley of Kashmir at 74°47’24” E Longitude and 34°5’24”N Latitude. The total geographical area of Srinagar urban area is 238 km^2. Srinagar urban area is administratively divided into 2 divisions viz Left River division and Right River division, 4 zones and 34 wards.

Demography

As of 2001, Srinagar city had a population of 894,940 and population density is 556 inhabitants/sq.km. The average decadal growth rate is 45%, and thus the projected population of 2011 is 12,97,663 and 16,81,611 in 2021.

Hydrometerology

The climate of Srinagar may be described as a humid subtropical climate with warm summers from June to August, and winters from December–February. The city generally gets some snowfall from December to February. The average temperatures are 24 °C in July and 4 °C in January. Precipitation is in the form of snow and sleet in the winter months and as rain or hail during rest of the year. The average annual rainfall is around 675 mm.

Physiography & Drainage

The general topographic slope in the northern part is towards the south, in the southern part is towards north while in the central part the master slope is towards west. The city has unique physiographic set up with steep hills in the east, low lying paddy fields on flood plain of Jhelum in the south and west and raised plateau lands in the south. The average elevation of alluvial tract is 1500 m amsl.

The natural drainage of the city is provided by three main rivers which are joined by small rivulets and canals. River Jhelum enters Srinagar in the south-east- flows through the city, leaving it in the west after dividing the city into two parts. In the south, drainage is provided by Doodhganga river and in the north by the River Sindh which drains into Anchar lake and ultimately joins Jhelum River.

Soil Type

Mainly two types of soils are found in the area viz. Hapludalfs found on the Karewa tops and uplands and Ochraqualfs found in plain to mid upland topography. The Hapludalfs are medium to fine textured soils, varies from yellowish brown to dark brown and the Ochraqualfs are moderately fine textured, dark brown to yellowish brown in colour.

STATUS OF WATER SUPPLY AND DEMAND

The total water supply of Srinagar city is 65.38 MGD of which the ground water meets only 13%. There was no proper water supply scheme one and a half centuries ago in Srinagar city. People used water from Jhelum river for drinking, bathing and washing purposes. During the rule of Maharaja Pratap Singh water works department came into existence. Harvan Reservoir was built to provide clean water to residents of Srinagar. It was fed by Marsar nullah. In all, five Surface Water Supply Schemes are in operation in the city, of which three are gravity and two are lift Schemes. At present 43.54 MGD of water is released from these schemes against the designed capacity of 57.55 MGD.

Ground water based water supply of Srinagar City was initiated in 1968. Total of 133 tubewells have been drilled in the city for water supply. Out of these, about 81 tubewells are being used by the PHED for water supply and providing 8.5 MGD of water.

WATER PROFILE

The surface water supply to the city is through five major schemes. These five Schemes are Nishat, Alastenag, Rangil, Doodhganga and Pokhribal and their sources are Dachigam Nalla, Sindh Nalla and Doodhganga respectively.

Besides, these the Dal lake which is the second largest lake in the State, occupies a major portion of the city. The lake is located within a catchment area covering 316 square kilometres in the Zabarwan mountain valley, in the foothills of the Himalayan range, which surrounds it on three sides. The lake, lies to the east and north of Srinagar city covers an area of 18 square kilometres. The shore line of the lake, about 15.5 kilometres. The average elevation of the lake is 1,583 metres.

GROUND WATER SCENARIO

Potential Aquifers

The hydrogeological condition of any area depends on the lithology, structure and geomorphic set up. Groundwater in the city area occurs both under water table and confined conditions. In alluvial sediments, that consists of valley fills & Karewa formation, the ground water occurs in the inter granular pore spaces of the individual grains under water table conditions. Recharge to the alluvial aquifers is received both by in situ filtration of rain water/ snow melt.

The bedrocks does not forms potential aquifers in the area, as they are hard, compact and lack primary porosity. Secondary porosity developed due to weathering and fracturing facilitates storage and movement of ground water. The near surface weathered zones forms the phreatic aquifers and is the source for circulation of water in the hydraulically interconnected deeper fracture zones. Thus, zones of secondary porosity in them form suitable areas, worthy for ground water development.

Dugwells have shallow water levels, generally less than five m bgl. Springs are also seen in the talus and scree material/alluvium. A good number of springs are present in the area. Discharges of springs range between 480 lpm and 2250 lpm.

The yield of tubewells in the area has a vide range from 11.2 m^3/hour to 121 m^3/hour (Idgah & Bus stand Batmaloo). Majority of the tubewells are yielding 22.5 m^3/hour to 67.5 m^3/hour. The Exploratory tubewells constructed by the Central Ground Water Board have shown a maximum yield of 188 m3/hour. Yield of tubewells tapping confined aquifers is expected to be in the range of 75 m^3/hour to 150m^3/hour/. Hydraulic conductivity of the tubewells constructed by the CGWB ranges from 0.464m/day (at Karan Nagar) to 43.34 m/day (at Badampora). The value of transmissivity ranges from 97.83 m^2/day (Satsukalan) to 931.77m^2/day (Badampora) and specific capacity has been found ranging from 2.04 m3/hour/m (Satsukalan) to 31.27 m3/hour/m (Bemina-II).

Ground Water Level

Water level behavior in the Kashmir Valley is entirely different from the other parts of the country. This is mainly because of the fact that about 60 to 70% of the precipitation is received in the form of snow during December to February while March to April are the months of heavy rainfall. May to September are relatively dry months. Hence recharging to the ground water takes place in the valley in the months of April to June with the melting of snow and onset of rainfall. Therefore water levels show rising trends from April onwards and falling from August onwards. Thus the pre and post monsoon conditions in the Kashmir valley shows a reverse scenario from the rest of the country.

The water levels in the Srinagar city are very shallow. The open dugwells have water levels generally less than five mbgl. The water levels are measured from 3 dugwells for the months of May 2010.

Location	Water Levels in May 2010	EC (micromhos/cm)	Cl mg/l
Rainawari	9.16	690	32
Regal Chowk	2.26	685	43
Mirgund	0.95	335	14

Status of Ground Water Development

PHE has constructed about 93 tubewells and CGWB has constructed 21 exploratory tubewells in the city which has a total area of 238 sq.km.

Hydrochemistry

The chemical quality in Greater Srinagar is by and large fit for drinking and irrigation purposes as per Indian Standards (IS-10500-1991). Chemical analysis of water samples from various sources like Dug wells, Handpumps, Tubewells, Springs, Jhelum river & Dal Lake has been taken in to consideration. The Iron content is slightly high at one to places which requires proper treatment before use.

A few tubewells have been found releasing methane gas (due to occurrence of peat in the Karewas), but in most cases it is not a problem, as it is released out and is not dissolved in water.

Electrical conductivity ranges from 335 micro mhos/cm to 850 micro mhos/cm pH varies from 7.35 to 7.56 which shows that ground water is quite alkaline in nature. Chloride varies from 14 mg/l to 46 mg/l. Bicarbonate concentration varies from 177 mg/l to 360 mg/l. Sulphate and Nitrate concentration ranges from 16mg/l to 70 mg/l and traces to 21 mg/l respectively. Fluoride concentration is also low. The concentration of Sulphate, Fluoride and Iron are well within the maximum permissible limit set up by BIS. Alkaline earth metals dominate over alkali metals i.e Na & K. Ground water is very hard.

Major Ground Water Related Problems

- The presence of high Iron content in ground water especially in deeper aquifers is one of the major problems.

- A few tubewells have been found releasing methane which is gas due to occurrence of lignite in Karewa formation.
- Water logging is also a problem in some of the areas of the city especially the southern part where the static water levels in the tubewells drilled were found from 0.32 m bgl to 4 m bgl at the time of their construction.

Feasibility for Rain Water Harvesting and Artificial Recharge

The rain water harvesting is feasible in the city provided there is availability of space for construction of water harvesting structures. But condition is quite different in case of feasibility for artificial recharge. The artificial recharge to the ground water is not feasible in the southern part of the city because this part has very shallow water levels and is prone to water logging.

GROUND WATER DEVELOPMENT STRATEGY

- Since the depth to water levels in valley portions are within 5 m bgl the ground water development is required to be given a fillip of construction of shallow tube wells, dug wells, hand pumps etc. Harnessing the shallow aquifers will also minimize the chances of getting comparatively higher Iron content which is a regular problem in the Karewas.
- Since there are data gaps in monitoring of depth to water levels, it is recommended to install piezometers to observe behavioral changes of water levels over a long period of time in order to know the trends.
- There is a need of State Ground Water Department which can take up the detailed and micro level studies in the field of ground water in the state.
- Over pumping of tubewells constructed by the State Government Agencies should be minimized.
- Further development of ground water by the State Government Organisations should be checked.
- At suitably identified locations, along the Sindh River, Collector Wells/ Percolation Wells/ Ranney Wells may be constructed, which can provide a large volume of filtered water to augment the drinking water supplies of Srinagar city.
- The ground water from the proposed tubewells/Collector Wells etc. should be dis-infected, by installing silver-Ionization plants. Silver based water purification systems offer the most reliable and cost effective alternative to chlorine. Chlorine is a chemical that is increasingly coming under fire for the carcinogenic impacts and ite by products generated and left in the treated water.
- People should be made aware for proper utilization and conservation of water resources available.

TRIVENDRUM CITY, KERALA

V.R.Rani, Anitha Shyam, P. Nandakumaran, CGWB, Trivendrum

INTRODUCTION

Thiruvananthapuram, formerly known as Trivandrum, is the capital city of Kerala state and erstwhile Travancore Kingdom. Thriuvanthapuram city and several other places in the district loom large in ancient traditions, folklore and literature. The city gets its name from the word Thiru-anantha-puram, meaning the "Abode of Lord Anantha".

The ancient political as well as cultural history of the city stood entirely independent from that of the rest of the Kerala. The *Ays* were the leading political power till the beginning of the 10th century A.D. The disappearance of the *Ays*, synchronised with the emergence of the rulers of *Venad*. In 1684, during the regency of Umayamma Rani, the English East India Company obtained a sandy piece of land at Anchuthengu (Anjengo) on the sea coast for erecting a factory and fortifying it and from here that the English gradually extended their domain to other parts of Thiruvithamcore anglicised as Travancore.

Modern history begins with Maharaja Marthanda Varma (1729 to 1758 AD) who is generally regarded as the *Father of modern Travancore.* During this period the city developed into a major intellectual and artistic centre. Thiruvananthapuram was made the Capital of Travancore in 1745 after shifting the capital from Padmanabhapuram in Kanyakumari district. The mid of 19th century was earmarked as golden age in the city's history under the reign of Maharaja Swathi Thirunal (1829 to 1847 AD) and of Maharaja Ayilyam Thirunal (1860-1880). During their reign the city ushered in an epoch of cultural progress and economic prosperity. This era saw the beginning of English education, establishment of English schools, colleges, observatory, charity hospitals and oriental Research Institute and Manuscript library.

A tremendous political and social change was associated with Maharaja Sree Moolam Thirunal reign. He inaugurated the Legislative Council in 1888 which was the first legislative chamber, instituted in an Indian State and Sri. Moolam Assembly came into being in 1904. During his reign, the activities of the Indian National Congress echoed in various parts of the city. The period of Maharaja Sri. Chitra Thirunal Bala Rama Varma who took the reigns of administration in 1931, witnessed many-sided progress. The Thiruvananthapuram Municipality came into existence in 1920 and was converted into corporation on 30th October 1940.

With the accession of Travancore to the Indian Union after Independence, the policy of the State Government as well as the political atmosphere underwent radical changes. Consequent on the recommendations of the State Reorganisation Commission, the four southern taluks of Thovala, Agastheewaram, Kalkulam and Vilavancode were merged with Tamil Nadu and the State of Kerala came into being on 1st November, 1956.

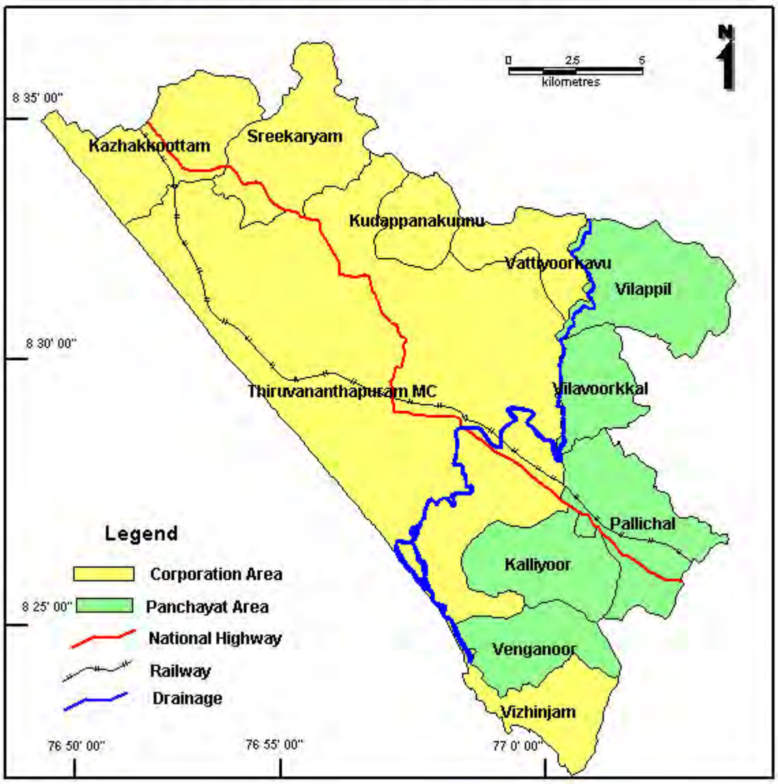
GENERAL FEATURES

Administrative Divisions

Trivandrum Urban Area (TUA) which house Capital city is located between North latitude of 8°21'45'' & 8°34'49'', east longitude of 76°49'39''& 77°00'25''. The TUA comes under the jurisdiction of Thiruvananthapuram Development Authority (TRIDA) which covers a geographical ambience of 296.35 sq.km (13.5% of district area). The Urban area is bordered by Nedumangad, Vellanad and Perumkadavila block in the east, less turbulent turquoise blue waters of the Lakshadweep sea in the west, Parassala and Athiyannur block in south and Attingal and Kilimanoor blocks in the north. Administratively, the Thiruvananthapuram Urban Area (TUA) is broadly divided into municipal corporation (Trivandrum City) and the adjacent 10 panchayats namely Kazhakootam, Sreekariyam, Kudapanakunnu, Vattiyoorkavu, Kalliyoor, Valavoorkal, Vilappil, Pallichal, Venganoor and Vizhnijam. Of these 10 panchayats, 5 panchayats given the status of corporation. The City Corporation is spread over an area of 215.86 sq.km (72.84%) of TRIDA area) and the adjoining 10 panchayats cover an area of 80.49 sq.km (27.16% of TRIDA area). The map showing the various administrative divisions of TUA is given in fig.1.

The city is well connected with other parts of the state and to almost all major cities in India by all weather networks of roads and railways. The National Highway (NH 47) passes through the entire length of the city which is almost parallel to the coastline. The Main Central Road (MC Road) together with NH 47connects the northern parts of the state with the city. In addition to these transport facilities, the city is well connected by air also. There is an International airport situated at Thiruvananthapuram.

Fig 1. Index Map of Trivandrum Urban Area



Demography

TUA registered a population of 11,32,394 (35% of the district population) as per census 2001 (Table 1). The population density for Trivandrum Municipal Corporation area and the total panchayat area is 4422 and 2210 persons per sq.km respectively, with an average value of 3026 persons per sq.km for the TUA. The literacy rate of the TUA is 89.36 %. The sex ratio indicates that there are more women than men in TUA. The City Development Plan(2006) has attempted to project the population and is estimated that the Thiruvananthapuram Municipal Corporation population which is 744893 in 2001 may grow to 7.70 lakhs in 2011.

Table 1. Constituent Units of TRIDA with their area and population (2001)

No.	**City/Panchayat**	**Area** (sq km)	**Population** (2001)	**Density** (p/sq km)
1	Thiruvananthapuram (M.C.)	141.74	744983	5256
2	Kazhakuttam (C)	19.47	34131	1753
3	Sreekaryam (C)	23.73	49145	2071
4	Kudappanakunnu (C)	7.69	38175	4964
5	Vattiyurkavu (C)	10.61	41890	3948
6	Kalliyur	17.23	36836	2137
7	Vilavoorkal	12.02	27495	2287
8	Vilappil	19.42	34079	1755
9	Pallichal	21.70	45118	2079
10	Venganoor	10.12	33372	3298
11	Vizhinjam (C)	12.62	47170	3738
	TOTAL	**296.35**	**1132394**	**3026**(Av.)

Hydrometeorology

The city experiences a humid type of climate condition with an oppressive summer since the climate borders Tropical Savanna and Tropical monsoon climate. The Trivandrum city is the first city along the path of south-west monsoon and gets its first showers in early June which contributes 48.9% of the total rainfall. The city also gets rain from receding north-east monsoon which hit the city by October and contributes 28.31%. Hence the city is characterized by high precipitation which is spread over very few wet days and long dry season (December-May). The average annual rainfall is 1623.9 mm (~1700 mm). The normal rainfall is 2001.6mm. Generally the rainfall increases from southwest to northeast in the city. During the period 2005-07, the rainfall was above the normal rainfall. The coldest months are December, January and February with a recorded lowest temperature of 15°C while March, April and May are hottest with a record high of 37°C. The mean wind speed during June to September varies between 9.6 to 11.2 km/hr and during October to December varies between 4.8 to 7.3 km/hr.

Physiography and Drainage

Physiographically, the TUA can be divided into two categories- lowlands and midlands. The lowland or coastal plain is the area with an elevation of less than 7.6 m amsl formed by a combination of fluvial and marine processes and is represented by a gently sloping terrain whereas elevation is between 7.6m and 76 m amsl in the case of midlands which is mainly formed by fluvial and denudational processes. The lowland is comparatively narrow and is densely covered with coconut palms while the midland is made up of tiny hills and valleys and is an area of intense agricultural activity.

The TUA is mainly drained by Karamana River and its main tributary, Killiyar, which debouches in to the Lakshadweep Sea. The river runs from NE – SW skirting the city and before the confluence with the sea form some islands, mainly Edayar. Formation of intervening bars or sand bars near the estuarine mouths are common features particularly produced by littioral drift of sand during the period of south-west monsoons. Karamana River is perennial in nature with dendritic drainage pattern. Two dams constructed across the river at Aruvikara and Peppara supply the drinking water to the TUA. Vellayani lake is the only freshwater lake available in TUA which form the main source of drinking water in Nemom block. And the only other lake of the city is Aakulam lake which is backwater lake.

Soil Type

The main types of soil found in TUA are coastal alluvium, riverine alluvium, lateritic soil and brown hydromorphic soil. Most predominant soil is lateritic soil and is mainly found along the midland region. Brown hydromorphic soils are mostly confined to valley bottom in the midland and low lying area of coastal strip. The lowland area is dominated by alluvium. Coastal alluvium is mainly found along the coastline while riverine alluvium is found along the banks of river and their tributaries.

STATUS OF WATER SUPPLY

The traditional practice of dependence on surface water and ground water is in the form of ponds and open dug wells and are in existence for generation is almost vanished from the society mainly in the city area. The piped water supply for the Trivandrum district started in 1930's by the erstwhile Travancore state. After the formation of the Kerala State, Kerala Water Authority (KWA) is entrusted with piped water supply. The water supply scheme in TUA comprises 183.76 sq.km with complete coverage of earlier Thiruvananthapuram Corporation (141.74 sq.km) and partial coverage of newly included area viz. Sreekariyam (23.73 sq.km), Kudapanakunnu (7.69 sq.km) & Vattiyoorkavu(10.61 sq.km).

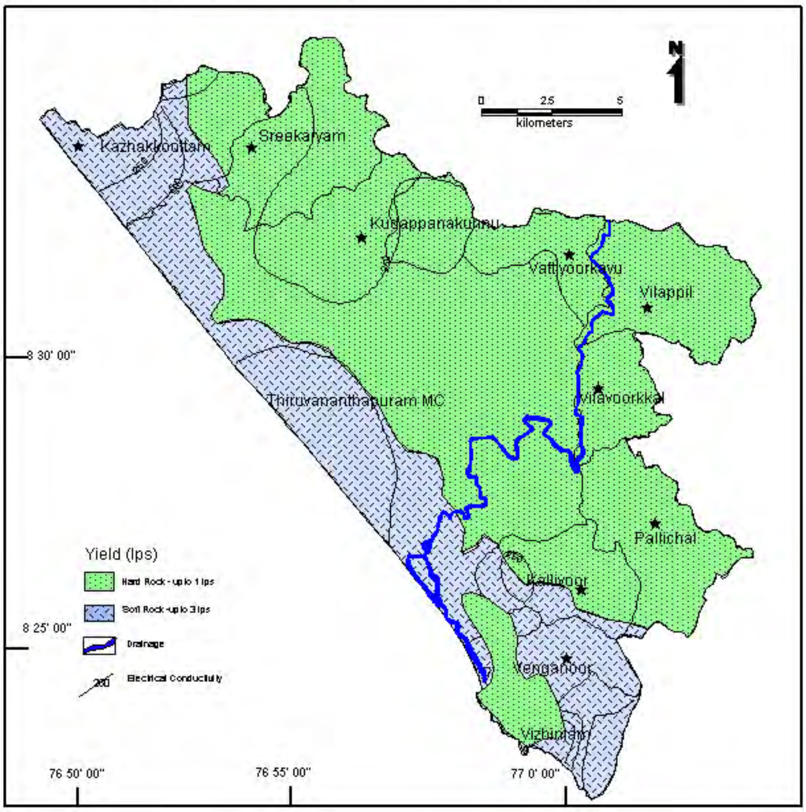
The main source of water for Trivandrum Urban Water Supply Scheme is the Karamana River. There are two reservoirs constructed at the upstream of the river for sufficient storage of water viz., Aruvikkara (which have a storage capacity of 2 million cubic meter) and Peppara (having 70 million cubic meter storage capacity). The water supply is designed for 24 hrs after proper treatment at various treatment plants. Presently the average per capita consumption is around 174 litres per day. The existing supply provides a supply of 185 mld of water as against present demand of 246 mld. In order to augment the water supply scheme, KWA has been taken up a project at the cost of Rs.311.91 crore with loan assistance from JBIC (Japan Bank for International Cooperation). This project has been formulated to provide a supply of 74 mld of water. The projected water demand for 2036, at the rate of 200 lpcd works out to be 410 mld which include domestic use along with a provision for non-domestic and industrial requirement. The ongoing JBIC project can supplement 74 mld still leaving the gap of 185 mld due to growth in population. This gap is proposed to be compensated by 3 tier system (1) augment the system by 76 mld (2) bring down the unaccounted water losses to the range of 15% from 35.5%. and (3) Cut-off some boundary areas from the city water supply system (WSS) by providing small WSS exclusively for those areas.

GROUND WATER SCENARIO

Trivandrum Urban Area is underlain predominantly by Precambrian crystalline rocks. Sedimentary formations ranging in the age from Miocene to Recent overlie these formations. The Precambrian rocks include Khondalite suite of rocks which is exposed in eastern part of TMC and charnockite which are seen mainly in Vizhinjam and Venganoor areas. The trend of both of these rocks is NW-SE. Based on the water bearing properties, the entire district can be broadly classified into crystalline formation and sedimentary formation. The crystallines include khondalites, charnockites, migmatites and intrusives occur at shallow or deep with or without fractures. Whereas sedimentary formation comprise the (1)Recent alluvium that occur along the coastal plain and in the valleys and are mainly composed of sand and clay (2) Tertiary formation such as Warkallai and Quilon beds and (3) laterites which occur as a capping over crystallines. Two types of laterite are seen in this area: the one developed over the crystallines and other formed during Tertiary. The insitu laterite developed by the weathering of khondalite is rich in clay content due to higher amount of feldspathic minerals in parent rock (CGWB, 1999). The hydrogeological map of TUA is given in fig.2.

Ground water occurs in all geological formations from crystallines to Recent alluvium either in unconfined or semi-confined/confined conditions. Phreatic conditions mainly exist in coastal alluvium and in weathered crystalline formation and are mostly developed by dug wells for domestic or irrigation purposes. Semi-confined/confined condition exists in deep fractures of crystalline rocks where storage and movement is mainly controlled by interconnected fractures which is developed by deep bore wells.

Fig 2. Hydrogeology of Trivandrum Urban Area



To understand the impact of modernisation and urbanisation on the ground water scenario of TUA, CGWB has established 21 key wells in various parts of the area and monitoring was carried out monthly since April 2007. Earlier TMC was only considered as urban area. Later while considering the population growth and other facilities in the outskirts of the city, adjoining panchayats were also included. Anticipating the impact of proposed Vizhinjam Container Terminal Project on ground water regime 5 more monitoring wells have been established recently in Vizhinjam and Kalliyoor panchayat.

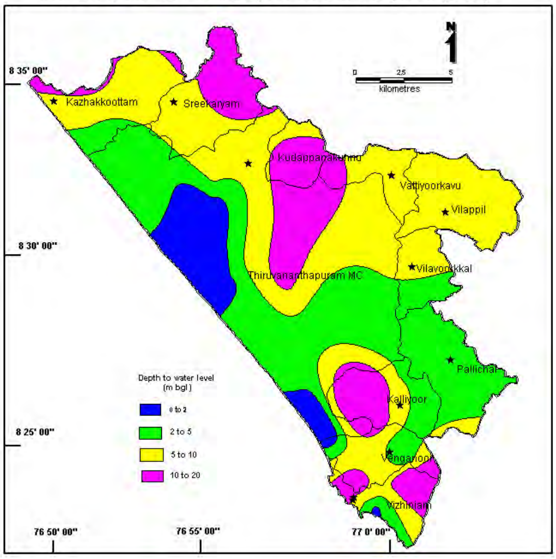
Potential Aquifers

Central Ground Water Board has drilled exploratory wells in hard rocks, particularly khondalites and in soft rocks to delineate the aquifer geometry and quality of formation water. The wells drilled in khondalites are in the depth range of 60 - 200 m bgl and the discharge ranges from 12 to 90 lpm. Exploratory drilling revealed the presence of 2 - 3 aquifer groups within the depth range of 200 m (CGWB, 2006). The bore wells tapping NNW, NE, NW lineaments in the district gives better yield. In the sedimentary formation wells of medium yields have been encountered from the granular zones of Tertiary formations down to maximum depth of 100 m bgl. The Warkallai formation has a limited potential in the Thiruvananthapuram district. The wells drilled in this formation are in the depth range of 32 to 100.5 m bgl have low discharge(CGWB,2008). Recent alluvial formation is thinner and the maximum thickness of alluvium is 18 m, which is encountered at Chakkai.

Ground Water Level

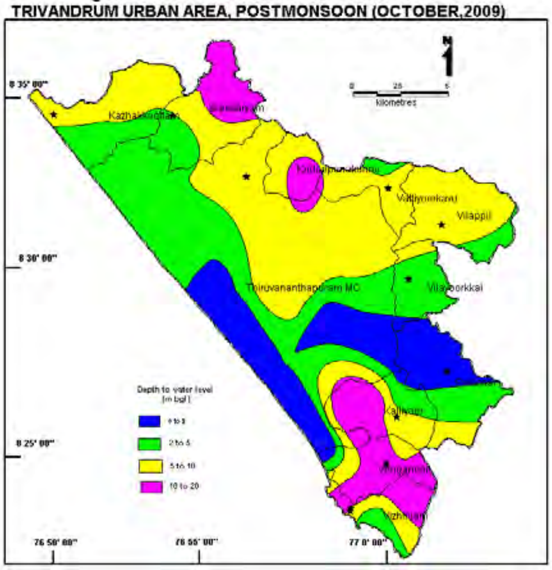
The monthly monitoring of depth to water level of 26 key wells reveals that deepest water level is noticed before the onset of south-west monsoon (pre-monsoon) and the shallowest water level during the month of October/November which in turn also depends on the retreating period of North-East monsoon. The depth to water level varies from 1.9 to 19.8 m bgl and 1.56 to 19.88 m bgl during pre-monsoon(Fig.3) and post-monsoon(Fig.4) respectively. The depth to water level ranges from 0 to 5 m bgl in wells tapping recent alluvium while the depth to water level is more than 10 m bgl particularly in laterite formation. Seasonal fluctuation also indicates that in major portion of TUA, there is rise in water level in the range of 0 to 5 m.

Fig.3. DEPTH TO WATER LEVEL SCENARIO IN TRIVANDRUM URBAN AREA, PREMONSOON (APRIL,2009)



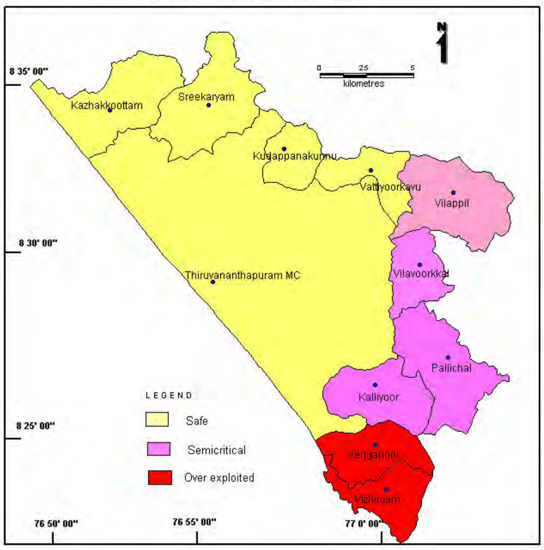
Ground Water Resources and Status of Development

Fig 4. DEPTH TO WATER LEVEL SCENARIO IN TRIVANDRUM URBAN AREA, POSTMONSOON (OCTOBER,2009)



The computation of ground water resource of urban area is difficult due to large built-up area and other structures, hence the Ground Water Resource of the district has been assessed based on Ground Water Resource Estimation Methodology–97 (GEC- '97) by considering administrative block as the assessment unit by excluding hilly regions and is computed based on the data available as on March 2004. The net groundwater availability of the Thiruvananthapuram (Rural) block is 14.90 MCM whereas the gross ground water draft of the block is 11.23 MCM, hence scope for further ground water development is possible. The stage of ground water development in Thiruvananthapuram block is 75.37% (CGWB, 2005) and is categorised under safe category indicating the presence of potential aquifer which can be harnessed. In addition to Thiruvananthapuram block, Kazhakuttam and Sreekaryam panchayats also show lesser development. Hence further ground water development can be taken up safely and more wells can be constructed. The Venganoor panchayat and Vizhinjam Corporation of Athiyanuur block shows development more than 100% . Analysis of trend of water table shows significant decline during pre and post-monsoon, hence both areas are categorised under over-exploited category which requires a restriction in ground water development. The 4 panchayats of Nemom block shows 91.7% of ground water development and is categorised under semi-critical category and this area requires a control on ground water development. The categorisation of TUA based on block-wise GEC calculation is depicted in fig.5

Fig 5. CATEGORISATION OF TRIVANDRUM URBAN AREA BASED ON GEC CALCULATION



The main groundwater abstraction structures for domestic and agricultural purposes are dug wells, bore wells and tube wells. In the crystalline and lateritic terrain the groundwater is developed through dug wells and bore wells while filter point wells and tube wells are in vogue in coastal alluvium. During the last few years, construction of private tube wells and bore wells has increased tremendously. Majority of the households in the panchayat area have their own dug wells or bore wells. Irrigation in TUA is mainly by means of surface water. The potential aquifers of fractured crystalline rocks are being tapped through tube wells/bore wells, ranging in depth from 70to 200m. The deep tube wells have depth range of 150 - 200 m and the diameter ranges from 152 mm to 305mm. Since the degree of weathering in charnockite is low the shallow bore wells in charnockites vary in depth from 6 to 13 m bgl. The depth of the wells in Tertiaries generally varies from 15 to 30 m bgl. The most potential aquifer in the area is alluvial deposits, which are composed of sand and clays. The depth of the wells ranges from 2 to 6 m bgl and is developed by shallow tube wells and filter point wells. The average yield is about 10 to 60 m^3/day.

Hydrochemistry

The ground water in the district is generally potable except in few locations such as areas adjacent to the seacoast and area polluted by industrial effluents. In the coastal plain the electrical conductivity is greater than 1000 μS/cm (Vizhinjam). Similarly the chloride content is also high in the same location. The water is generally alkaline in nature. All the major constituents are within the permissible limit. The ground water is suitable for domestic and drinking purposes. The minimum and maximum values of various constituents in water samples collected from TUA is given in Table .2

Table. 2: Chemical Quality of Ground Water in TUA

Constituents	Minimum	Maximum
pH	4.15	9.9
EC	93	1294
Total Hardness mg/l	14	2582
Ca^{2+}	4.2	89
Mg^{2+}	1.5	7.3
Na^+	5.7	140
Cl^-	11	337
No_3	2.1	152
F	0	0.53

Major Ground Water Related Problems

The important ground water related problems in Trivandrum Urban area are:

- Over-exploitation: With the adoption of modern drilling techniques, construction of bore wells has become a common practice to meet domestic as wells as agriculture needs. This increase in tube wells may result in more ground water draft from potential aquifers.
- Pollution: Mainly due to municipal waste and due to waste disposal particularly around Vilapilsala where the waste disposal facility has been established. The E.Coli content is very high in ground water of this area whereas the other constituents are within the desirable limit.
- Water marketing: Mainly seen during summer months, particularly in Vengannur panchayat and area near to Aakulam lake, due to heavy withdrawal resulting in decline of water table.

Feasibility of Rainwater Harvesting and Artificial Recharge

Due to lateral spread of urbanisation, ground water is vulnerable both quantitatively and qualitatively and hence it is very necessary to take up artificial recharge schemes in urban area. The identification of feasible areas for artificial recharge to groundwater was made on the basis of depth and declining trend of water level. Rain water harvesting, conservation of existing water bodies in the neighbourhood and recharging of these water bodies with filtered drain water etc. should be considered instead of allowing all run off to drain into the sea or to cause flooding in some part of the city. Artificial recharge and rainwater harvesting are the best-suited and most effective methods to augment ground water resources in the area (CGWB, 2009). Sub surface dams and dykes are the main structures feasible for the artificial recharge of ground water in the upstream portion of Karamana basin. The most feasible structure is the roof top rainwater harvesting technique. Such schemes can arrest the decline in groundwater levels and improve groundwater quality. Recharge pits and trenches are ideal structures for rainwater harvesting in the midland areas of Trivandrum Urban Area. Roof water can be used for recharge the dug wells, bore wells and tube wells. In TUA, a large number of ponds, tanks and other abstraction structures in the area are filled up with silt, clay and hence sufficient recharge is not taking place in the aquifers. Hence restoration of these structures has to be done to induce recharge. Similarly, many quarry ponds are present in and around Vizhinjam, Kovalam and Pothencode areas which can be effectively used for rainwater harvesting structures.

GROUND WATER DEVELOPMENT STRATEGY

There is scope for further ground water development for irrigation in TUA in areas where the stage of development is low. Ground water development should be coupled with management of rainwater and surface water. The existing water resources and dug wells, ponds and streams should be protected and conserved. Rainwater harvesting and artificial recharge schemes should be taken up on a massive scale. An essential part of management of the resource is the proper spacing of abstraction structures. The spacing between shallow tube wells should be kept 225 m and for deep tube wells the spacing between the well should be kept 800m.

Hydrologeologically, the areas have been grouped into hard rock and alluvial areas. Since the water level is very shallow in alluvial aquifer, artificial recharge can be considred only in hard rock areas. The surface spreading techniques such as check dams, gully plugs and nalah bunds are most appropriate for TUA. As per the Master Plan for Artificial Recharge to Ground Water(2002), in Karamana River basin 544 nos of Check dams of capacity 0.1 MCM, subsurface dykes of 0.03 MCM(906nos), Gully plugs(1360 nos) of 0.02 MCM and Nalah Bunding(1360 nos) of 0.02 MCM is feasible. The impact of artificial recharge to ground water shall be created mainly at the downstream side of the recharge structures.

RECOMMENDATIONS

The TUA is predominantly underlain by hard rocks especially Khondalite with low porosity which in turn reduce the infiltration capacity. Moreover, the city has the highest population density in Kerala resulting in more built up area which reduce the groundwater recharge. In order to tackle the declining water level trend in urban area, groundwater management techniques such as roof top ran water harvesting system and artificial recharge structures should be constructed to augment the groundwater reservoir. The area can withstand only low to moderate capacity tube wells. Filter point wells are in vogue in coastal areas. Since the ground water is potable, it is recommended that the ground water can be made use for domestic needs. Groundwater resource in blocks with low stage of development is recommended for further development. It is necessary to regulate the construction of groundwater abstraction structures. There is also need for creation of awareness among the public on judicious use of ground water resources and for capacity building of stakeholders at the grass root level on various aspects of ground water conservation and augmentation.

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