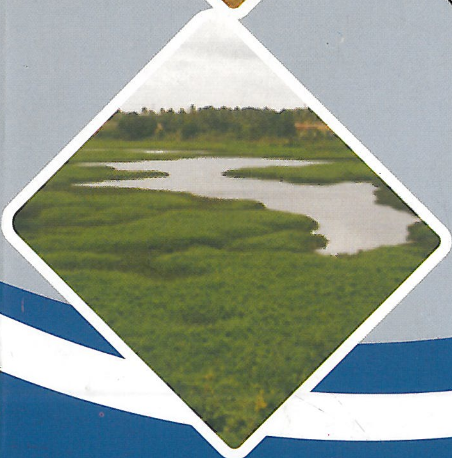
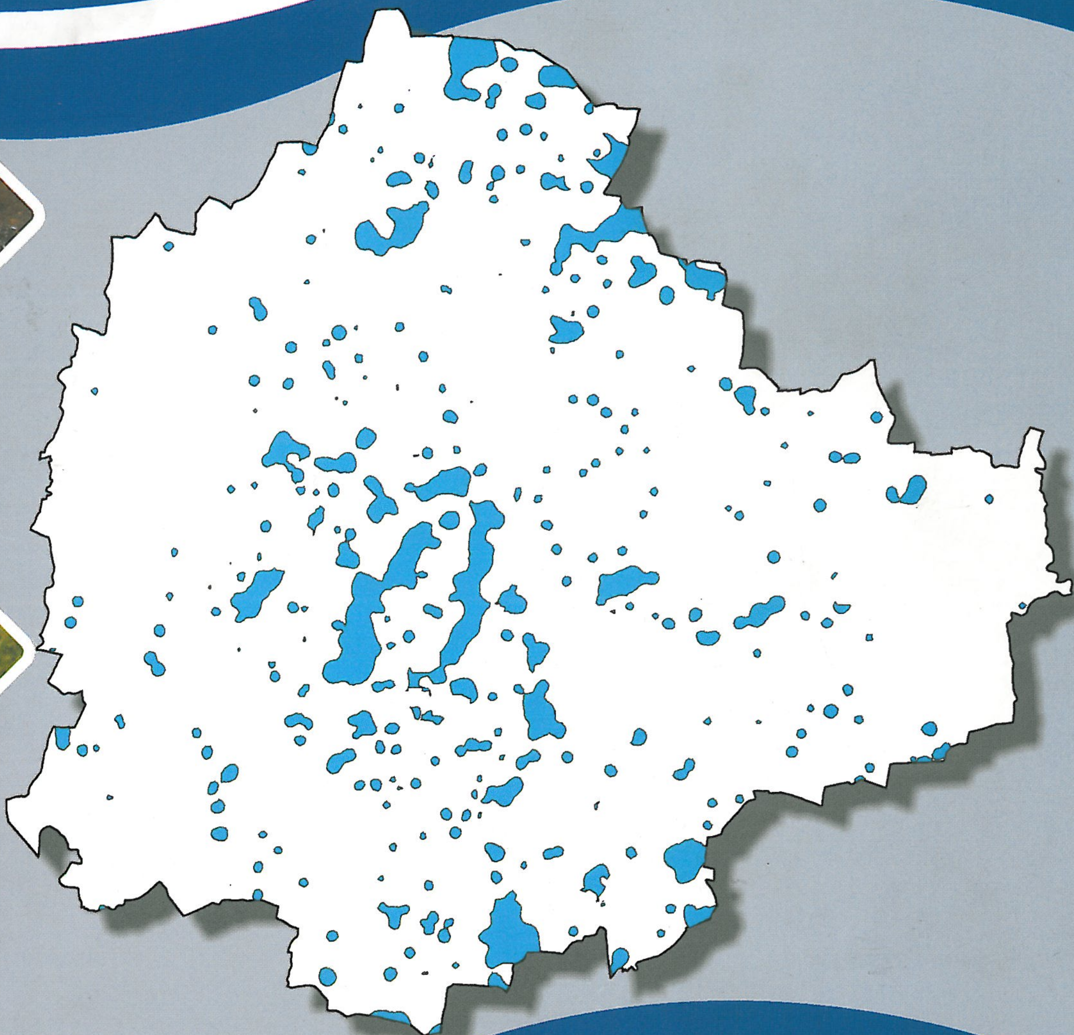
HP Technical Assistance
HYDROLOGY PROJECT

# GROUNDWATER HYDROLOGY AND GROUNDWATER QUALITY IN AND AROUND BANGALORE CITY






Department of Mines and Geology
49, Khanija Bhavan, Race Course Road,
Bangalore - 560 001


**March 2011**

# Groundwater Hydrology and Groundwater Quality in and around Bangalore City

*Published by*
**Director**
**Department of Mines and Geology**
49, Khanija Bhavan, Race Course Road,
Bangalore – 560 001

**March 2011**

"ಕನ್ನಡ ಅನುಷ್ಠಾನ ವರ್ಷ-೨೦೦೯"

GOVERNMENT OF KARNATAKA

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# Foreword

Happy to note that the Department of Mines and Geology is implementing the groundwater component programmes of the World Bank Aided Hydrology Project Phase-II and has been a faculty in carrying out an intensive study on "Urban Groundwater Hydrology and Groundwater Quality in and around Bangalore City."

The study involved monitoring of the fluctuation of groundwater table from 12 piezometers in addition to those already existing and carry out intensive groundwater quality study from the voluminous water samples that were collected. The samples collected were subjected to chemical, biological and heavy metal analysis. The results obtained have thrown light on the suitability of groundwaters of the city aquifers for drinking purposes.

The study has revealed that ever increasing demand on water supply has resulted in a depletion of groundwater table at an alarming rate, particularly in blocks where population is dependent mainly on groundwater. Among 2209 groundwater samples analysed for various chemical parameters, nitrate in 638 samples (29%), iron in 214 samples (10%), total hardness in 185 samples (8.5%) and fluoride in 14 samples (0.6%) are found in excess of the desirable/permissible limits rendering groundwater from such locations unfit for drinking. The presence of E-coli / Total coliform bacteria and certain heavy metals are reported in certain water samples throwing light on them being unsuitable for domestic consumption

It is hoped that the details presented in this volume shall be of use to the common man and more so to the administrators to effectively implement better planning and management and to take measures to revive the rapidly depleting groundwater resources of the city.

March 03, 2011

**(P.N. Sreenivasachary)**

**H.R. Srinivasa, I.A.S.,**
ನಿರ್ದೇಶಕರು
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# Preface

The Groundwater Survey and Investigation wing of the Department of Mines and Geology has been monitoring the groundwater quality in the State since early seventies through a net work of more than 1700 monitoring stations spread over different parts of the state. Studies on groundwater quality were oriented particularly in the rural and urban blocks. The Department there on had brought out special publications related to the quality of groundwater of Bangalore Metropolis and of Karnataka State.

Over exploitation of groundwater has resulted in fast depletion of groundwater table and deterioration in quality within and around the city limits. The Department under the "World Bank Aided Hydrology Project Phase-II-a Purpose Driven Study (PDS)" carried out further intensive study to evaluate the present status of groundwater quality in and around Bangalore city. More than 3000 groundwater samples from various sources besides a few surface water samples were collected and analysed in the Chemical Laboratory at Directorate office for different chemical, biological and heavy metal parameters.

The present study refers mainly to the urban groundwater hydrology, quality and possible factors that are causative of groundwater pollution in Bangalore city and its neighbouring area. By referring to the standard specifications, the suitability of groundwater in Bangalore City for drinking purposes is discussed.

I strongly believe that the results of the present work brought out in the current volume, shall be a material of reference and applicability to a common man and the government agencies while to plan, programme, implement and manage the groundwater based projects in the Bangalore and its agglomerate parts. Groundwater has now been a precious natural resource which deserves a call for its judicious usage.

March 03, 2011

**(H.R. Srinivasa)**

## Acknowledgements

The present study entitled "Groundwater Hydrology and Groundwater quality in and around Bangalore City" is a Purpose Driven Study, under World Bank Aided Hydrology Project Phase-II. The study is of three years duration from July 2008. Geohydrological investigations were carried out besides groundwater quality studies in and around Bangalore city. To have closer net work of monitoring stations 12 additional bore wells with in the city limits have been drilled as part of the present study.

Collection of more than 3000 water samples in a systematic manner was an uphill task and that was made easier by the then Director of the Department Sri M.E. Shivalinga Murthy, I.A.S. who has extended all the required support to carry out the present study. We remain thankful to him for his encouragements at different stages of the study. We are grateful to our present Director Sri H.R. Srinivasa, I.A.S. for his continued support and keen interest to bring out this volume. Our thanks are due to Sri. P.N. Sreenivasachary, I.A.S. Secretary to Government, Water Resource Department (MI), for useful discussions and suggestions during investigation and finalization of this report.

The field investigation and water sample collection team of Officers of the Department comprised of Sriuths D. Srikanta Murthy, C.I. Ashok, Deputy Directors, Pathi Basavaraj Deputy Chief Geophysicist, Dr. G.V. Hegde, Shashikant Reddy, Senior Geologists and Sri DHM Veerashekara Swamy, Senior Geophysicist all from Head Office, Smt. Ambika and Renuka Senior Geologists, Ramanagar, and the Geologists Smt. K.S. Prathima and Ms.N.M.Vindhya from Head Office, Smt. M.S. Asha from Chikkaballapur, Zilla Panchayath (GW), Chandrashekar from Mysore, Zilla Panchayath(GW), Dileep Kumar from Bangalore Zilla Panchayath(GW) and H.T. Chidanand, Geophysicist, Mandya Zilla Panchayath (GW). Water samples collected were analysed at the Directorate Chemical Laboratory headed by Smt. M.V. Shashirekha, Chief Chemist, Smt. K.N.Sumathi, Senior Chemist, B.S. Chethan and B.H. Satishkumar Chemists, R. Umesh and Ms. Lakshmi Data Entry Operators. The studies carried out by all these officers as **a team,** made it possible to achieve the task well within the scheduled time and are duly acknowleged.

Our thanks are due to the reviewers for valuable comments and suggestions, and to the Project Coordinate Secretariat (PCS), Ministry of Water Resources, New Delhi and TAMC team for technical support and the World Bank for assistance. Special efforts by Dr G.V. Hegde, Senior Geologist and Smt. Nithya.V, Geologist in the preparation of different water quality maps in Arc GIS environment and bringing out this volume deserve greater appreciation.

March 05, 2011

**(H. M. Khayum Ali)**
Additional Director (GW)/Nodal Officer HP-II
and the Principal Investigator (PDS)

# Table of Contents

## Part III : Quality of Lake Waters

# List of Tables

## Part I : Urban Groundwater Hydrology



## Part II : Groundwater Quality



## Part III : Quality of Lake Waters

# List of Figures

## Part I : Urban Groundwater Hydrology



## Part II : Groundwater Quality

## Part III : Quality of Lake Waters

# Abbreviations

| | |
|---|---|
| BBMP | Bruhath Bangalore Mahanagara Palike |
| BDA | Bangalore Development Authority |
| BWSSB | Bangalore Water Supply and Sewerage Board |
| CGWB | Central Ground Water Board |
| CMC | City Municipal Council |
| DMG | Department of Mines & Geology |
| DO | Dissolved Oxygen |
| EC | E-Coli |
| GPS | Global Positioning System |
| GW | Groundwater |
| GWS | Grandwater Survey |
| ham | Hectare Metre |
| HIS | Hydrological Information System |
| HP | Hydrology Project |
| IS | Indian Standards |
| MI | Minor Irrigation |
| MLD | Million Litre per Day |
| MoWR | Ministry of Water Resources, New Delhi |
| MPN | Most Probable Number |
| PCS | Project Co-ordinate Secretariat |
| PDS | Purpose Driven Study |
| pH | Hydrogen Ion Concentration |
| PM | Plan Monitoring |
| R & D | Research and Development |
| SC | Specific Conductance |
| TC | Total Coli |
| TDS | Total Dissolved Solids |
| TMC | Town Municipal Council |
| UVS | Ultra Violet Spectometer |
| WHO | World Health Organisation |
| WRD | Water Resource Department |
| ZP | Zilla Panchayat |

Abstract

The previous studies carried out by the Department of Mines and Geology during 1994, 1995 and 2003 on the groundwater quality of Bangalore Metropolis had established that the groundwater pollution in the city is mainly due to sewage disposal and recommended to prevent pollution from sewage and industrial wastes.

The population and the areal extent of the city have increased at an alarming rate in recent years. The basic requirements like water and power supply could not be enhanced in pace with the ever growing demand. Water – one of the natural resources has remained a deficit resource in Bangalore since long. The supply of required quantity of safe quality drinking water to the population has now been a big challenge to the concerned authorities. To address these issues, the groundwater wing of the Department has taken up fresh study on "urban groundwater hydrology and groundwater quality in and around Bangalore City" under the World Bank aided Hydrology Project, Phase II, Purpose Driven Studies.

As part of the present groundwater quality studies, over 3000 groundwater samples were collected over an area of 800 sq. km. in and around Bangalore City. The study area was divided into four quadrants and each such quadrant was further made into one sq. km. grid. Two or three samples were collected from each such grid and got analyzed in the chemical laboratory at Directorate of Mines and Geology, Bangalore.

The study has revealed:

- Fast demographic growth of the city over a last few years, ever increasing demand for water and deficiency in the public water supply system developed a heavy strain on the groundwater aquifers of the city.
- Over draft of groundwater has resulted in steep decline in groundwater level, drying up of unconfined aquifers and mining of groundwater situation at many parts of the city.
- Total dissolved solids (TDS) and fluoride content in groundwater on higher side from deeper bore wells are the signals of deterioration of the quality of groundwater.
- Among 2209 groundwater samples analyzed, the nitrate content in excess of the desirable/permissible limit is found in 638 samples (29%), iron in 214 samples (10%), total hardness in 185 samples (8.5%), and fluoride in 14 samples (0.6%).

- Whereas the presence of heavy metals in groundwater is attributable to the infiltration of effluents from the industrial waste disposals, higher content of $NO_3$, low and high values of pH and the presence of e-coli and total coliform bacteria are mainly due to discharge of untreated sewage waste into the natural drainage system.

- The causative factor for groundwater pollution is more anthropogenic than being geologic.

- Groundwater, once polluted/contaminated is difficult to bring back to the required drinking water standards. The cost of treatment of contaminated water to make it potable shall be enormous.

- The best option is to avoid disposal of solid, liquid domestic and industrial waste within the city premises.

- As per ***IS 2003 drinking water specification***, 31% of the city groundwater is non potable as against 50% found in the previous study conducted in 2003. This is attributed to the remedial measures implemented to prevent groundwater pollution.

- Top priority be given for the conservation of rainwater through appropriate rain water harvesting measures.

- Creation of greater awareness among the public towards economical, social and health implications of pollution of water resources.

- Judicious use of available potable water resources is the need of the hour.

# PART – I

# Urban Groundwater Hydrology – Bangalore City

D. Srikanta Murthy

## Introduction

Groundwater Hydrological Information System (HIS) in Hydrology Project, Phase-I was successfully implemented by the Department of Mines and Geology between 1996-1997 and 2002-2003. Hydrology Project, Phase-II is now conceived to promote effective application of HIS for water resources planning and management.

The Vertical Extension Components are provided with more than 33% of the project budget to demonstrate the hydrological data applications for future replication through selective upgradation of spatial data input and output and data visualization. Purpose Driven Study (PDS) was one of the proposals of the project to

- identify the issue concerning water management in the agency's area of competence and operation.
- specific issue of water management of public concern

Bangalore, one of the fast growing cities in India, branded as 'Silicon Valley of India' is plagued with water problems.

Demographic growth of the city took a quantum leap over a last few years. Consequently, the growth of groundwater exploitation has been phenomenal, largely through lakhs of private borewells. The World Bank assisted Hydrology Project Phase-II PDS provided the required platform to the Department to carryout the study on "Urban Groundwater Hydrology and Groundwater Quality in and around Bangalore City".

Approval for the Purpose Driven Study proposal was conveyed by the Central Ground Water Board and Project Co-ordinate Secretariat (PCS), Ministry of Water Resources, MoWR, New Delhi on 25th July 2008.

A large number of lakes/tanks which provided water for irrigation, drinking, fishing and washing during non-monsoon period in the past, either dwindled in number or became cess pool for sewage water. With the city's unprecedented growth, open spaces vanished over the years. The space for infiltration of groundwater reduced drastically. Many of the wells including those wells set up by the Department to monitor groundwater level fluctuation dried up. The Department was left with only a few inadequate piezometers in Bangalore city area and its surroundings. Inadequacy of piezometers within the city surroundings posed problems in assessing true picture of groundwater levels.

The Purpose Driven Study (PDS) provided the right platform to fill the monitoring network gap. After consultations with the CGWB, it was decided to construct 12 piezometers in different parts of the city. Permission was there on obtained from the concerned authorities to construct the piezometers in public secured places like BBMP office premises, Schools, BDA etc.,

## Focus on Scientific Investigation

The Bruhat Bangalore Mahanagara Palike (BBMP) lies between North latitude 12°49'34" to 13°18'9" and East longitude 77°27′41" to 77°47′5" over an area of 710 sq.km and with a total perimeter of 151.9 km. This area is covered in part of Survey of India topo maps No.57 H/9, H/5, H/13, H/16, G/12, G/8 on 1:50,000 scale. The BBMP in its website has displayed the map which included newly added municipal councils, panchayats and villages and 198 wards (Fig. 1).

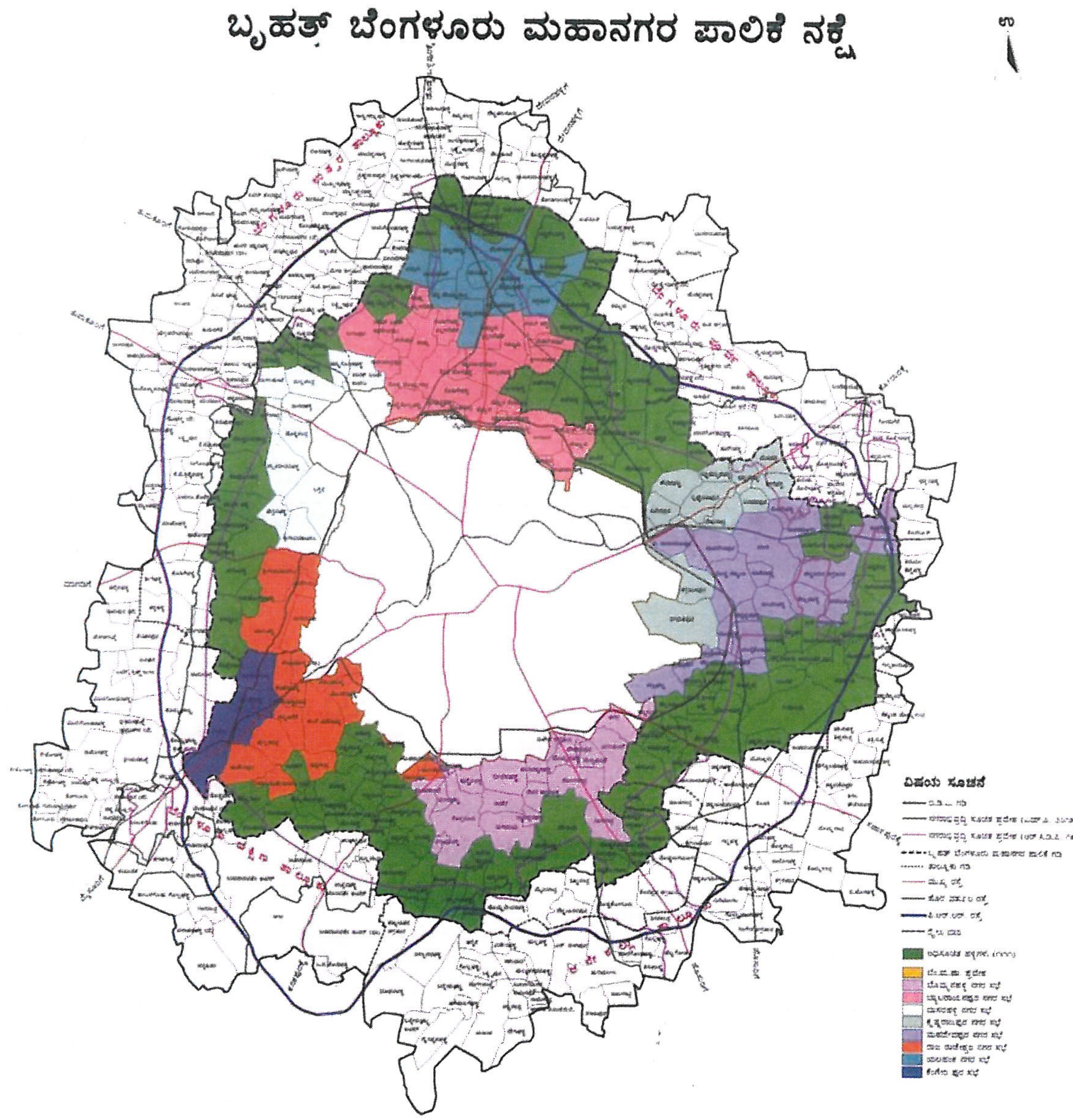



**Figure 1 : Map of Bruhat Bangalore Mahanagar Palike (BBMP)**

*(Source : BBMP web site)*

Based on the geohydrological features of the area and geophysical survey results, 18 sites were identified for the construction of piezometers in BBMP area. But, due to field constraints only 12 sites were confirmed.

Piezometer depth, approximate casing requirement, construction of concrete platform and protective cover with locking facility were all specified in the tenders that were invited as per World Bank norms. When the tender evaluation reports were sent to the Project Coordinate Secretariat (PCS) Hydrology Project-II, Ministry of Water Resources, New Delhi for approval, permission was accorded to complete the work during 2009-10. Details of the new piezometers constructed under the project are furnished in Table-1. The location of newly drilled borewell alongwith the earlier monitoring network stations is given in Figure 2.

**Table 1 : Details of piezometers**

| Village | Date of Drilling | Depth Drilled (m) | 1st Water Bearing Zone (m) | 2nd Water Bearing Zone (m) | Casing (m) |
|---|---|---|---|---|---|
| Bagalkunte | 23-02-2010 | 107.80 | 33.30 | 86.00 | 38.80 |
| Jalahalli | 23-02-2010 | 107.80 | 25.20 | 55.00 | 30.00 |
| Sadashivanagar | 26-02-2010 | 147.00 | 107.70 | - | 39.30 |
| Laggere | 01-03-2010 | 113.40 | 56.00 | - | 46.00 |
| Hebbal Kempapura | 02-03-2010 | 135.15 | 95.00 | - | 28.60 |
| Kalkere | 05-03-2010 | 141.00 | 40.00 | 136.00 | 42.00 |
| K Narayanapura | 06-03-2010 | 107.80 | 50.00 | 79.50 | 42.20 |
| Dodda Kannalli | 09-03-2010 | 119.60 | 54.00 | - | 41.00 |
| HSR Layout | 10-03-2010 | 125.00 | 45.00 | | 11.50 |
| Mahadevapur | 12-03-2010 | 158.00 | 150.00 | | 6.00 |
| Pattanagere | 22-03-2010 | 152.00 | 95.00 | 142.00 | 16.80 |

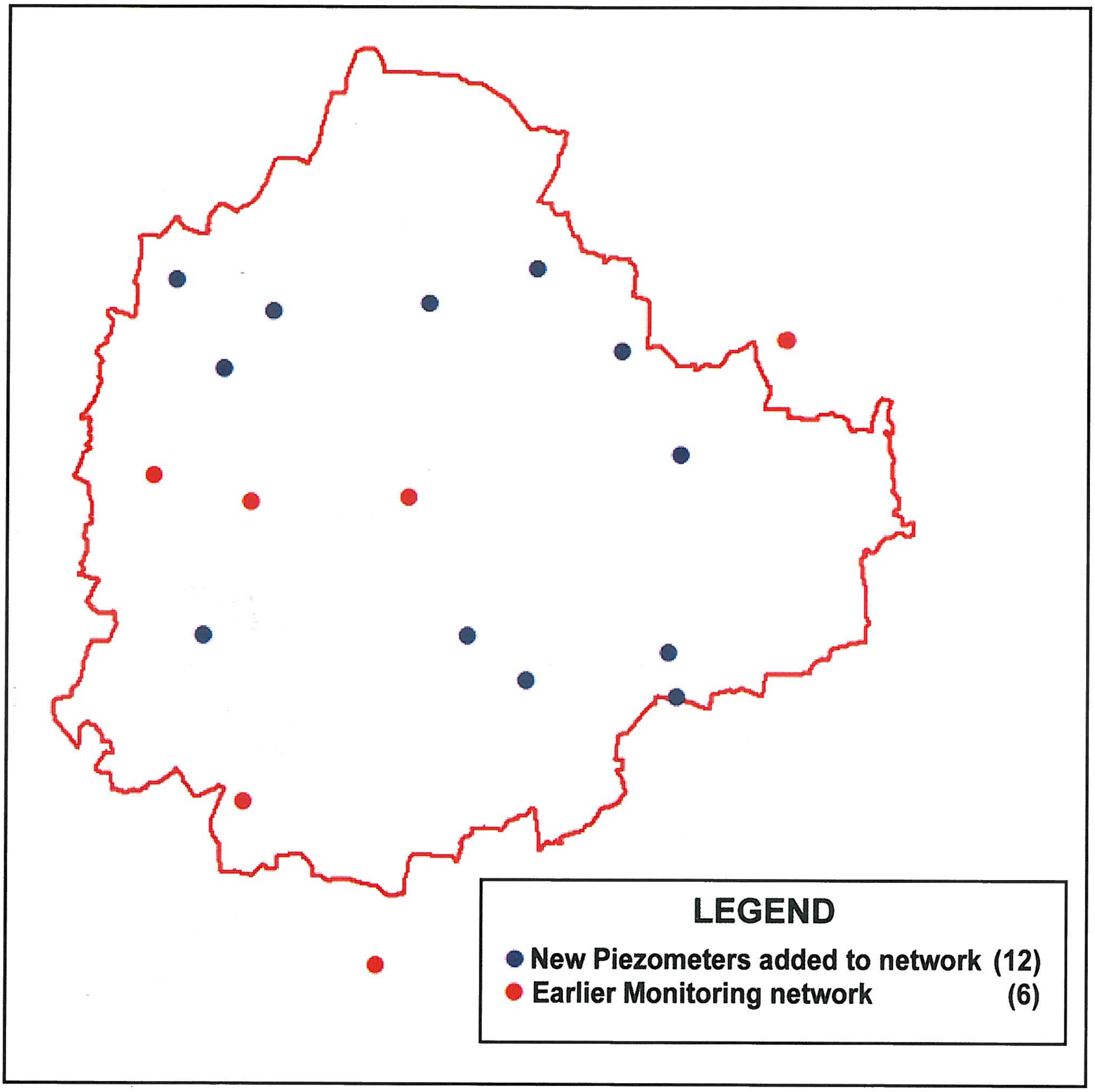



Figure 2 : Groundwater monitoring network in BBMP area

Another important aspect covered under the project was groundwater quality studies. This part of the project was mainly at the instance of encouragement, guidance and interest bestowed by the Director of Mines and Geology.

Survey of India guide Map of earlier Bangalore City available on 1 : 25,000 scale was initially selected as the base map. The map presents 540 sq. km of Bangalore City area and was divided into one square kilometer grids. But, since the BBMP area covered an extent of about 741 sq. km. The corresponding topo maps of 1 : 50,000 scale was enlarged to the guide map scale and thereon one square kilometre grids were further extended to cover the entire BBMP area (Figure 3).

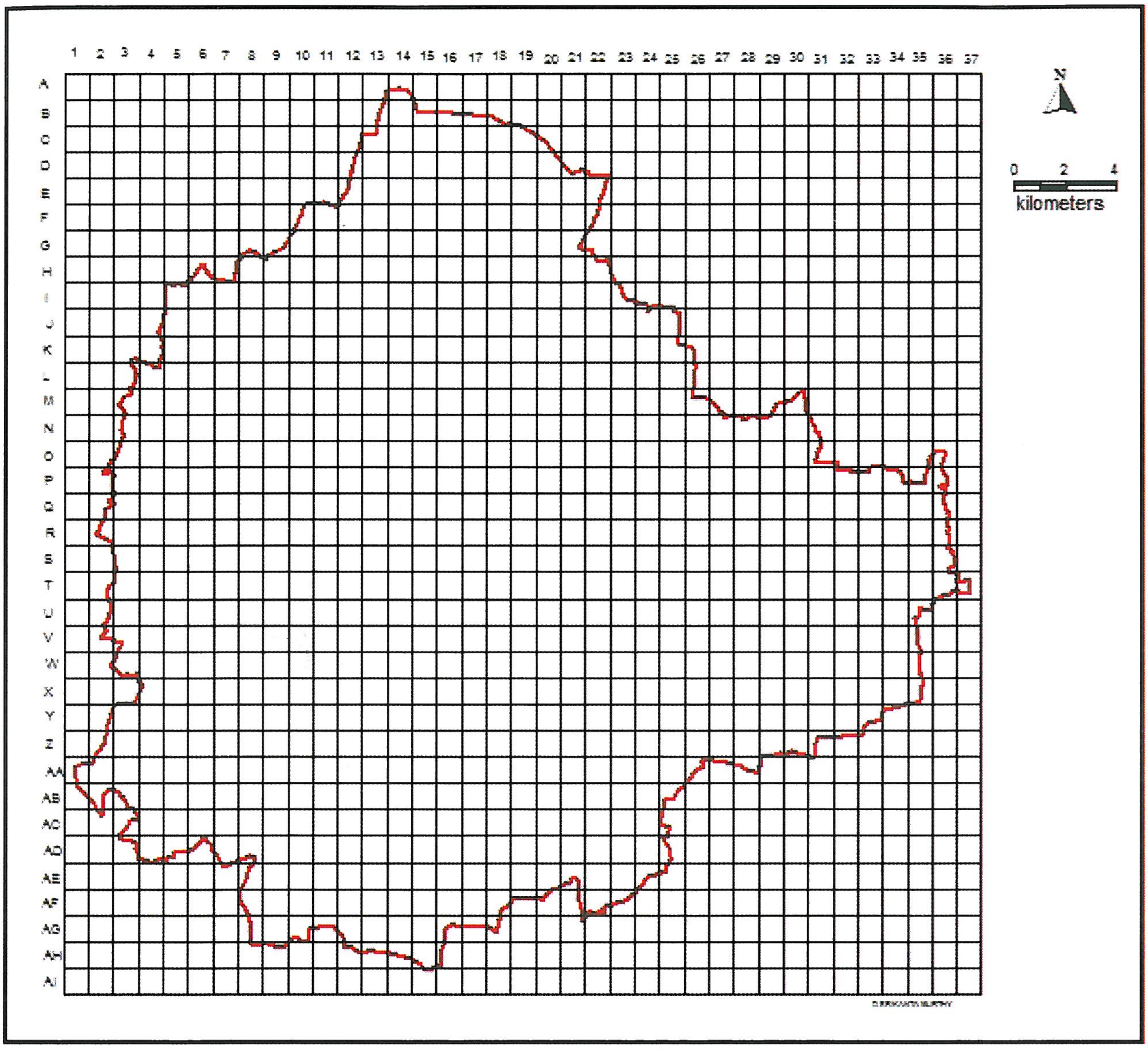



Figure 3 : One sq.km grid with BBMP boundary

About 800 grids were demarcated and given alpha numeric numbering. For the purpose of study the BBMP area was divided into North-East (NE), South-East (SE), South-West (SW) and North-West (NW) quadrants. Some of the grids in the fringe parts covered only the parts of BBMP area. Three groundwater samples were collected from bore wells/dug wells in use from each grid. Nine teams were formulated to complete the work. Each team was provided Global Positioning System (GPS) instrument to obtain the geo-reference of each sampling point (bore well/dug well/lakes etc.).

**Table 2 : Departmental Officers involved in the study**

<table>
<tr><td colspan="3">H.M. Khyum Ali,<br>Additional Director (GWS) /<br>Nodal Officer HP-II</td><td colspan="2">Principal Investigator</td></tr>
<tr><td>Sl. No</td><td>Zone</td><td>Team Leader</td><td>Deputy Team Leader</td><td>Other Officers assigned for the study</td></tr>
<tr><td>1.</td><td>North East Quadrant No.1</td><td rowspan="2">D.SrikantaMurthy,<br>Deputy Director<br>(GWS)</td><td>Patti Basavaraj<br>Deputy Chief<br>Geophysicist</td><td>1) Asha, Geologist, Chikkaballapur (ZP)<br>2) Chandrashekar.K, Geologist, ZP, Mysore</td></tr>
<tr><td>2.</td><td>South East Quadrant No.2</td><td>Shashikanth<br>Reddy<br>Senior Geologist</td><td>3) Dileep Kumar B.G, Geologist, Bangalore (ZP)<br>4) Prathima K.S, Geologist (PM) H.O<br>5) Vindhya N.M. Geologist (R &D) H.O</td></tr>
<tr><td>3.</td><td>South West Quadrant No.3</td><td rowspan="2">Ashok C.I.<br>Deputy Director<br>(R and D)</td><td>G.V. Hegde<br>Senior Geologist</td><td>6) Nagaveni, Geologist, Bangalore (ZP)<br>7) Chidanand murthy Geologist, Bangalore (ZP)<br>8) H.T. Chidanand Geophysicist Mandya.</td></tr>
<tr><td>4.</td><td>North West Quadrant No.4</td><td>D.H.M.V.<br>Swamy<br>Senior</td><td>8) Ambika, Senior Geologist, Ramanagara<br>9) Renuka, Senior Geologist, Geophysicist Ramanagara</td></tr>
</table>

The samples collected were got analyzed by the Chief Chemist in the Directorate of Mines and Geology. The staff involved in the chemical analysis is given in Table 3.

**Table 3 : Head Office Chemical laboratory Staff**

| Sl.No. | Name | Designation |
|---|---|---|
| 1 | M V Shashirekha | Chief Chemist |
| 2 | K N Sumathi | Senior Chemist |
| 3 | B S Chetan | Chemist |
| 4 | B N Satishkumar | Chemist |
| 5 | R Umesh | Data Entry Operator |
| 6 | Y Lakshmi | Data Entry Operator |

The collection of groundwater samples were also in the localities of solid waste disposal and open drains and these were more particularly for bacterial analysis. Lake water samples were also collected to determine Dissolved Oxygen (DO) and other parameters. Based on the fluoride presence of over and above the threshold value, more number of samples around those locations were collected for further analysis. Such an approach made it easier to identify the areas where groundwater is not suitable for domestic purposes.

## Climate and Rainfall

The December-January are the months with an average low of 15°C and the April-May are the months where the temperature soars upto 37°C. The average maximum temperature during these months is 33°C. The highest temperature ever recorded in Bangalore is 38.9°C and the lowest is 7.8°C.

BBMP area receives an annual average rainfall of 900 mm. Nearly 72% of this annual rainfall is from South-West monsoon (June to September) and rest of the rainfall is from North-East monsoon (October to December). The rainfall attains a characteristic peak during October month (Figure 4). January to March are dry months.

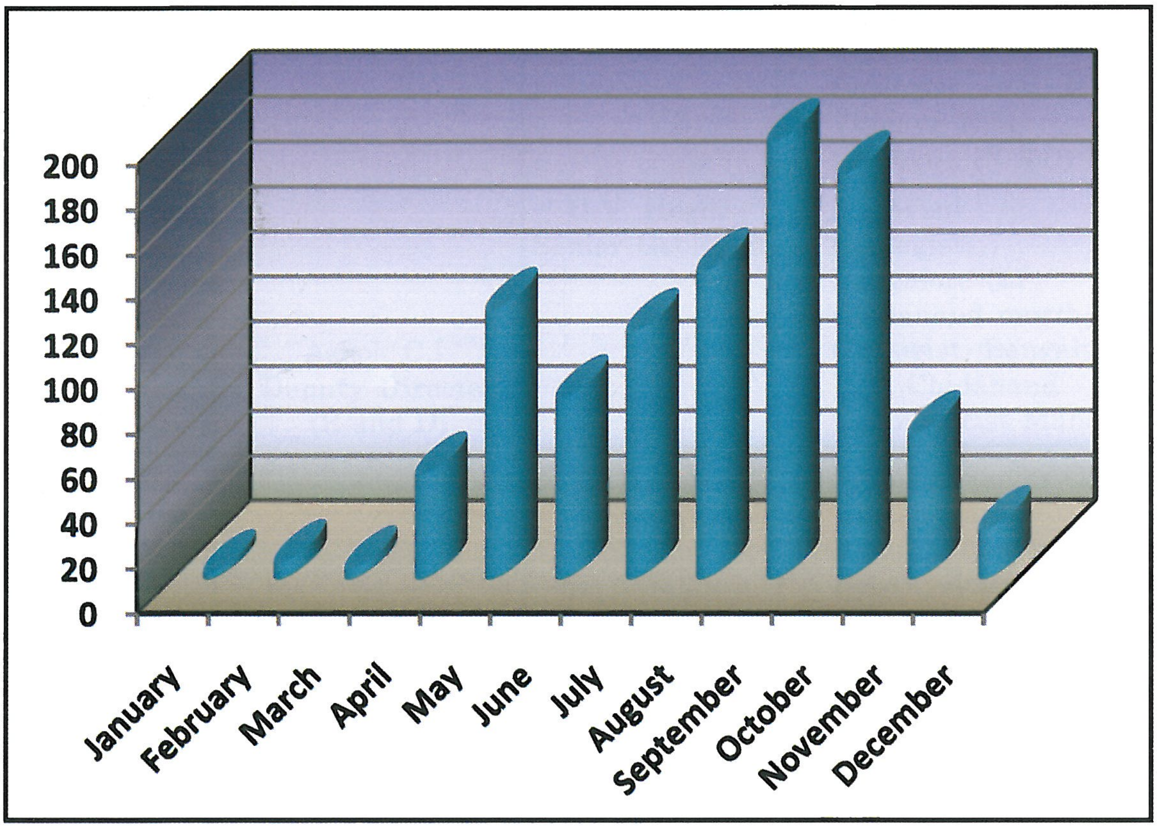



**Figure 4 : Mean monthly rainfall (mm), Bangalore city**

The relative humidity varies from 43% in the month of March to 78% in July. The relative humidity is more than 70% during June - November months. Sunlight hours for the City range from 3.0 hours during July to 9.5 hours during March. Area experiences sunshine hours of 6.7 per day. Average monthly data of different meterological parameters like minimum temperature, maximum temperature, average temperature (°C), precipitation (cm), Wet days (>0.1 mm), sunshine hours per day, wind speed (Beaufort), and relative humidity for Bangalore are shown in Figure 5.

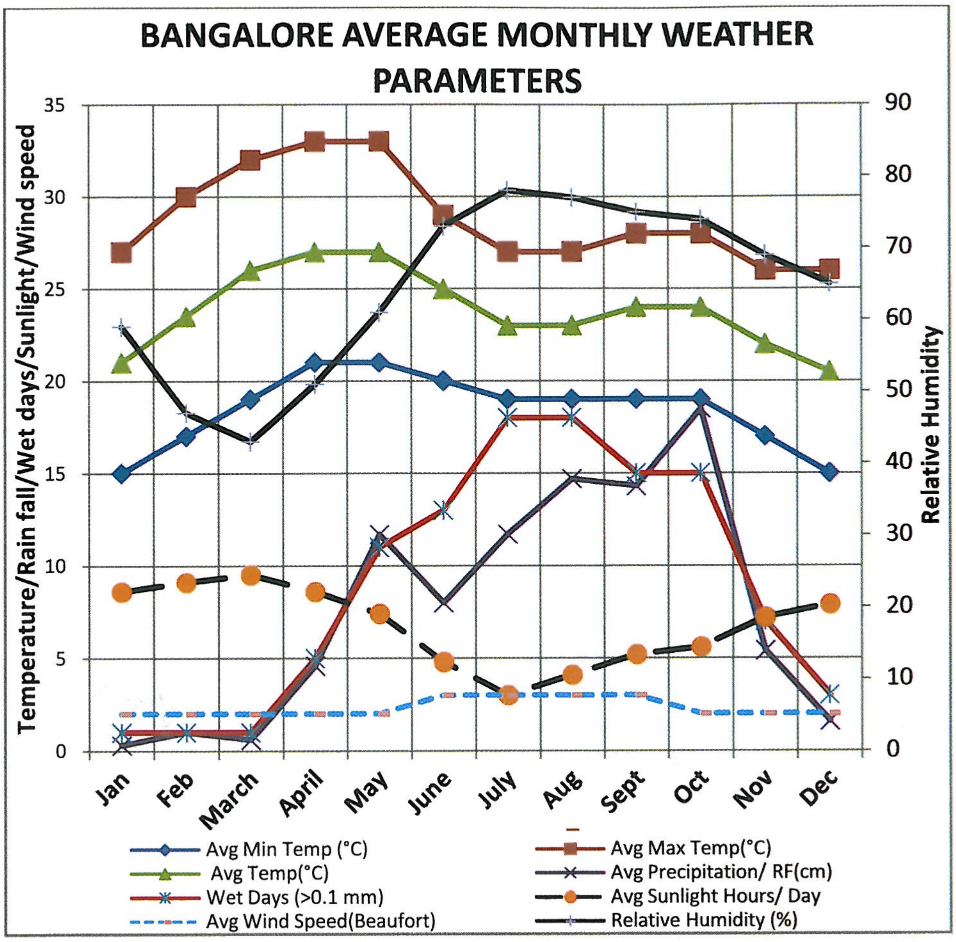



**Figure 5 : Average monthly meteorological parameters of Bangalore City** *(Source : Meterological Department Website).*

## Natural Drainage

Bangalore city is situated at an elevation of more than 920 m above mean sea level. The BBMP area is mainly drained by a part of the Arkavathi river catchment to the west, South Pennar or South Pinakini river to the east (Figure 6).

The area is characterized by first and second order streams and only near Bellandur it passes on to third order. There are many large sized lakes in this sub-basin. In the Arkavathi sub-basin, the landscape is dotted with number of mounds and hills and possesses only small sized tanks. These two main catchments are further divided into three main watersheds namely; 4C1C8, 4B3B6 and 4B3B8 (Figure 6).

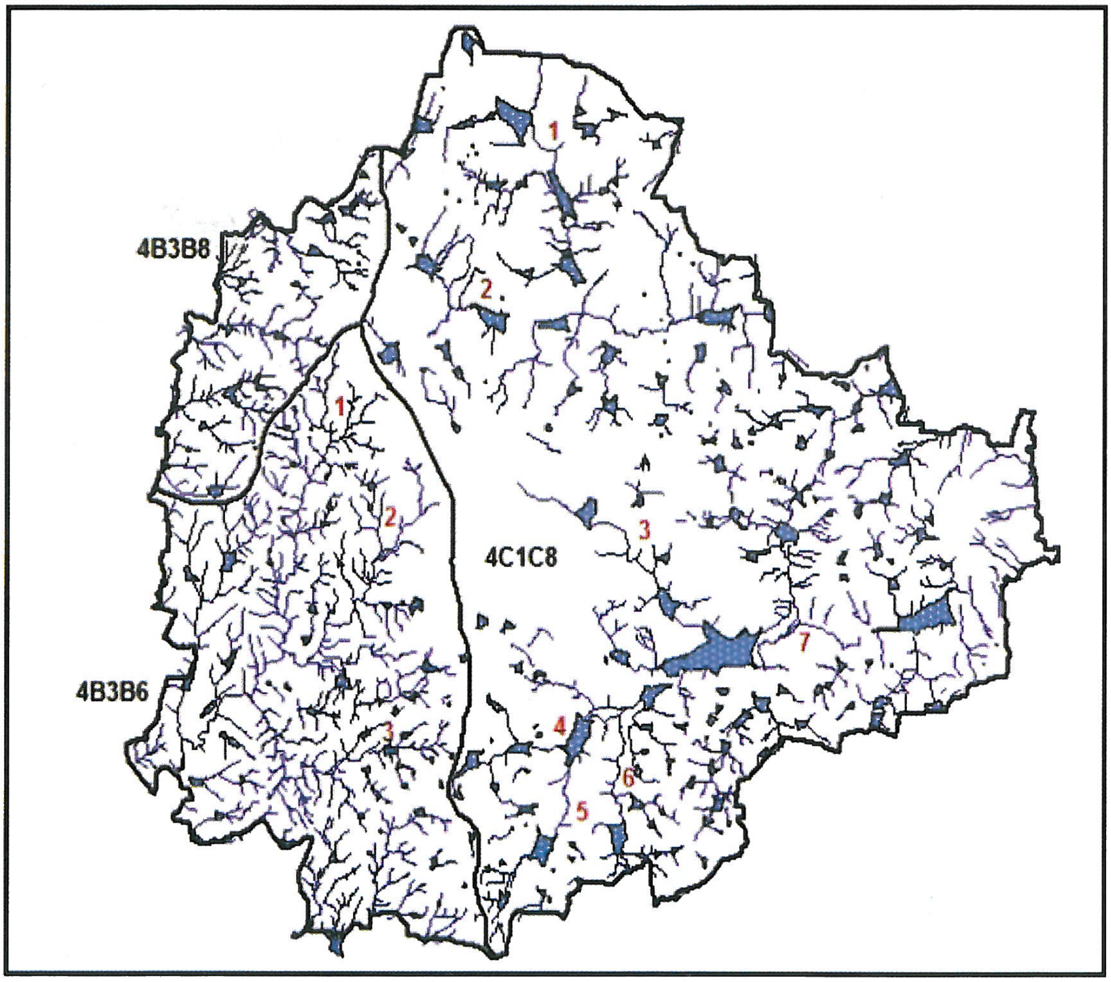



**Figure 6 : Natural drainage system of BBMP area**

In the watershed 4B3B6 there are two main tributory systems are flowing from North East to South West direction and the other from east to west and confluencing each other at Mysore road.

The watershed 4C1C8 (South Pennar or South Pinakini) in the eastern part of Bangalore covers more than 2/3 of the BBMP area. There are two major drainages, one is from Yelahanka flowing south easterly and the other from Sarakki area flowing North easterly and both draining into the Bellandur tank and further the stream system taking an easterly course.

## Geology

The BBMP area forming a part of Peninsular Gneissic Complex is represented by mafic gneiss, biotite gneiss, granodioritic gneiss with intrusives like dyke and pegmatites. In the extreme eastern part, the gneissic rocks are encapped by laterites. The Geological Survey of India identified this gneissic rock of more then 2.5 billion years at the famous Lalbagh gardens and declared it as a National Geological Monument. This Geological Monument is mainly biotite gneiss of granitic to granodioritic composition and contain enclaves of older rocks.

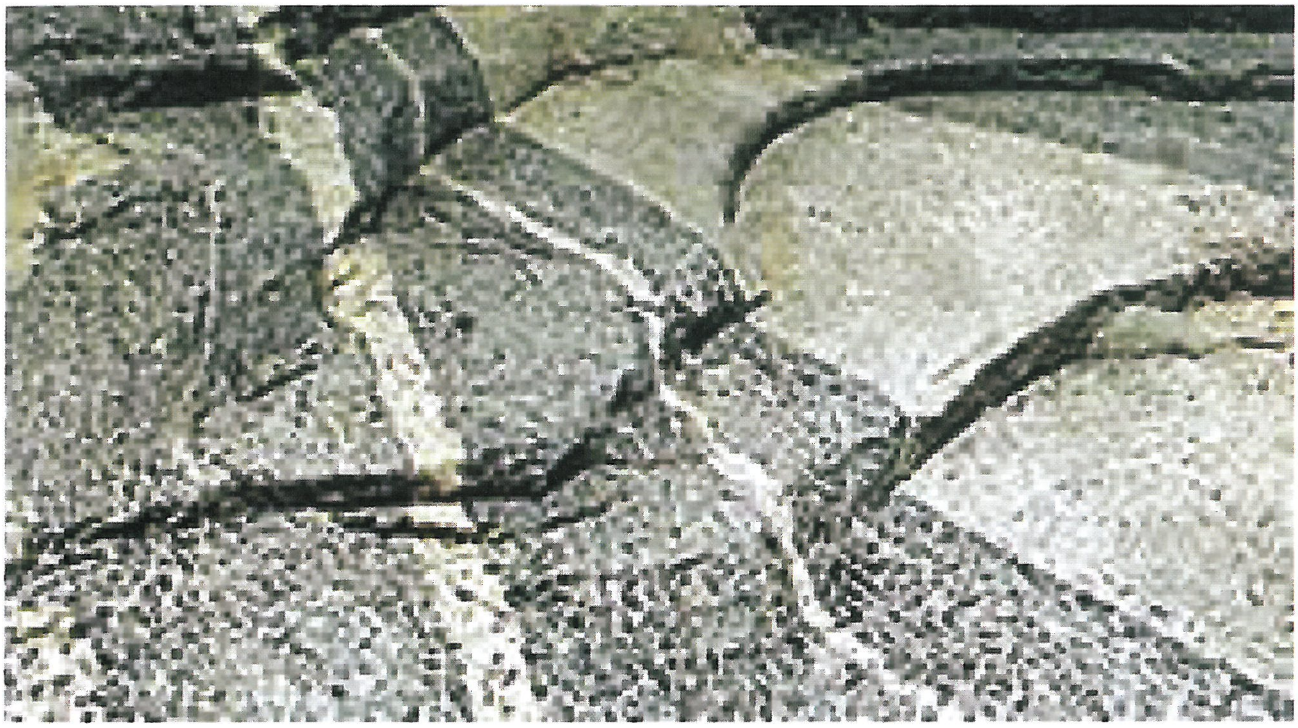


**Figure 7 : Peninsular gneiss in Lalbagh garden**

Gneisses and granites are intruded by pegmatite, quartz veins and by basic dykes. Dolerite dykes trending east-west direction across the gneissic foliation are common. These dykes vary from 6 to 20m in width and stretches 1 to 3 Km in length. Around Gavipuram locality porphyritic gneiss is well exposed. An outcrop of augen gneiss is at Uttarahalli. Well foliated biotite gneiss inter layered with 2 to 10 cm thick pegmatitc veins are at Hulimavu, Adugodi, Hennur quarries and Ulsoor lake in the eastern part of BBMP. Amphibolites of the Sargur super group are to the north of Kamakashipalya.

There are many old quarry workings concentrated in South East, North East and North part of Bangalore City (Figure 8).

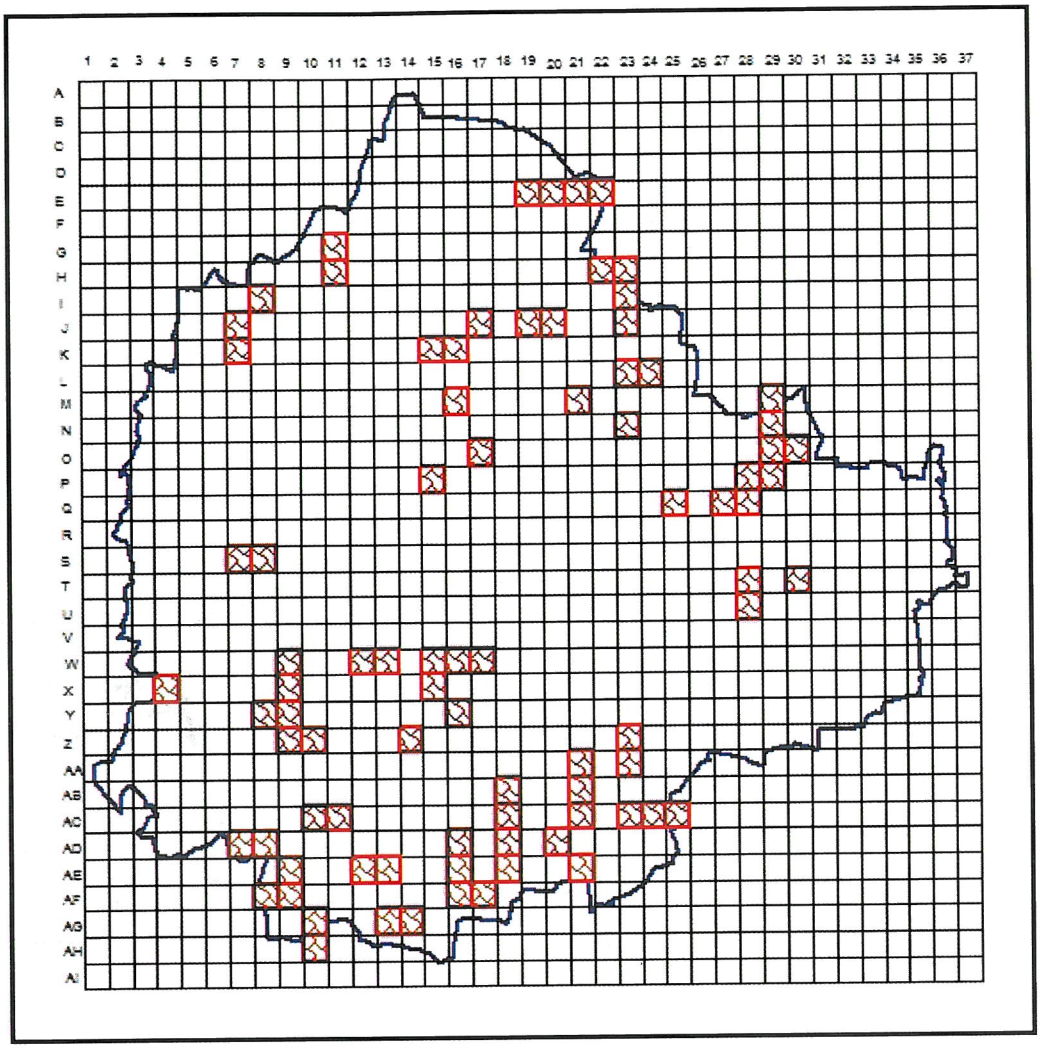


**Figure 8 : Old quarry workings in BBMP limits**

Parts in eastern block of BBMP like Byatarayanapura, Yelahanka, Domlur, Marthahalli, Whitefield, Hudi are covered by thick laterite and or saprolite which are the altered products of basement formation. These thick lateritised and weathered formation are followed by hard granitic gneiss.

## Water Supply to Bangalore

Water supply to Bangalore prior to 1896 was from a number of lakes viz., Dharmambudi, Sampangi, Ulsoor etc, supplemented by dug wells and Kalyanis. In 1894 the first protected water supply was provided from Hesarghatta lake across Arkavathi river.

Due to drying up of Hesaraghatta lake in subsequent years, urgent remedial measures had to be initiated by a Committee headed by Sir M. Visweswaraiah and there on a reservoir was commissioned on river Arkavathi (Chamaraja Sagar) at Tippagondanahalli, downstream of Hesaraghatta lake. It was also to receive flow from Kumudvati stream.

The Cauvery river water supply was commissioned to the city in the year 1974 and water supply position was further periodically improved by commissioning three more stages with Cauvery river water as its main source. Water is being pumped from the river Cauvery, from a distance of about 100 km at approximately 900 million liters per day (MLD). Bangalore Water Supply and Sewerage Board (BWSSB) is the authority for providing protected drinking water supply. The details of Arkavathi and Cauvery water supply schemes are as below:

| | Source | | Established year | Potential (in MLD) |
|---|---|---|---|---|
| **1. Arkavathi** | a) | Hesarghatta | 1896 | 36 |
| | b) | T.G.Hally | 1933 | 148 |
| **2. Cauvery** | a) | Stage-1 | 1974 | 135 |
| | b) | Stage-2 | 1982 | 135 |
| | c) | Stage-3 | 1993 | 270 |
| | d) | Stage-4 | 2002 | 270 |

On the basis of demographic growth and projection for subsequent years (Figure 9), as against the requirement at 200 LPCD, the shortage is estimated at 570 MLD. Shortages are met from groundwater. There is hence a tremendous pressure in exploiting groundwater resource.

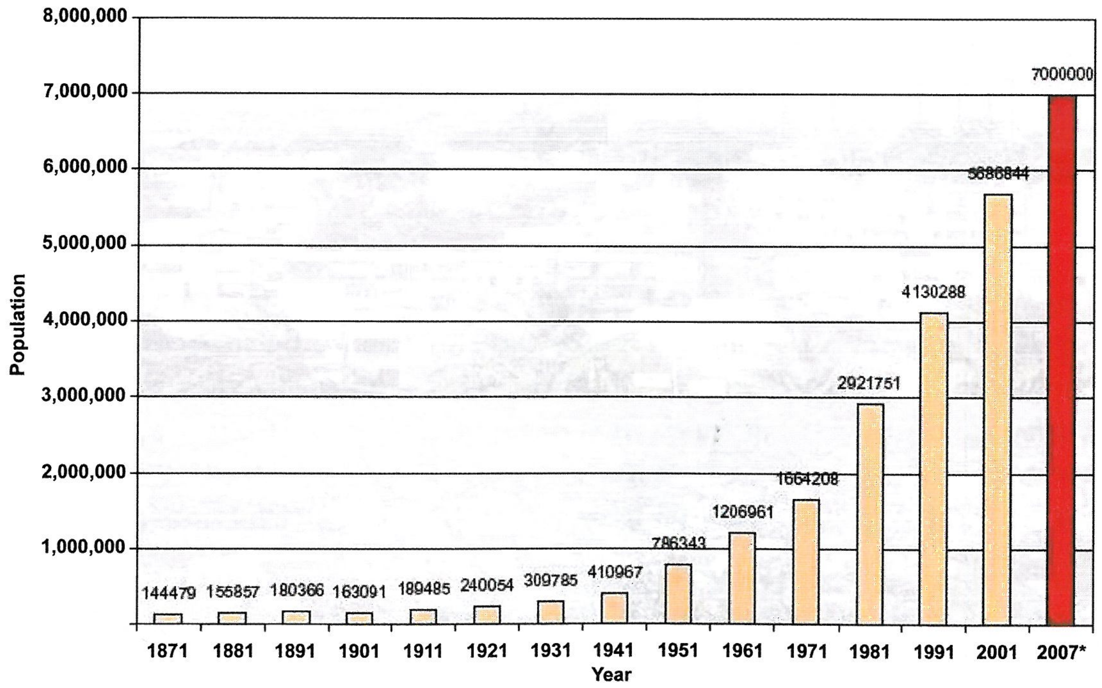



**Figure 9 : Population growth of Bangalore city** ***(Source: Census of India 2001)***
***(78 Lakhs for 2010 Projected)***

Zone wise details of BWSSB water supply connection and number of borewells in the area of operation are given in Figure 10. It indicates that South and West zones have the highest number of borewells. The old Bangalore is having better water supply and also has the highest number of borewells (Figure 10).

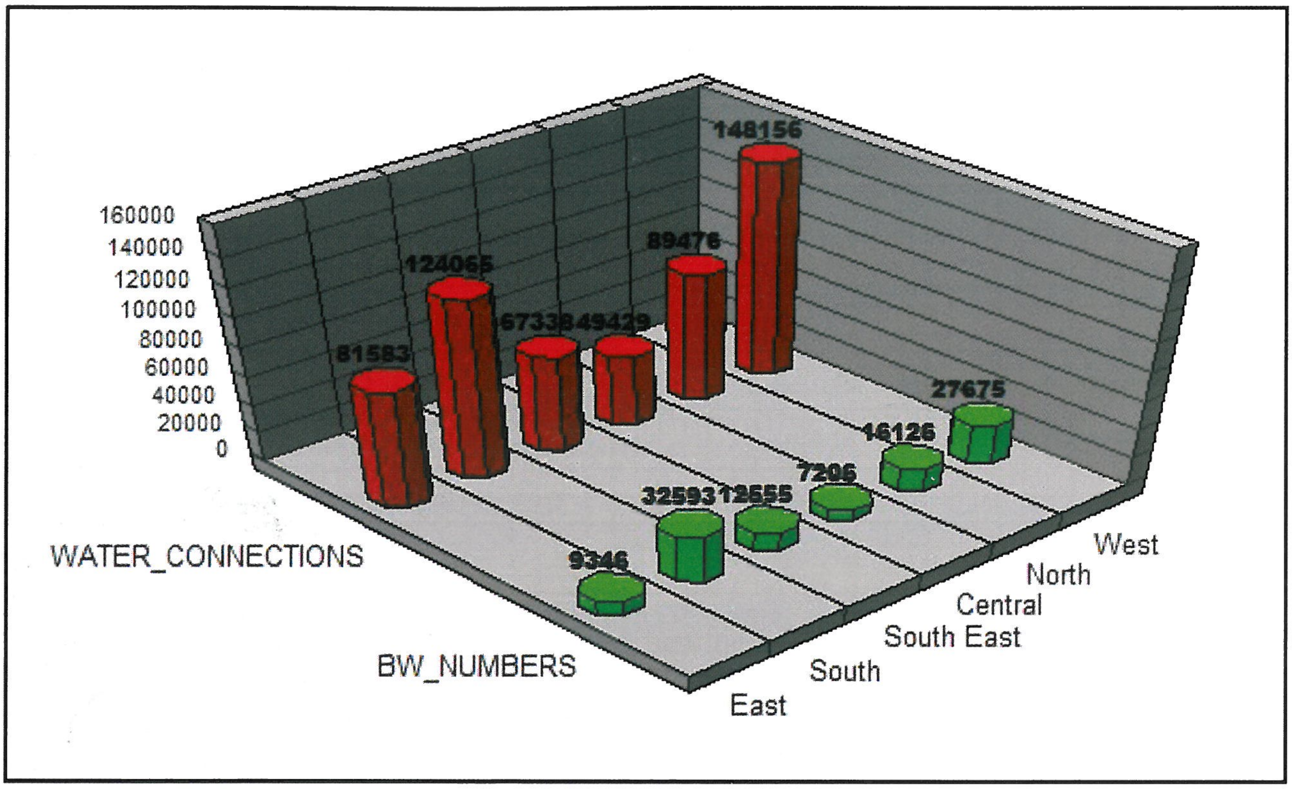



**Figure 10 : Water supply connections and borewells, 2009**

*(Source: BWSSB)*

## Impact of Lakes/Tanks on Groundwater Hydrology

Bangalore lakes are part of the local hydrologic system. The lakes built since 16th century have stood the test of time to canalise the monsoon flows. The lake water was meeting the requirement of the then population. The entire scenario changed from 1970 onwards. Preservation of lakes and maintaining appropriate ecosystem came in danger through unprecedented demographic growth of the city. Bangalore gave a boost to IT industry and there on it was called 'Silicon Valley' of India. By focussing only on economic advantages, the lakes were grossly neglected ( Figure 11).

**Figure 11 : Ulsoor lake and its surroundings**

The demographic explosion has put pressure on real estate. The residential areas encroaching the drained lakes and domestic discharge into lakes caused pollution. Many lakes are now the repositories of domestic and industrial wastes and open sewage discharge. To compound the situation, there is little place for groundwater recharge within the City limits. The groundwater recharge has dropped to the lowest due to major extent of BBMP having turned into a concrete jungle.

Groundwater was once being exploited through open / dug wells or shallow bore wells. The shallow aquifers have now dried. Now most of the deep bore wells have tapped static groundwater resources. The groundwater resources in many parts available at deeper levels also are unfit for consumption. The density of bore wells in core area of 330 sq.km extent is 230 per sq.km.

## Groundwater and Bangalore city

The groundwater exploitation in Bangalore is now largely through lakhs of bore wells tapping the deep seated aquifer. The groundwater resource is fast dwindling and this is reflected by many bore wells drilled earlier having gone dry. More than 800 deep bore wells have become defunct due to various reasons.

This is quite revealing by the pace at which the scramble for groundwater exploitation is heading in Bangalore. In a span of one year (between February 2009 to January 2010), 14,483 bore wells were drilled (Table 4). The average growth of bore wells during this period is 14.88 %. The bore well registered with BWSSB in its area of operation of 330 sq.km stood at 1, 05,501. Many more bore well must have been added during 2010 calendar year. The growth of bore well in Bangalore City during 2009 along with cumulative number of bore wells in BWSSB operated area is represented graphically in Figure 12.

**Table 4 : Growth of bore wells during February 2009 - January 2010 in Bangalore city**

| Months | New bore wells added each month | Bore wells registered with BWSSB | Monthly % growth |
|---|---|---|---|
| Jan-09 | | 91018 | |
| Feb-09 | 924 | 91942 | 1.02 |
| Mar-09 | 705 | 92647 | 0.77 |
| Apr-09 | 965 | 93612 | 1.04 |
| May-09 | 1136 | 94748 | 1.21 |
| Jun-09 | 748 | 95496 | 0.79 |
| Jul-09 | 904 | 96400 | 0.95 |
| Aug-09 | 868 | 97268 | 0.90 |
| Sep-09 | 2062 | 99330 | 2.12 |
| Oct-09 | 838 | 100168 | 0.84 |
| Nov-09 | 875 | 101043 | 0.87 |
| Dec-09 | 2699 | 103742 | 2.67 |
| Jan-10 | 1759 | 105501 | 1.70 |
| Total | **14483** | Average | **14.88** |

***(Source: BWSSB, 2010)***

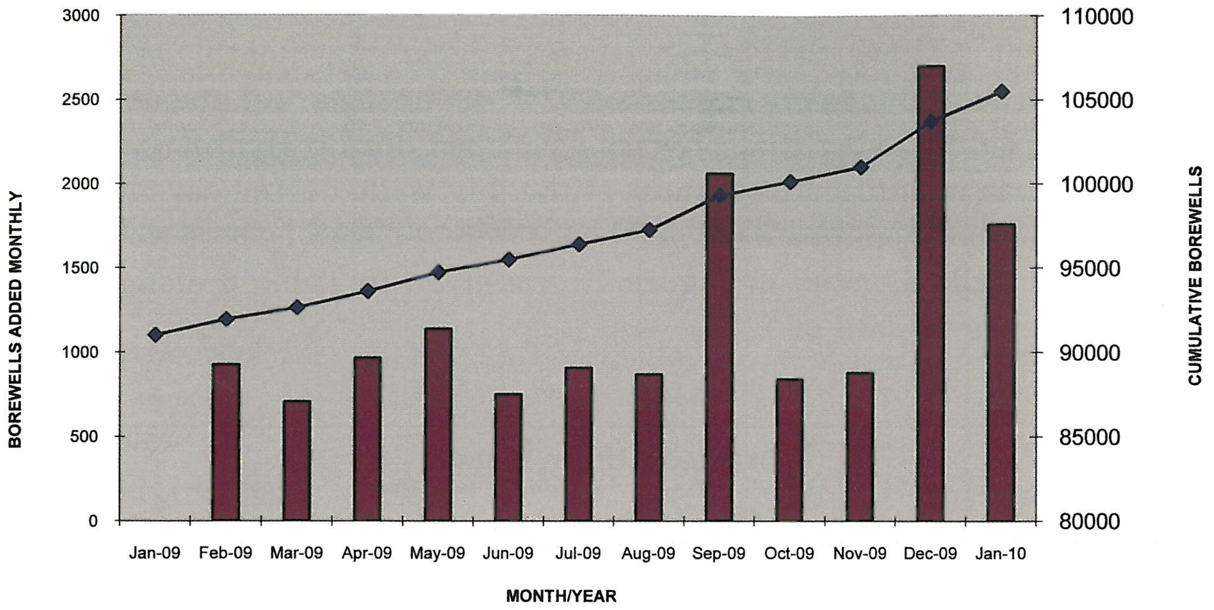



**Figure 12 : Growth of Borewells in Bangalore City During 2009**

*(Source: BWSSB, 2010)*

There is a tremendous pressure on this natural resource to meet the domestic, industrial and commercial water supply demands. Demographically, Bangalore city is on the path of high growth since 1970s. It is also depending on groundwater to meet ever increasing demand.

## Groundwater level fluctuations

The Department of Mines and Geology has been monitoring monthly groundwater levels in and around Bangalore city since 1973/74. The historical and current data are computerized by using the software developed during Hydrology Project I. The water levels monitored from most of the dug wells during seventies of the last Century became non-functional and hence were replaced by bore wells. Details of monitoring wells as cited in Figure 13 are given in Table 5 along with pre monsoon water level data of 1975.

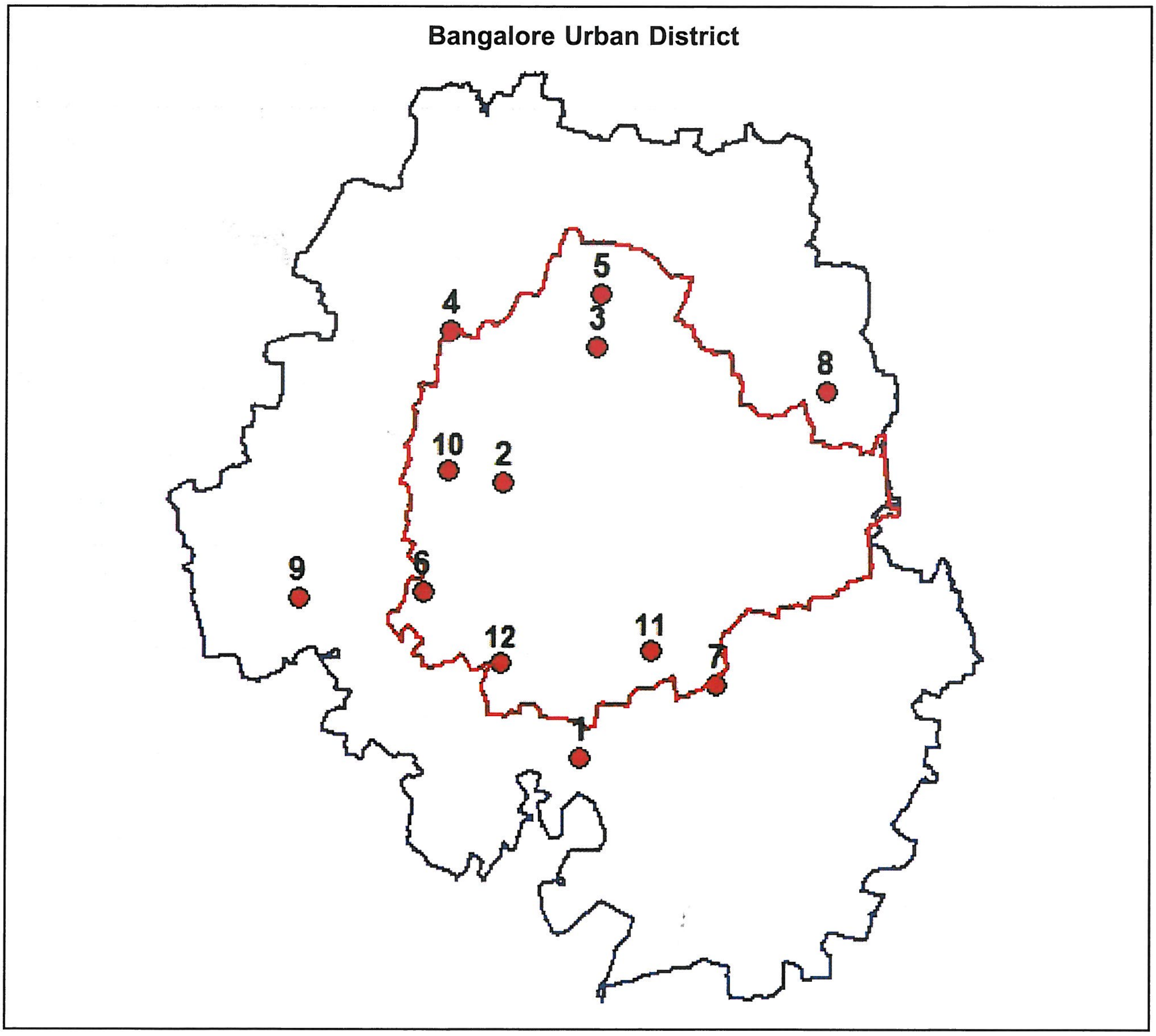



**Figure 13 : Bangalore Urban District, BBMP area and monitoring wells (numbered)**

## Table 5 : Observation dug wells

| Sl. No | Location | Year of commencement | Elevation (m) above MSL | Depth (m) | Dia (m) | Steining (m) | Water level monitored upto month/year | Pre monsoon water level - 1975 |
|---|---|---|---|---|---|---|---|---|
| 1 | Bannerughatta | 1973 | 920.00 | 13.60 | 2.70 | 8.00 | 11-1992 | 9.93 |
| 2 | Thimmenahalli | 1974 | 882.00 | 9.75 | 2.10 | 9.00 | 6-1991 | 4.62 |
| 3 | Byatarayanapura | 1974 | 902.60 | 14.25 | 10.40 | 14.00 | 6-1985 | 10.38 |
| 4 | Chikkabanavara | 1974 | 879.00 | 26.69 | 1.75 | 20.00 | 12-1990 | 21.91 |
| 5 | Yelahanka | 1974 | 893.00 | 11.00 | 3.50 | 11.00 | 6-1981 | 10.17 |
| 6 | Kengeri | 1974 | 808.00 | 11.05 | 2.10 | 11.00 | 6-1989 | 9.21 |
| 7 | Konappana agrahara | 1974 | 920.00 | 13.00 | 2.90 | 13.00 | 9-1987 | 4.62 |
| 8 | Avalahalli | 1974 | 875.35 | 17.80 | 2.55 | 12.00 | 6-1985 | 8.87 |
| 9 | Kethohalli | 1973 | 810.00 | 10.90 | 1.85 | 10.00 | 12-1999 | 8.40 |
| 10 | Byadarahalli | 1972 | 876.20 | 18.00 | 2.30 | 16.00 | 8-1991 | 15.67 |
| 11 | Begur | 1973 | 900.00 | 9.40 | 2.50 | 9.00 | 10-2000 | 7.46 |
| 12 | Talaghatpura | 1974 | 863.00 | 16.00 | 2.50 | 14.50 | 5-1993 | 9.97 |

The groundwater levels for pre and post-monsoon period for the year 2010, monitored through piezometers are furnished in Table 6.

## Table 6: Pre-monsoon and post-monsoon depth to water level(m), 2010

| Sl. No | Location | Pre-Monsoon (m) | Post-Monsoon (m) |
|---|---|---|---|
| 1 | Bannerughatta | 10.52 | 5.85 |
| 2 | Thimmenahalli | 4.80 | 3.12 |
| 3 | Byatarayanapura | 10.30 | 7.20 |
| 4 | Chikkabanavara | 22.01 | 21.35 |
| 5 | Yelahanka | 10.75 | 8.03 |
| 6 | Kengeri | 9.30 | 8.94 |
| 7 | Konappana agrahara | 4.85 | 3.98 |
| 8 | Avalahalli | 9.30 | 6.94 |
| 9 | Kethohalli | 8.98 | 4.05 |
| 10 | Byadarahalli | 16.01 | 12.10 |
| 11 | Begur | 8.27 | 3.82 |
| 12 | Talaghatpura | 10.31 | 9.92 |

By the year 2009-10 all the observation dug wells were replaced by bore wells as many of the monitoring stations were lost in road widening or buildings.

Bangalore northern and eastern region is covered by thick saprolite and hence the recharge to groundwater is limited and depletion of water level is faster. Many bore wells in these regions have gone dry and consequently the population depends on water supply through tankers. The regular water supply system by BWSSB and corporation is yet to reach these areas.

In case of monitoring stations located in Bannerughatta, Thimmenahalli, Avalahalli, Kethohalli, Talaghatpura and Yelahanka, the water levels have declined. In certain pockets, there has been transformation of these areas from agricultural base to urban agglomeration.

## Correlation of Bore Well Depth with Total Dissolved Solids and Fluoride in Groundwater

Apart from collection of groundwater samples from bore well/dug well, the investigation included collection of other details like depth of bore wells, casing depth, yield of bore wells, lifting device etc. Deeper bore wells are more in SE, SW and Northern parts of the BBMP area.

The bore well depth data is projected as inverted surface plot in 3D (Figure 14) which exhibits the different zones where the deeper bore wells are ventured. In Figure 14, the red colour represents deepest bore well zones beyond 230 m. This is followed by purple colour representing between 160 m to 230 m and blue represents between 60 m to 160 m. The shallowest depth in green colour occupies very small zone is upto 60 m depth. In earlier years of bore well advancement, shallow zone was the common depth considered.

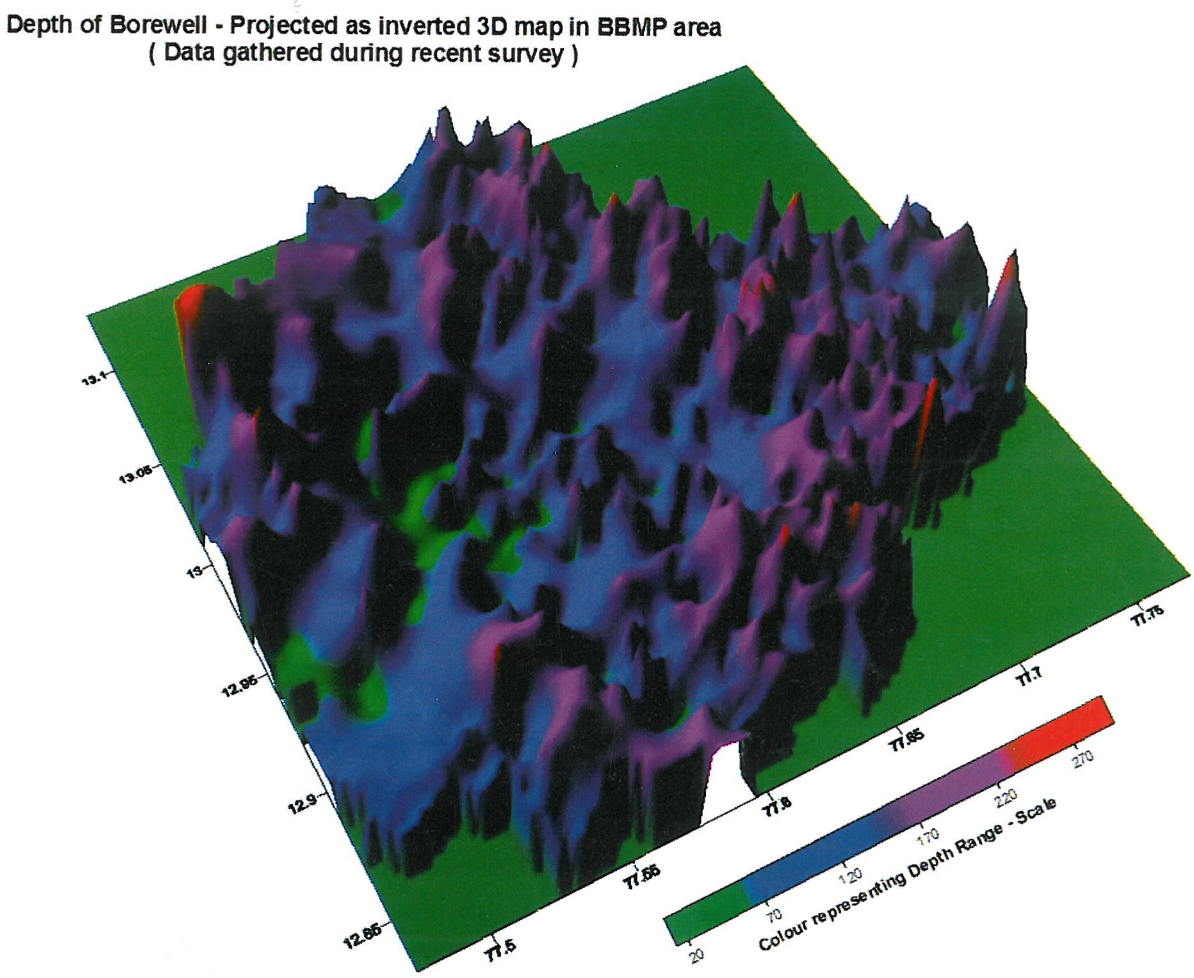



Figure 14 : Depth of bore well projected as inverted 3D surface

The frequency range of depth reflects that more than 54 % of bore wells are between 100 m and 200 m depth. About 30% of bore well are below 100 m depth range. More than 300 m depth range bore wells are 0.56%. But, 200 m to 300 m depth range accounts to 14.62% (Figure 15).

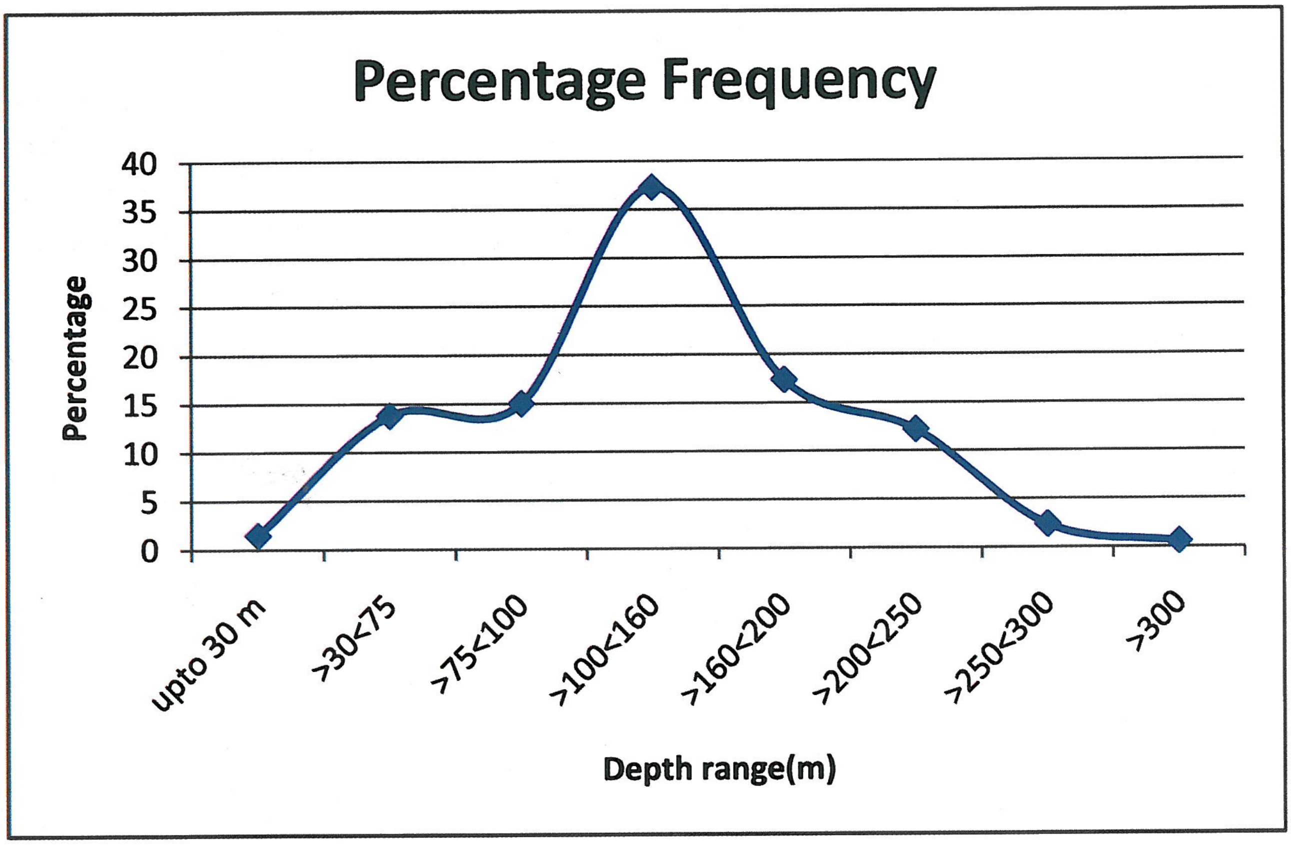



**Figure 15 : Percentage Frequency curve for different depth ranges of bore wells from study area**

## Total Dissolved Solids

There are several factors that affect groundwater quality. Longer the duration groundwater moves through the rocks or sediments, the more mineralized it becomes. Generally, water in recharge zones has a low level of mineralization than in the discharge areas. Deeper bore wells comparatively have higher levels of total dissolved solids.

Groundwater salinity is directly dependent on the concentrations of Na+ and Cl- ions, which is derived from interaction of water with soil and rock. High TDS values of 5970 mg/L and 2580 mg/L were obtained from N19 and Q25 grids respectively. Fig 16 shows the distribution of groundwater samples where the TDS value is more than 1000 mg/L.

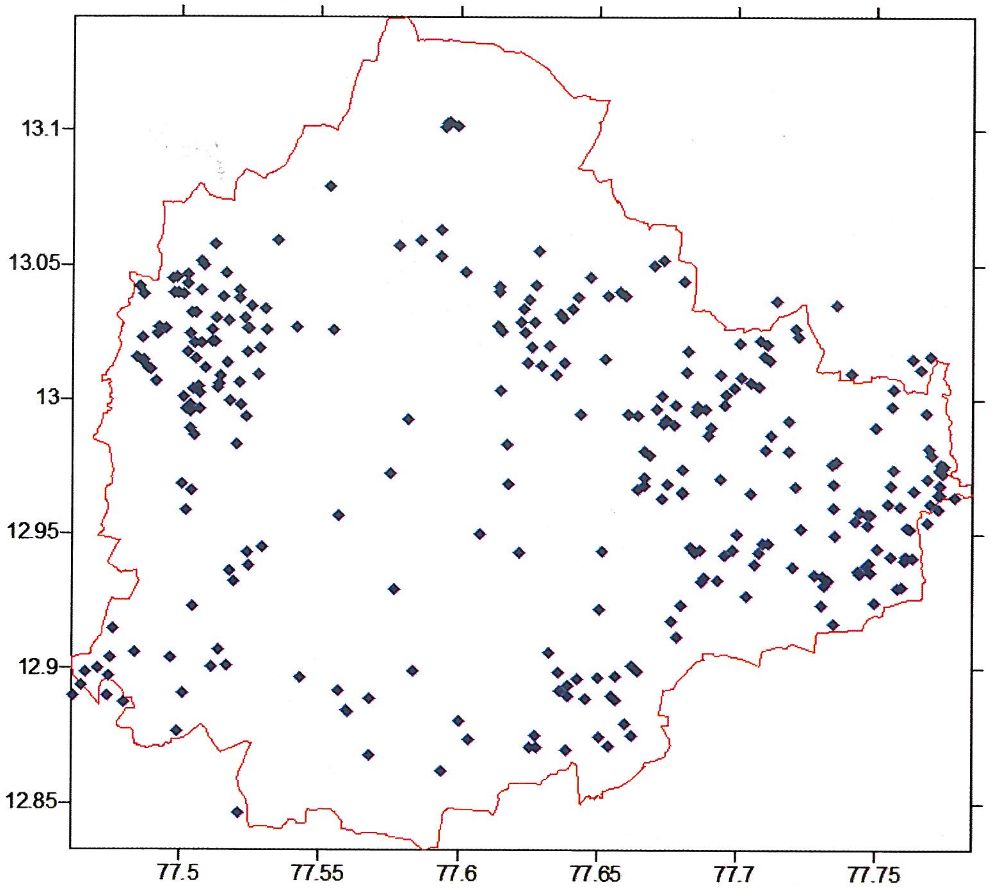



**Figure 16 : Total Dissolved Solids (>1000mg/L) in BBMP area**

Out of 2137 ground water samples, about 14.60 % have analysed TDS of more than 1000 mg/L. Figure 16 reveals that SE zone accounts for 33.0 %, followed by NE zone and NW zone with 27.5 % and 25.54 % respectively where the TDS is more than 1000mg/L. The SW is a zone with low content of TDS as compared to the rest of the area. Significantly this correlates with depth of bore well analysis as shown in Figure 14.

## Groundwater and Fluoride

Quality of groundwater is in general dependent upon the types of soil, weathered depth and mineralogy of rock formations. Concentration of fluoride in groundwater depends on the geological, chemical and physical characteristics of aquifers. Rock chemistry, geological structures, hydrological condition, groundwater age and residence time are some of the important factors of F rich groundwater. The presence of high HCO3, Na, and pH favour release of F from aquifer matrix into groundwater.

The data obtained on the depth of bore well is further correlated with the fluoride concentrated area. Some of the samples analysed from South East, North East and South West grids reflected the presence of fluoride more than the permissible limit. To know the extent of its lateral distribution sampling was extended to neighbouring grids around these vicinities and also from deeper bore wells (Figure 17).

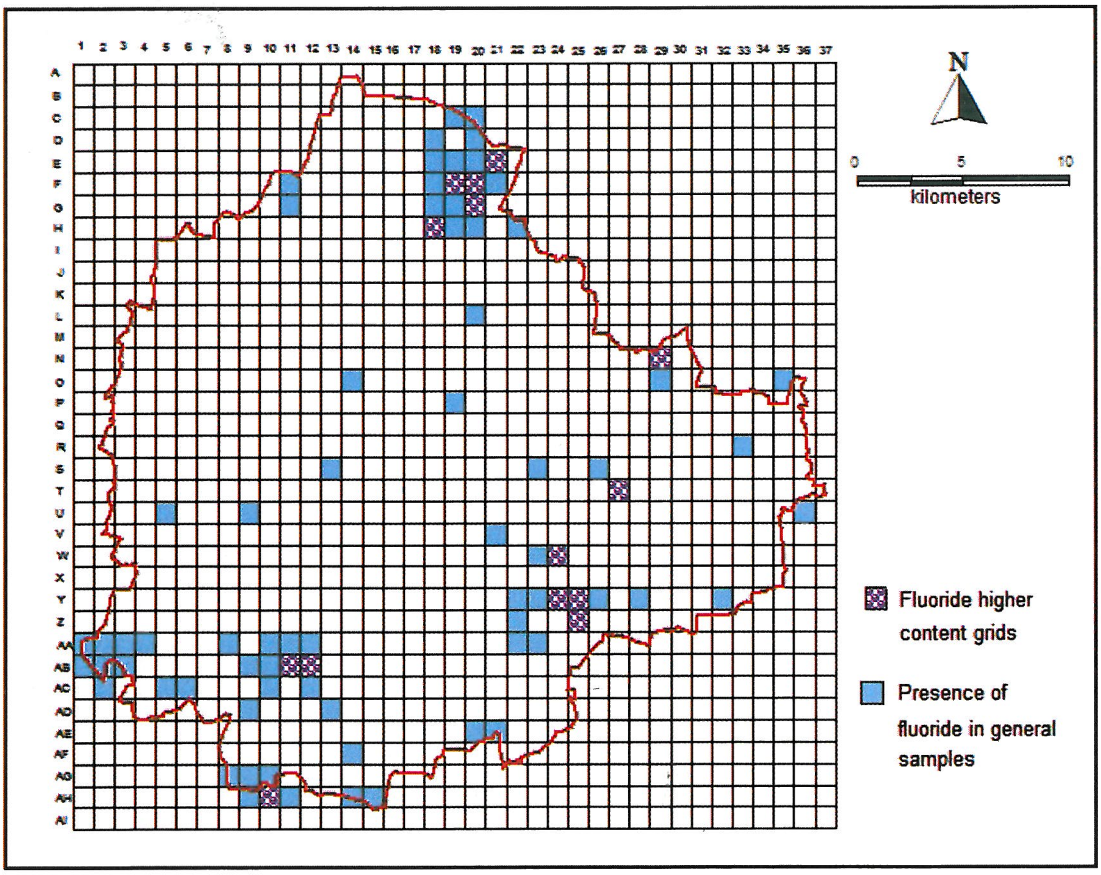



**Figure 17 : Fluoride in Groundwater, BBMP area**

Highest fluoride content of 5.54 mg/L near Bellandur was analysed in groundwater. Because of this more number of samples around these grids was collected. As a result, three zones are identified where the fluoride concentration is above the drinking water standard of 1.5 mg/L (Figure 17).

## Groundwater Hydrology

The Bangalore Urban District comprises of crystalline basement, mainly gneisses and granites intruded by basic dykes. These formations have altered to laterite along the eastern fringe of the city. The weathered mantle shall be the zone to transmit water through fractures. The depth of weathering is often pronounced along the linear features.

The weathered zone and the underlying sparsely fractured fresh rock form the aquifer system in the area. Recharge to the system will be through the shallow weathered zone, into deeper fractured rock.

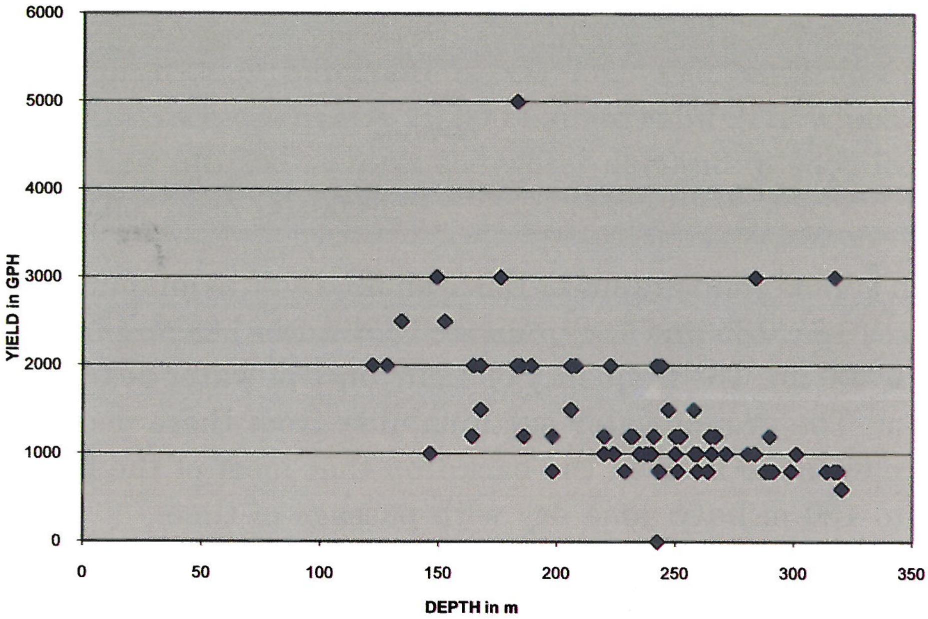



**Figure 18a : Depth versus Yield of bore well, Dasarahalli area**

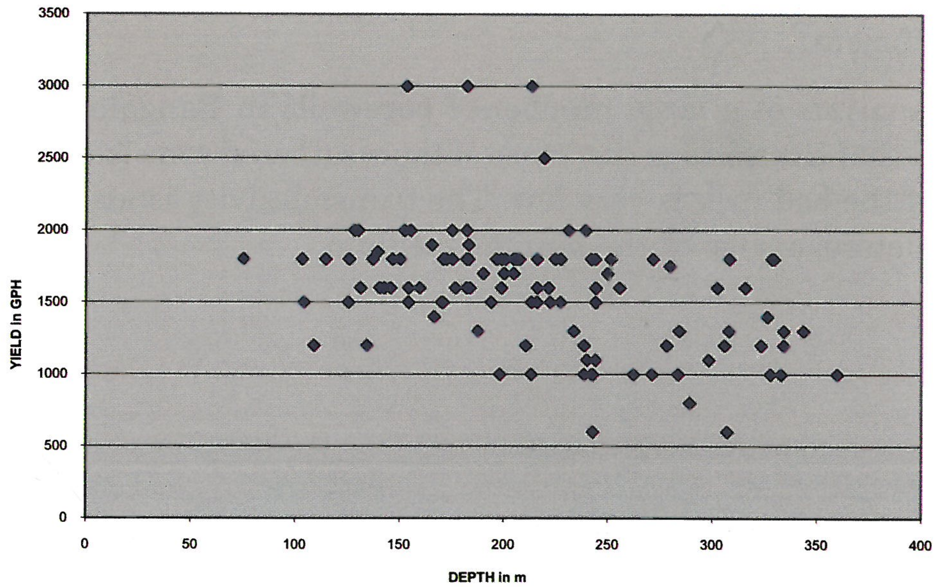



**Figure 18b : Depth versus Yield of bore well, Bytarayanapura area**

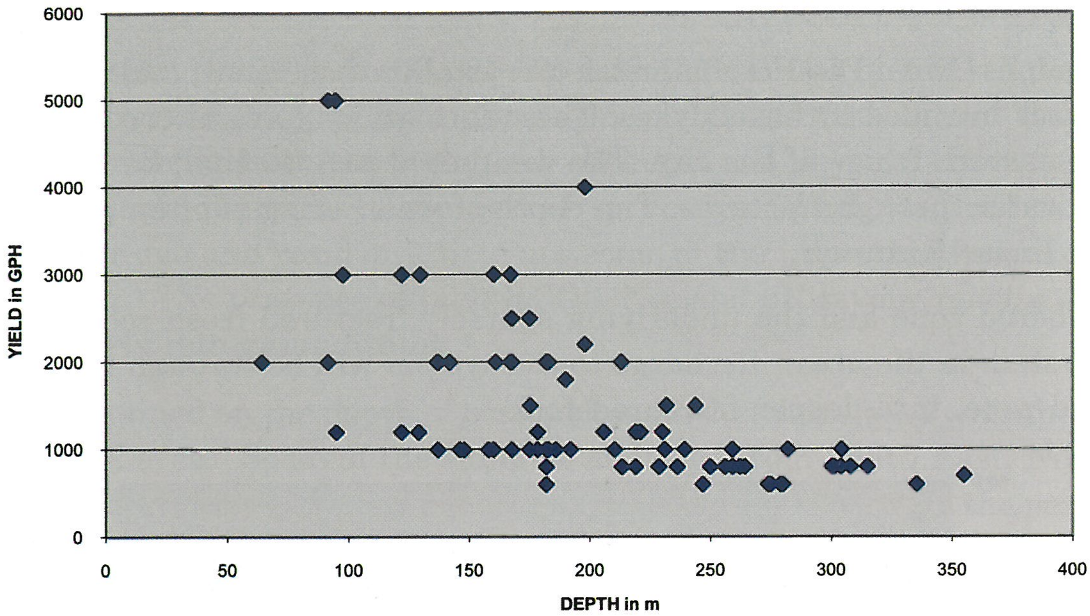



**Figure 18c : Depth versus Yield of bore well, Yalahanka area**

The depth versus yield graphs of Dasarahalli, Bytarayanapura and Yalahanka CMCs (Figures 18a, 18b and 18c) indicate that water bearing fracture zones are upto 250 m to 300 m. The frequency of occurrence of water bearing zone declines beyond 250 m. The groundwater sustainability from these deep sources are at stake. It is relevant to keep in the backdrop that most of the bore wells drilled upto 150 m to 180 m have gone dry with passage of time.

Saprolite a clay rich weathered material derived from prolonged in situ decomposition of parent rock is tens of metres thick in the eastern part of Bangalore city. As this is rich in clayey material, it generally displays very low permeability of the order of 10-6 m/s, and generally sustains low yield and low storage coefficient.

Statistical analysis of a large number of borewells in Bangalore urban district has revealed that the average thickness of the weathered zone is 10 m. The storage coefficient of the bed rock is very low. The transmissivity is also highly variable because of heterogeneity of the aquifer medium.

## Groundwater availability and utilization

Bangalore city is located at an altitude of over 920 meters above mean sea level and forms a part of water divide of the Arkavathi Sub basin towards west the South Pinakini or South Pennar towards east.

In the absence of major perennial surface water resource nearby, the city at several location/layouts depend on groundwater resource for daily requirements. The main supply from the Cauvery river to Bangalore is from a distance of 98 km. This Cauvery river water supply is since inadequate to meet the increasing demand, over exploitation of groundwater by the enlarging city agglomerates' has further resulted in fast decline of groundwater level.

The average precipitation of Bangalore is 900 mm. The Bangalore city, over an extent of 800 sq. km. receives nearly 72,000 ham of rainfall of which atleast 50% can be conserved and utilized to meet the water demand in such locality where water supply has not been initiated.

The groundwater recharge is worked out on certain assumptions by considering the extent of BBMP area. The total recharge for entire city is 3075 ham.

## Groundwater Utilization

For computation of groundwater utilization, the data on existing dug wells/bore wells in the Bangalore Urban agglomeration is very essential. Different departments like BWSSB, KEB, City Corporation etc., though were contacted to obtain realistic data on number of wells/bore wells, hours of pumping, yield of bore wells etc. the same were not available from any of the agencies. However, BWSSB, seven CMC's and one TMC area provided some data on the existing bore wells located in core area maintained by them. Apart from it, information was also obtained about number of private bore wells registered with them. After considering the above available data from BWSSB, the groundwater draft of the entire city area is worked out at 8169 ham.

The groundwater exploitation estimation in the city area is arrived at after obtaining information from private water suppliers on the average hours of pumping, average yield and average number of trips the water supply is made by them per day. Thus, it is very difficult to asses the actual draft, as these parameters vary from season to season and is solely demand driven. It is reported that the peak demand could be from March to July or August of every year. However considering all these aspects, the draft of groundwater is more than twice the dynamic groundwater resources i.e. available for exploitation annually in the extended BBMP area.

The total recharge assessed for the newly constituted BBMP area includes return infiltration from the lakes. The assessment of groundwater resource in the extended BBMP area of Bangalore city indicates that the resource is over exploited. Consequent to this over exploitation, the quality of groundwater has also deteriorated. The groundwater resource exploitation must be restricted to the dynamic groundwater resource available during the year.

## Artificial Groundwater Recharge

The demand for water is mainly due to population pressure and higher scale of social and economic activity. Groundwater level is declining drastically in the last three decades resulting in drying up of open wells and shallow bore wells.

The only remedial measure to overcome the problem of over exploitation is to conserve rain water and to have a judicious approach while using the water resources.

In recent years the groundwater development is from the fractured aquifers occurring at different depths between 100 m to 300 m. Recharge to the aquifers should be such that the infiltration reaches the deep seated fracture system. It is necessary to identify the location where recharge methods have to be implemented. Geological investigation may come handy for such identification. The information in regard to fractures, their depth etc. need be obtained mainly by geophysical investigations or from the local enquiry from the public/ house owners.

The data available with BWSSB (for the core area of 330 sq.km) reveals that the average density is 320 bore wells per square kilometer. The newly added area of 380 sq.km and its habitations are solely dependent on ground water. The density of bore wells must be still high in these areas. The total number of bore well may be about 2.25 lakh. However, the same data could be extrapolated to these areas in the absence of any reliable and accurate data for analysis purpose. The uninhibited drilling of bore wells is a pointer of the city slipping to the brink of a major groundwater crisis.

To reduce the impact of over exploitation of groundwater and consequent drying up of aquifers in the city, the BWSSB brought out legislation and made mandatory to implement some of the measures by property owners. This is known as "The Bangalore Water Supply and Sewerage (Amendment) Act, 2009". It envisages that "Every owner or occupier who has constructed building in the site area of 2400 square feet and above whether for residential / non residential / Government/ Commercial and any other purposes shall provide rain water harvesting structures within nine months from the date of commencement of the amendment Act 2009 in the following manner".

i. Roof top rainwater shall be harvested through a storage tank or recharged through an open well or a bore well in the building irrespective of the nature of sub-soil conditions.

ii. Land based rain water from the open spaces around the buildings/ gardens parks shall be harvested using appropriate groundwater recharge structures depending on the nature of the sub-soil conditions.

Similarly, the same conditions also apply to new constructions with site area of 1200 square feet and above. Apart from teething problems of aquifer acceptance, this is one of the steps towards restoring the damage caused to the natural groundwater aquifer system. Therefore roof top rain water harvesting measures are to be strictly implemented as per "The Bangalore Water Supply and Sewerage (Amendment) Act, 2009"

To overcome the onslaught of over exploitation of groundwater, various other measures of artificial recharging of groundwater by active participation of different civic agencies and other concerned faculties are needed. Important considerations are to observe geohydrological features of the location where the recharge structures are to be implemented.

## Restoration of lakes or tanks and Rainwater Harvesting

The benefit from restoration of lakes is huge. Hence, in the first instance it is necessary to divert and bypass the sewage water flowing into the lakes. Only unpolluted rainwater is to be made to flow into these lakes. This storage after mandatory treatment and filtration could be a supplementary supply to residential complexes. Some of these measures could be in the regions where BWSSB has not yet initiated its regular water supply.

Due to the constraint of available open space in the city area, the parks and other huge open premises are to be considered for recharge measures.

The infiltration galleries when to be provided can be of rectangle, square, circular etc. Walls of these infiltration galleries could also be designed in such a way that the water infiltrates through them without causing any sub surface erosional problem.

Part II

# Evaluation of Groundwater Quality in and around Bangalore City

G.V. Hegde and M.V. Shashirekha

## Introduction

Water quality is as important as the quantity of water in water resource management. The suitability of water for different purposes will be decided on its quality. The water quality studies yield useful information of the environments in which water is circulated. The rain water through soil/rock interaction alters its chemistry. Groundwater sample analysis provides important clue about the chemical characteristic of water of the sampled area. The present study is to obtain comprehensive information on the quality of groundwater of Bangalore City.

Under the Purpose Driven Studies (PDS) of the World Bank Aided Hydrology Project Phase-II, a comprehensive study entitled "Groundwater Hydrology and Groundwater Quality of Bangalore City" was taken up by the Department of Mines and Geology, during the period from 2008-09 to 2010-11. To achieve this objective, the study area was divided into northwest (NW), northeast (NE), southeast (SE) and southwest (SW) quadrants. Each quadrant was further divided into one square kilometer grid (Fig. 1). Depending upon the availability of groundwater based structures, two to three water samples were collected from each grid. Over 3000 groundwater samples were collected and got analyzed for its quality in the Laboratory at Directorate of Mines and Geology, Bangalore.

## Previous work

The earlier studies conducted on groundwater quality of Bangalore City by the Department are:

1. Urbanization and its effects on Environment-Groundwater pollution by sewage in the Vrishabavathi valley near Bangalore Metropolis-A case study; Gaikwad, R.L. et al. (1994, Groundwater studies 260).
2. Evaluation of Groundwater Quality Bangalore Metropolis; Shivashankar, T.M and Vijaya Bhaskar Reddy, R. (1995 - Groundwater studies 287)
3. Interpolation of Groundwater Quality of Bangalore urban Agglromeration; D.Srikantamurthy (1998 - Groundwater studies 397)
4. Status of Groundwater Quality in and around Bangalore and its environs; Basappa Reddy, M. (2003, Groundwater studies 426).

These studies indicated the pollution of groundwater through sewage effluents. Because of groundwater contamination due to sewage and waste disposal and occurrence of fluoride in groundwater, a systematic investigation of hydrogeology and water quality of Bangalore city aquifers was taken up.

# Methodology

## A. Sample Collection

Sample collection formats were designed for recording the field data. Sample locations were recorded using Global Positioning System (GPS). Totally, 3456 water samples were collected during the pre-monsoon period of 2010, over an area of 800 sq km in a grid pattern as already mentioned. Groundwater samples so collected were from bore wells and dug wells in use (Fig. 1, Fig. 2 and Table 1).

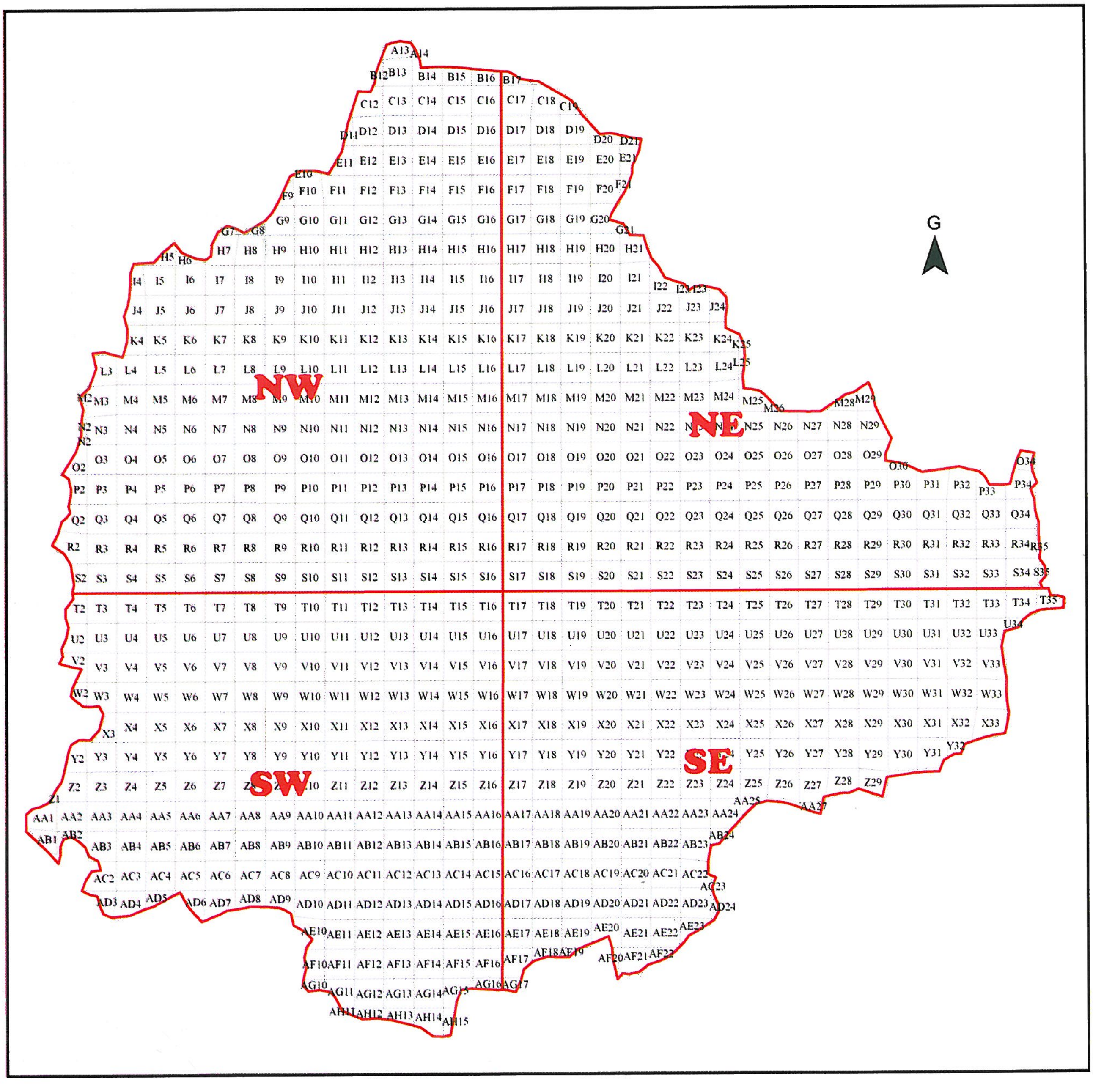



Figure 1 : Grid Map, Bangalore City

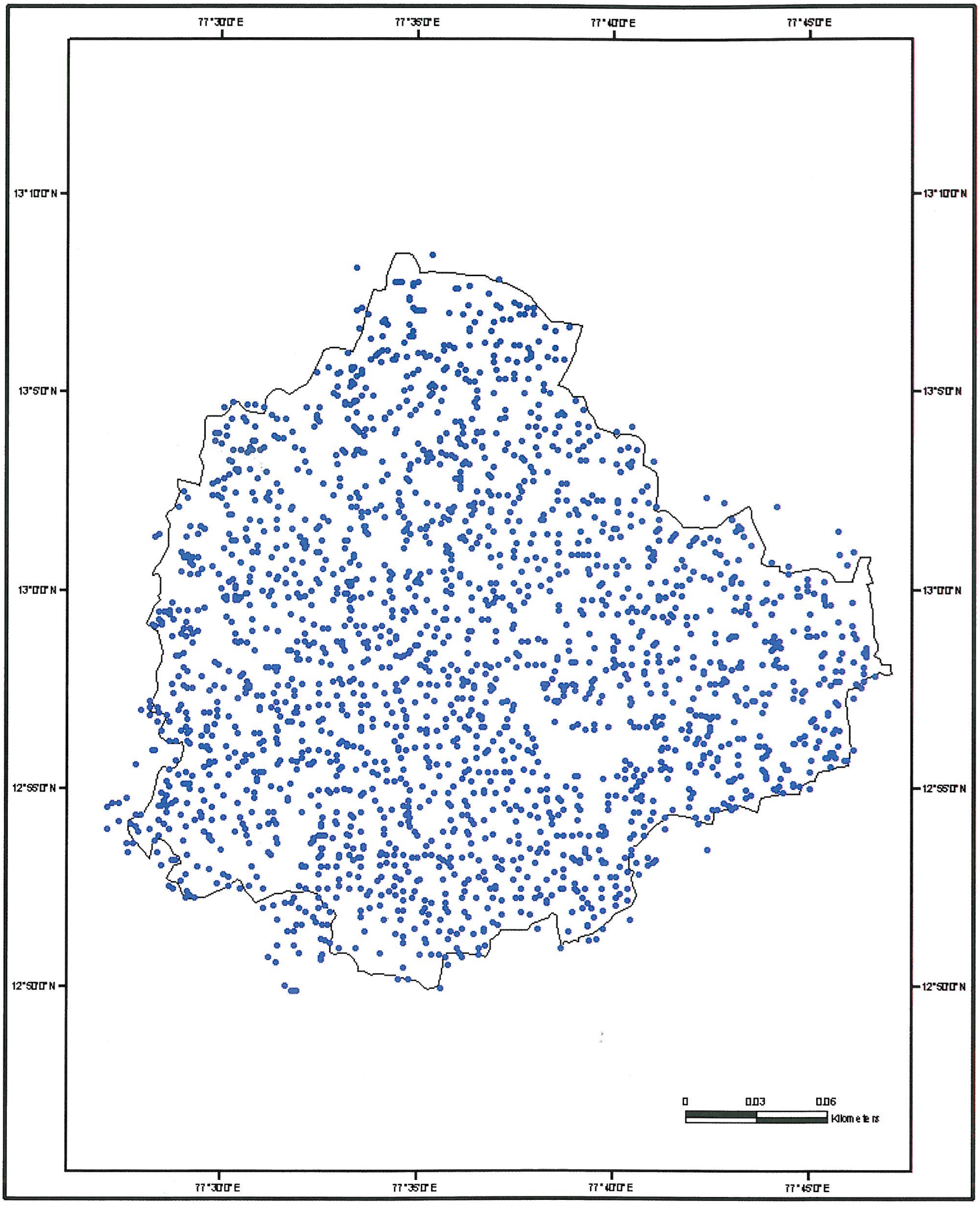



**Figure 2 : Location of water samples collected, Bangalore city**

**Table 1: Statement of water samples collected**

| Type of sample | Total Grids | 735 |
|---|---|---|
| A | Groundwater samples | |
| | Samples collected for chemical parameters | 2137 |
| | Samples for biological analysis | 269 |
| | Samples exclusively for fluoride analysis | 279 |
| | Samples exclusively for heavy metal analysis | 276 |
| | Repeated samples | 97 |
| | Samples for determination of contamination from Petroleum products (oil/grease) | 11 |
| B | Surface water samples (Lakes and Tanks) | |
| | Total Lake/Tank samples | 384 |
| | Sewage effluent samples | 3 |
| | **Total water samples collected for analysis(A+B)** | **3456** |

The water sample bottles were thoroughly rinsed with water to be sampled and packed under air tight condition. On field, the physical parameters like odour, colour, temperature, pH were determined for all the samples and Dissolved Oxygen (DO) only in case of lake water samples. Water sample collected were chemically analysed within 24 hours. A few samples were re-collected for reconfirmation of the results. The geochemical, bacteriological and heavy metal analysis results of groundwater samples were utilized for generation of geochemical maps in the GIS environment using Arc GIS software.

## B. Chemical Analysis

Determination of Calcium and Magnesium were by EDTA titrations method, Sodium and Potasium by flame emission photometry, total iron(Fe) by Phenanthroline Spectrophotometry, Bicarbonate and Carbonate by titrimetry, Chloride by Argnetometric titration, Nitrate by UV Spectrometry, Sulphate by nephelometry, Total Dissolved Solids by gravimetry, Total Hardness by potentiometry, fluoride by ion selection electrode method. Representative samples collected for bacteriological contamination were analyzed for faecal coliforms by electrical temperature fermentation and total coliforms by standard multiple tube fermentation, and determined by adopting Most Probable Number (MPN) method. The heavy metals like zinc, copper, lead, manganese, chromium, aluminum in groundwater samples were determined by Atomic Absorption Spectrometer. Suspected contamination of groundwater by petroleum products due to

## Table 2 : Range of Chemical constituents in Groundwater of the Study area

| Constituents | Min | Max | Avg |
|---|---|---|---|
| Ca | 3 | 688 | 93.00 |
| Mg | 1 | 295 | 30.06 |
| Na | 6 | 1099 | 100.15 |
| K | 0.04 | 346 | 7.20 |
| Fe | 0.001 | 48.5 | 0.51 |
| $HCO_3$ | 25.1 | 900 | 292.68 |
| $CO_3$ | - | 38 | 13.95 |
| Cl | 8 | 2394 | 167.54 |
| $NO_3$ | 0.05 | 554 | 38.11 |
| $SO_4$ | 0.03 | 895 | 72.40 |
| TDS | 60 | 5970 | 682.72 |
| TH | 16 | 2720 | 353.21 |
| F | 0.05 | 5.32 | 0.39 |
| SC | 80 | 9850 | 1159.59 |
| pH | 5.49 | 8.99 | - |

(All values except pH and SC (μmhos/cm at $25^{0}$C) are in mg/L. n=2209)

## Table 3 : Minimum, maximum and average values for Bore well and dug well water samples

| Constituents (mg/L) except pH and SC | Borewell | | | Dugwell | | |
|---|---|---|---|---|---|---|
| | Min | Max | Avg | Min | Max | Avg |
| Ca | 3 | 688 | 93.11 | 30 | 283 | 91.5 |
| Mg | 1 | 295 | 30.36 | 4 | 150 | 22.8 |
| Na | 6 | 1099 | 98.69 | 22 | 524 | 135.8 |
| K | 0.04 | 284 | 6.70 | 0.36 | 346 | 19.2 |
| Fe | 0.001 | 48.5 | 0.50 | 0.01 | 23.66 | 0.7 |
| $HCO_3$ | 25.1 | 900 | 290.99 | 123 | 860 | 334.6 |
| $CO_3$ | - | 38 | 14.38 | - | 0 | 0.0 |
| Cl | 8 | 2394 | 166.84 | 25 | 857 | 185.6 |
| $NO_3$ | 0.05 | 554 | 38.53 | 0.34 | 173 | 29.0 |
| $SO_4$ | 0.03 | 895 | 72.23 | 2.4 | 263 | 77.8 |
| TDS | 60 | 5970 | 679.75 | 220 | 2180 | 759.6 |
| TH | 16 | 2720 | 354.76 | 108 | 1308 | 319.7 |
| F | 0.05 | 5.32 | 0.39 | 0.09 | 1.09 | 0.4 |
| SC | 80 | 9850 | 1155.02 | 335 | 3790 | 1279.1 |
| pH | 5.49 | 8.94 | - | 6.06 | 8.1 | - |

anthropological activity was tested by adopting gravimetric method. The accuracy of the chemical analysis was verified by calculating ion-balance errors. The chemical analysis results of the water samples were further subjected to statistical analysis and the minimum, maximum and average values of the chemical composition of groundwater are given in Table 2 and 3, and the average values for major cations and anions in respect of bore wells and dug wells are shown in Fig. 3.

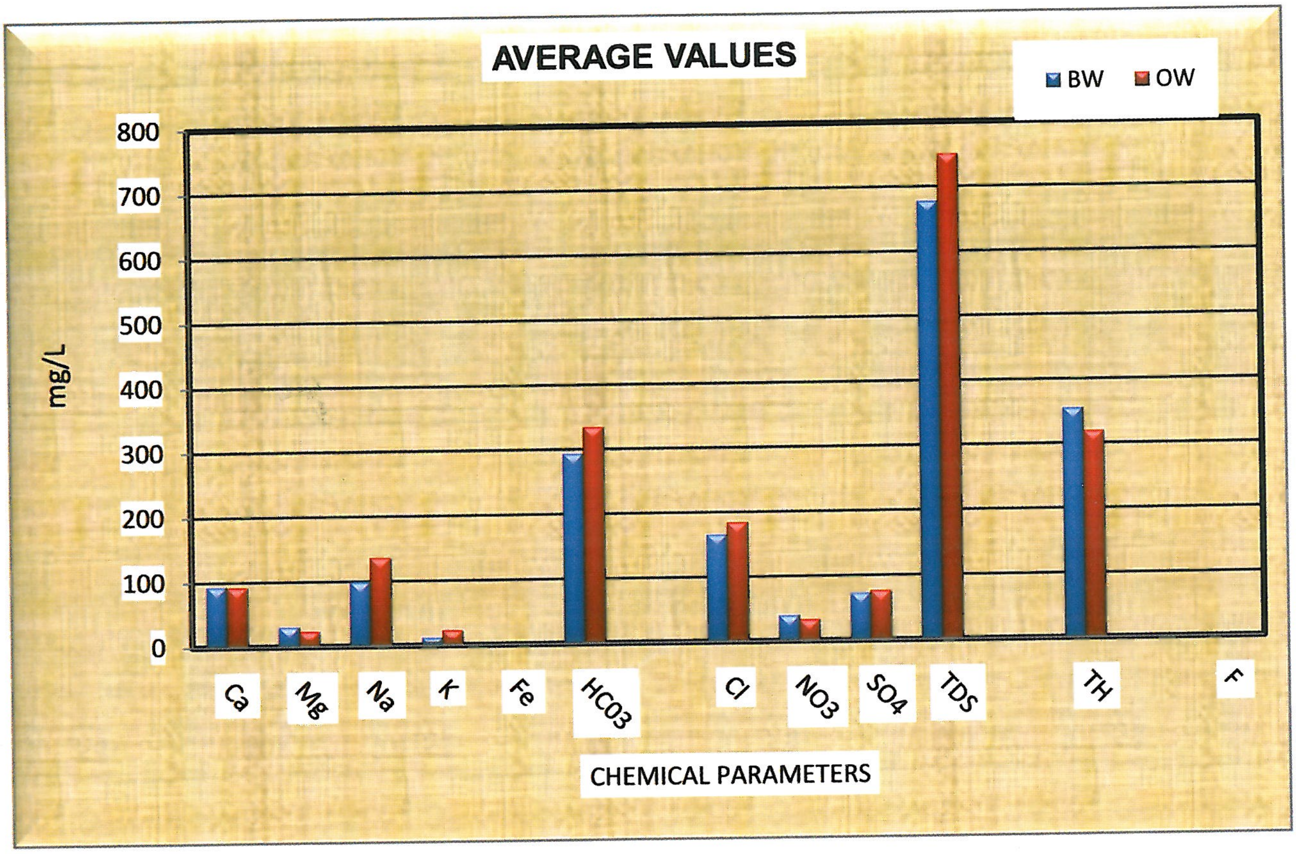



Figure 3 : Bore well and Dug well Average values

## Discussion

Drinking water need be free from colour, turbidity and micro organisms. The groundwater in the study area is mainly used for drinking, domestic and industrial purposes. A detailed analysis to determine the groundwater quality for drinking and public health purposes as per the specification issued by the World Health Organization (WHO, 1984) and Indian Standard (IS: 2003) was carried out and is provided in Table 4.

**Table 4 : Critical paramaetrs and its effect on human body**

| Sl. No | Parameters (mg/L) except pH | BIS prescribed limits IS:10500,2003 | | Probable effects |
|---|---|---|---|---|
| | | Desirable limit | Permissible limit | |
| 1. | pH | 6.5-8.5 | No relaxation | Indicative of acidic or alkaline water. affects taste and corrode water supply system. |
| 2. | Hardness as $CaCO_3$ | 300 | 600 | Affects water supply system (Scaling), excessive soap consumption calcification of arteries, may cause primary concretions, diseases of kidney or bladder and stomach disorder. |
| 3. | Iron (Fe) | 0.3 | 1.00 | Gives bitter sweet astrigent taste, causes staining of laundry and porcelain in traces it is essential for nutrition. |
| 4. | Chloride (Cl) | 250 | 1000 | May be injurious to some people suffering from diseases of heart or kidneys, taste, indigestion, corrosion and palatability are affected. |
| 5. | Total Dissolved Solids (TDS) | 500 | 2000 | Palatability decreases and may cause gastro-intestinal irritation in human, may have laxative effect particularly upon transits. |
| 6. | Calcium (Ca) | 75 | 200 | Insufficiency causes severe rickets, excess causes concretions in the body such as kidney or bladder stones and irritation in urinary passages. Essential for nervous and muscular system, cardiac functions and in coagulation of blood. |
| 7. | Sulphate ($SO_4$) | 200 | 400 | Causes gastro intestinal irritation with Mg or Na can have cathartic effect on users. Conc.more than 400mg/L along with Mg may have laxative effect. |

| | | | | |
|---|---|---|---|---|
| 8. | Nitrate ($NO_3$) | 45 | No relaxation | Causes infant methaemoglobinacmia (Blue Babies) at very high concentration causes gastric cancer and adversely affects central nervous system and cardiovascular system. |
| 9. | Fluoride (F) | 1.0 | 1.5 | Reduces dental carries, very high concentration may cause crippling, skeletal flurosis. Less than 1.0 mg/L is essential |
| 10. | Magnesium (Mg) | 30 | 100 | If sulphate is more than 400 mg/L and Magnesium exceeds 30 mg/L then it affects our Intestinal system. |
| 11. | Arsenic (As) | 0.01 | No Relaxation | Leads to gastro-Intestinal disorders like pain, vomiting, diarrhea. And also leads to cardio-vascular disorders. |
| 12. | Copper (Cu) | 0.05 | 1.5 | Astrigent taste, discoloration and corrosion of pipes, fitting and utensils will be caused beyond this. |
| 13. | Manganese (Mn) | 0.10 | 0.3 | Beyond this limit taste/appearance are affected, had adverse effect on domestic uses and water supply structures. |
| 14. | Cadmium (Cd) | 0.01 | No Relaxation | Beyond this the water becomes toxic. |
| 15. | Lead (Pb) | 0.05 | No Relaxation | Beyond this the water becomes toxic. |
| 16. | Zinc (Zn) | 5.0 | 15.0 | Beyond this limit it can cause astringent taste and an opalescence in water |
| 17. | Chromium (Cr) | 0.05 | No Relaxation | May be carcinogenic above this limit. Hydro chemical facies and groundwater classification: |

## Hydrochemical Facies and Groundwater Classification

The hydrochemical facies of groundwater is the cumulation function of soil, lithology and other factors and can be classified based on dominant cations and anions. The chemical composition of groundwater is dependent on various factors such as rock weathering, rainfall, industrial discharges etc. The dominant factor, however, is weathering of rocks. Most of the pollutants could be anthropogenic. It is evident that the dissolved ions in groundwater are from rock water interaction. The varied conditions of weathering may result in change of groundwater chemistry.

## Cation Relationship

The constituents of Na, K, Ca and Mg in groundwater are commonly from soil-rock-water interaction. However in urban area, sewage and industrial effluents change the groundwater quality to variable extent. The concentration of Na, K, Ca and Mg vary from 5.2 to 1099 mg/L(avg.100.10 mg/L); 0.04 to 4.58 mg/L (avg. 10.43 mg/L); 3.0 to 823 mg/ L(avg. 93.30 mg/ L) and 0.6 to 295 mg/ L(avg.30.1mg/ L), respectively. The percentage contribution of these cations is 43, 40, 13, and 4, respectively indicating that sodium and calcium are the dominant cations in the groundwater of the study area Fig. 4

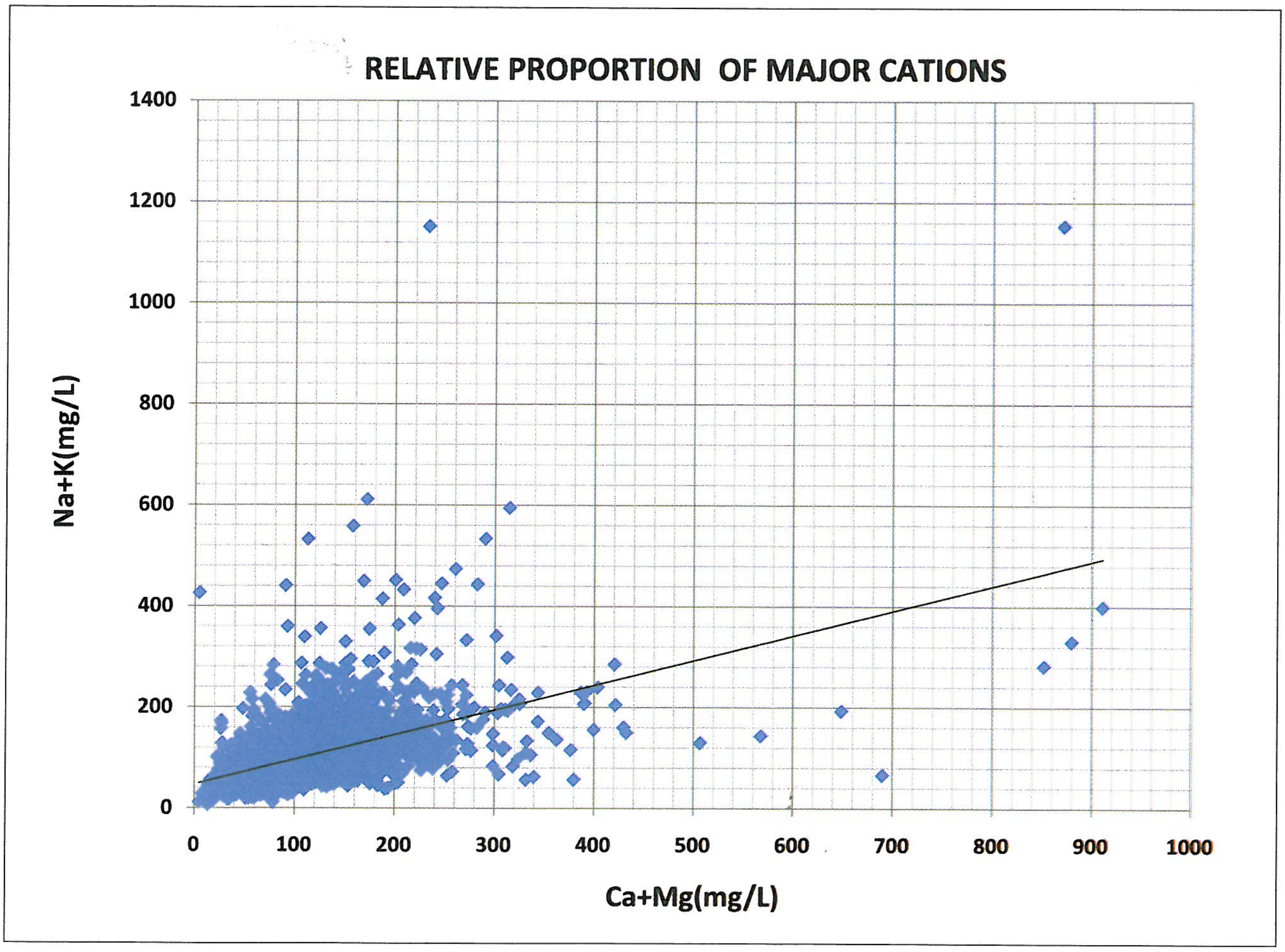



Figure 4 : Relative proportion of major cations

## Anion Relationship

Among the anionic concentrations bicarbonate varies from 25.10 mg/L to 3118 mg/ L(avg.294mg/L),Chloride from 8.0mg/L to 2394mg/L (avg.166.98 mg/L), Sulphate 0.03 mg/L to 895 mg/L (avg. 72.65 mg/L, Nitrate 0.05 mg/L to 554 mg/ L (avg.38.15mg/ L ), Carbonate 2.00 mg/ L to 38.0 mg/ L (avg.13.95 mg/L) and Fluoride from 0.05 mg/L to 5.32 mg/L (avg.0.39 mg/L ). In terms of percentage the major anions like $HCO_3$ Cl, $SO_4$, and $NO_3$ contribute 50, 25, 12 and 07, respectively. Bicarbonate is the dominant ion followed by chloride, sulphate and nitrate. The relative proportion of major anions is shown in Fig. 5. Correlation co-efficient matrix of chemical data of groundwater of the study area is given in Table 5.

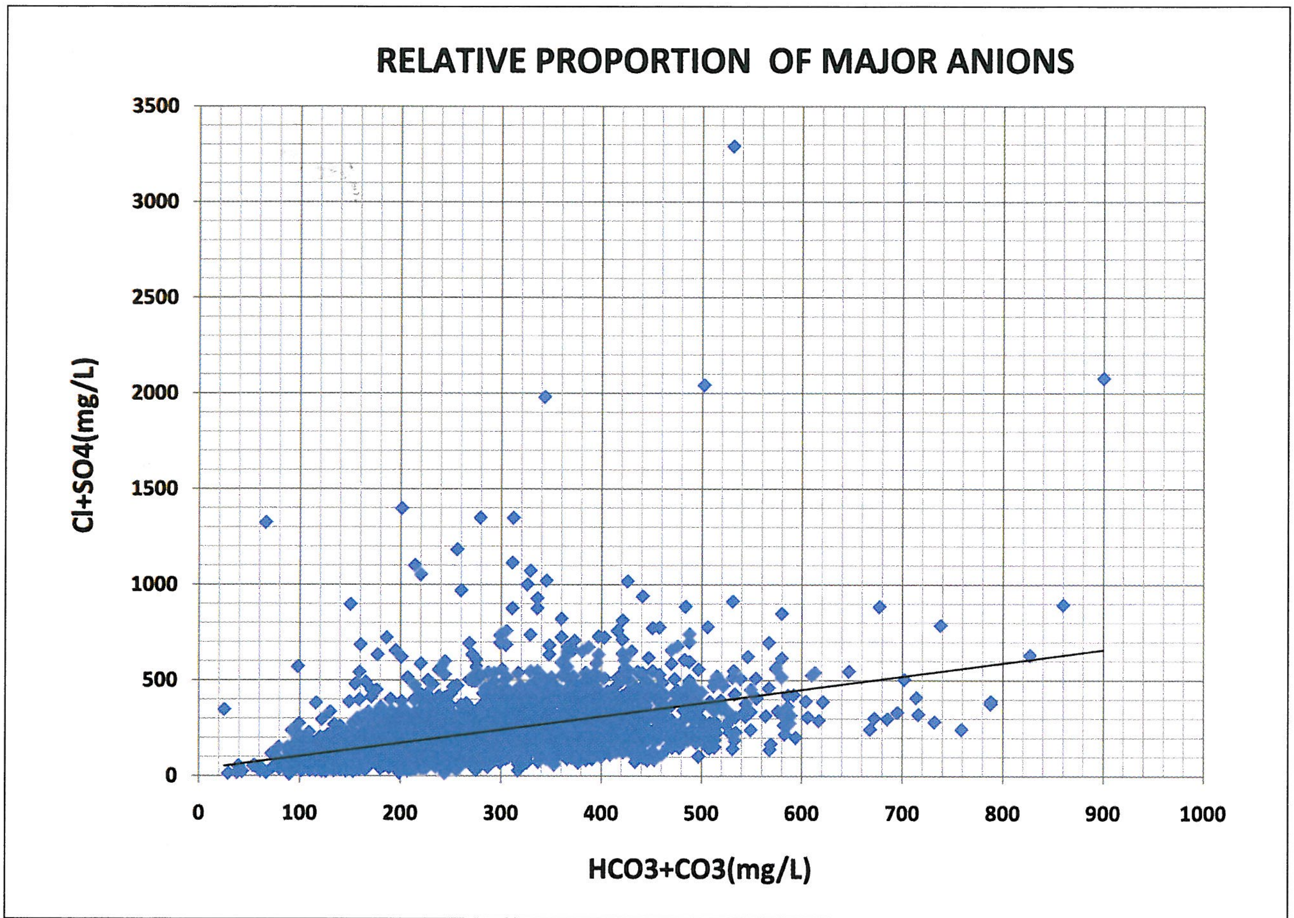



Figure 5 : Anion Concentration in Groundwater

## Relative proportion of major anions in groundwater

### Table 5: Correlation coefficient matrix of chemical data of groundwater, Bangalore City (n=2209)

| Sl. No | Ca | Mg | Na | K | Fe | $HCO_3$ | $CO_3$ | Cl | $NO_3$ | $SO_4$ | TDS | SC | TH | pH | F |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Ca | 1 | | | | | | | | | | | | | |
| 2 | Mg | 0.69 | 1 | | | | | | | | | | | | |
| 3 | Na | 0.60 | 0.27 | 1 | | | | | | | | | | | |
| 4 | K | 0.09 | 0.02 | 0.19 | 1 | | | | | | | | | | |
| 5 | Fe | -0.02 | -0 | -0.01 | -0.03 | 1 | | | | | | | | | |
| 6 | $HCO_3$ | 0.54 | 0.52 | 0.52 | 0.19 | -0 | 1 | | | | | | | | |
| 7 | $CO_3$ | 0.47 | 0.05 | 0.12 | -0.26 | 0.09 | 0.02 | 1 | | | | | | | |
| 8 | Cl | **0.89** | 0.67 | **0.72** | 0.12 | -0 | 0.37 | 0.23 | 1 | | | | | | |
| 9 | $NO_3$ | 0.31 | 0.19 | 0.35 | 0.18 | -0 | 0.04 | 0.02 | 0.30 | 1 | | | | | |
| 10 | $SO_4$ | 0.62 | 0.48 | 0.6 | 0.16 | -0 | 0.43 | 0.30 | 0.50 | 0.20 | 1 | | | | |
| 11 | TDS | **0.91** | 0.69 | **0.82** | 0.22 | -0 | 0.62 | 0.29 | 0.90 | 0.40 | 0.70 | 1 | | | |
| 12 | SC | 0.86 | 0.68 | 0.74 | 0.17 | -0 | 0.59 | 0.31 | 0.90 | 0.30 | 0.60 | **0.92** | 1 | | |
| 13 | TH | **0.94** | **0.86** | 0.52 | 0.06 | -0 | 0.57 | 0.40 | 0.90 | 0.30 | 0.60 | **0.89** | 0.90 | 1 | |
| 14 | pH | 0.01 | 0.02 | -0.01 | 0.02 | -0.10 | 0.20 | 0.67 | -0.10 | -0.20 | 0.10 | 0.00 | 0.00 | 0.00 | 1 |
| 15 | F | -0.03 | -0.00 | 0.07 | 0.03 | -0 | 0.20 | 0.28 | -0.10 | -0.10 | 0.10 | -0.00 | 0.00 | -0.00 | 0 1 |

The cationic and anionic percentages calculated based on average value for dug well and Bore well samples reveal Na>Ca >Mg>K and $HCO_3$ > Cl >$SO_4$> $NO_3$.

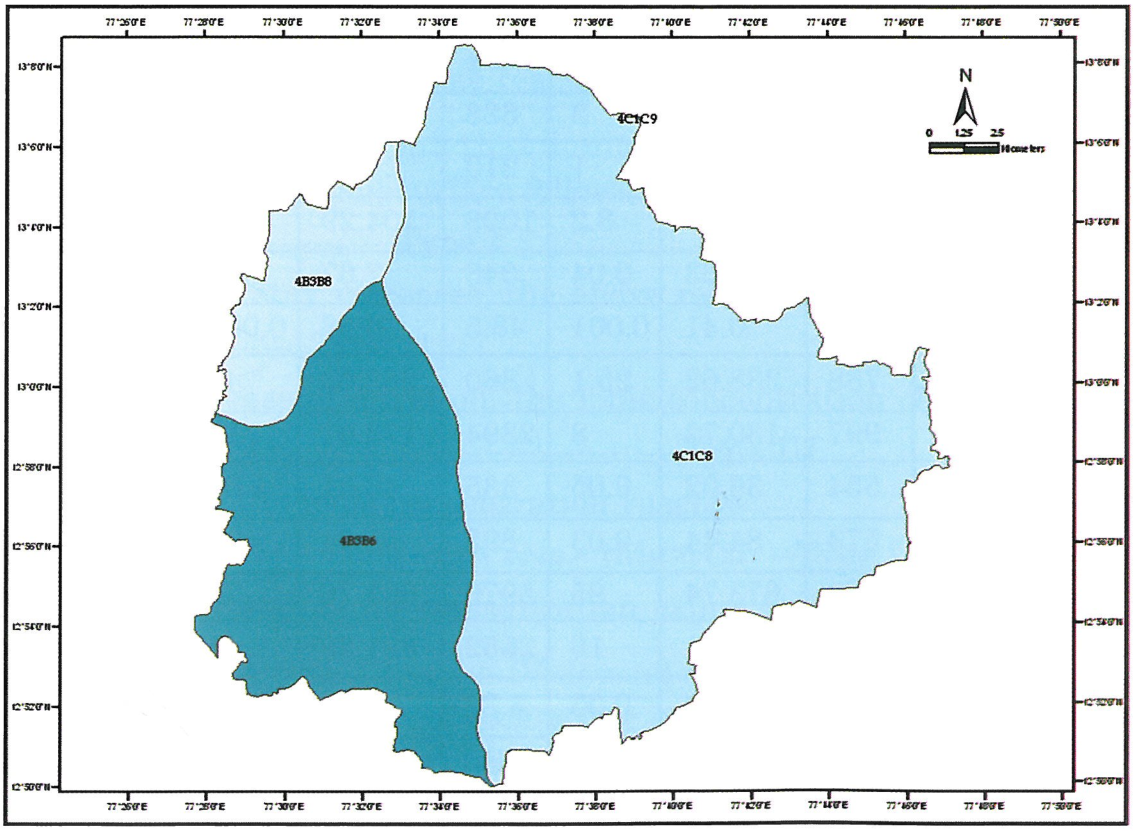



Figure 6 : Watershed Map of Bangalore City

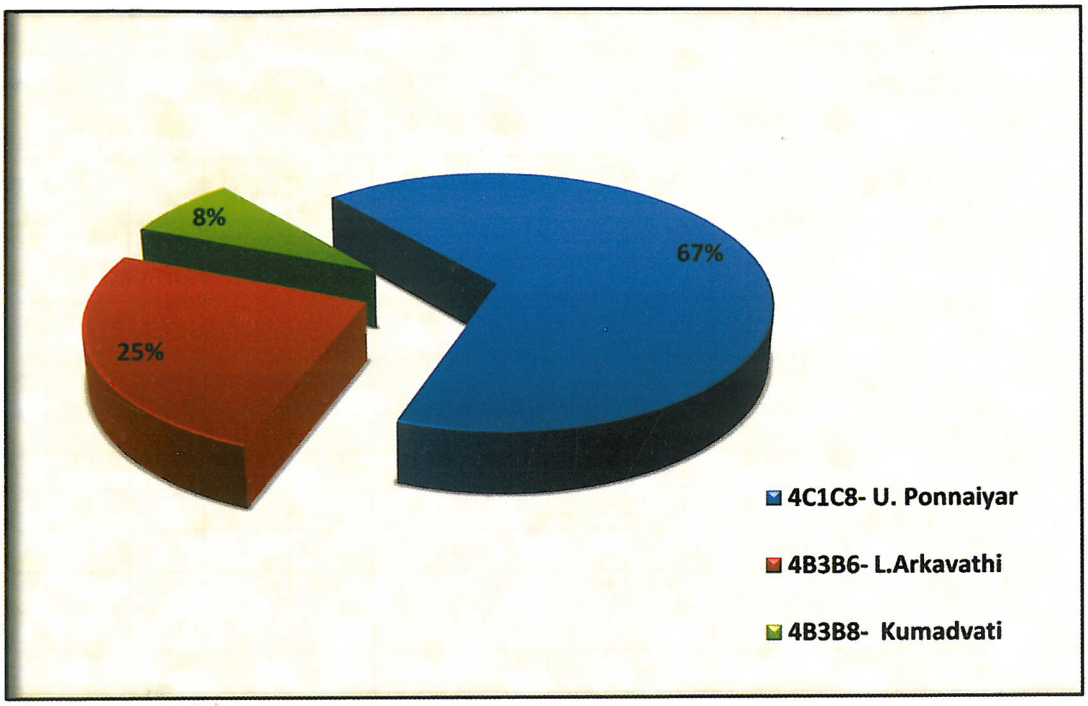



**Figure 7 : Watershed area (%), Bangalore City**

**Table 6 : Minimum, Maximum and Average values for three watersheds**

| Constituent (mg/L) except pH & SC | Lower Arkavathi 4B3B6 | | | Kumadvati (Upper Arkavathi) 4C1C8 | | | Ponniayar (South Pinakini) 4B3B8 | | |
|---|---|---|---|---|---|---|---|---|---|
| | Min. | Max. | Avg. | Min. | Max. | Avg. | Min. | Max. | Avg. |
| Ca | 10 | 312 | 90.74 | 3 | 688 | 89.66 | 10 | 680 | 140.2 |
| Mg | 4 | 156 | 35.42 | 1 | 210 | 24.20 | 1 | 295 | 63.2 |
| Na | 6 | 325 | 91.92 | 8.2 | 1099 | 104.29 | 8 | 385 | 100.6 |
| K | 0.52 | 226 | 6.63 | 0.04 | 346 | 7.67 | 1.29 | 43.6 | 7.3 |
| Fe | 0.004 | 18.4 | 0.41 | 0.001 | 48.5 | 0.58 | 0.001 | 10.44 | 0.4 |
| $HCO_3$ | 38 | 788 | 338.62 | 25.1 | 860 | 263.63 | 43 | 900 | 356.3 |
| Cl | 8 | 997 | 130.72 | 8 | 2394 | 173.01 | 17 | 1870 | 290.0 |
| $NO_3$ | 0.06 | 554 | 36.02 | 0.05 | 335 | 40.01 | 1.09 | 180 | 38.9 |
| $SO_4$ | 2.7 | 573 | 84.44 | 0.03 | 895 | 65.04 | 4.4 | 400 | 101.1 |
| TDS | 60 | 1860 | 673.74 | 95 | 5970 | 661.76 | 70 | 4035 | 959.8 |
| TH | 40 | 1308 | 369.41 | 16 | 2552 | 321.28 | 44 | 2720 | 605.3 |
| F | 0.09 | 2.73 | 0.48 | 0.05 | 5.32 | 0.36 | 0.061 | 0.72 | 0.3 |
| SC | 105 | 3340 | 1152.60 | 80 | 9850 | 1111.82 | 120 | 7210 | 1703.1 |
| pH | 6.32 | 8.39 | - | 5.49 | 8.94 | - | 6.39 | 8.3 | - |

As already mentioned, there are three main watersheds namely, Ponniayar (4C1C8) in the eastern part of the city covering 67 % of the area, Arkavathi (4B3B6) in the southwestern part which covers 25% of the area and Kumadvathi (4B3B8) in the northwestern part covering a small area of 8% of the study area(Fig. 6 and Fig. 7). The minimum, maximum and average values for three watersheds are given in Table 6.

The major Constituents based on average value for the three watersheds show:

(a) Na>Ca>Mg>K and $HCO_3$>Cl> $SO_4$>$NO_3$ relationship for Ponniayar and Arkavathi watersheds and

(b) Ca>Na>Mg>K and $HCO_3$>Cl> $SO_4$>$NO_3$ relationship for Kumadvathi watershed.

Thus based on the cation - anion percentage, the groundwater of Bangalore city is categorised as "Na-Ca and $HCO_3$-Cl-$SO_4$ facies in the order of dominance"

The "Indices of base exchange" (IBE) also known as "Chloro- Alkaline Indices" (CAI) were calculated for bore well and dug well samples and also for all the three watersheds separately, to know the process of ionic exchange during rock-water interaction by adopting the formula proposed by Schoeller (1977):

CAI 1 = Cl- (Na + K) / C1 and

CAI 2 = Cl- (Na + K) / ($SO_4$ + $HCO_3$ + $NO_3$)

Positive CAI values noted for most of the groundwater samples suggest that the sodium and potasium from water are exchanged with calcium and magnesium in the rock following Base Exchange reactions (chlro-alkaline equilibrium).

Schoeller (1967) pointed out that ionic concentration during the stay of groundwater within the subsurface follows the order:

$rHCO_3$ > $SO_4$ ----------------- Type I

As the duration of stay increases, the above relation changes to

r $SO_4$ > rCl ------------ Type II

With further increase of duration, the ionic concentration charges to

rCl > r $SO_4$ > $rHCO_3$ ---------------------------- Type III

In the final stage the ionic concentration reaches

rCl > r $SO_4$ > $rHCO_3$ along with rNa> rMg>rCa --Type IV

(Where r stands for concentration expressed in epm)

These changes from type I to type IV depend on the residence time of water in the subsurface and the extent of rock-water interaction. As per Schoeller (1967) classification, the groundwater of the study area belong to type I category where $rHCO_3$ > r $SO_4$. The study has thus indicated that Na-Ca and $HCO_3$ - Cl - $SO_4$ facies dominated in the area.

## Potability of Groundwater

The quality of drinking water is mainly referred to pH, Total Hardness as $CaCO_3$, Total Dissolved Solids, $NO_3$, Fe and F apart from heavy metals and possible bacteriological contaminations. The water suitability for drinking purposes is categorized based on the specifications of WHO and IS standards - 2003.

## Hydrogen Ion Concentration (pH)

The pH the hydrogen ion concentration in water, from which the acidic or alkaline nature of water can be determined.

The pH of groundwater in the study area varies from 5.49 to 8.94. A total of 94.30% of the samples have pH ranging from 6.5 to 8.5. The water with pH value less than 6.5 (which exists in 5% samples) and more than 8.5 (that exists in only 0.70% of samples) which are acidic and alkaline, respectively are not potable. The variation in pH value of groundwater of the study area is attributable to lithological factors and also due to the anthropogenic activities.

Location wise and zone wise variation of pH value in groundwaters of Bangalore is shown in Fig. 8, Fig. 9 and Fig. 10.

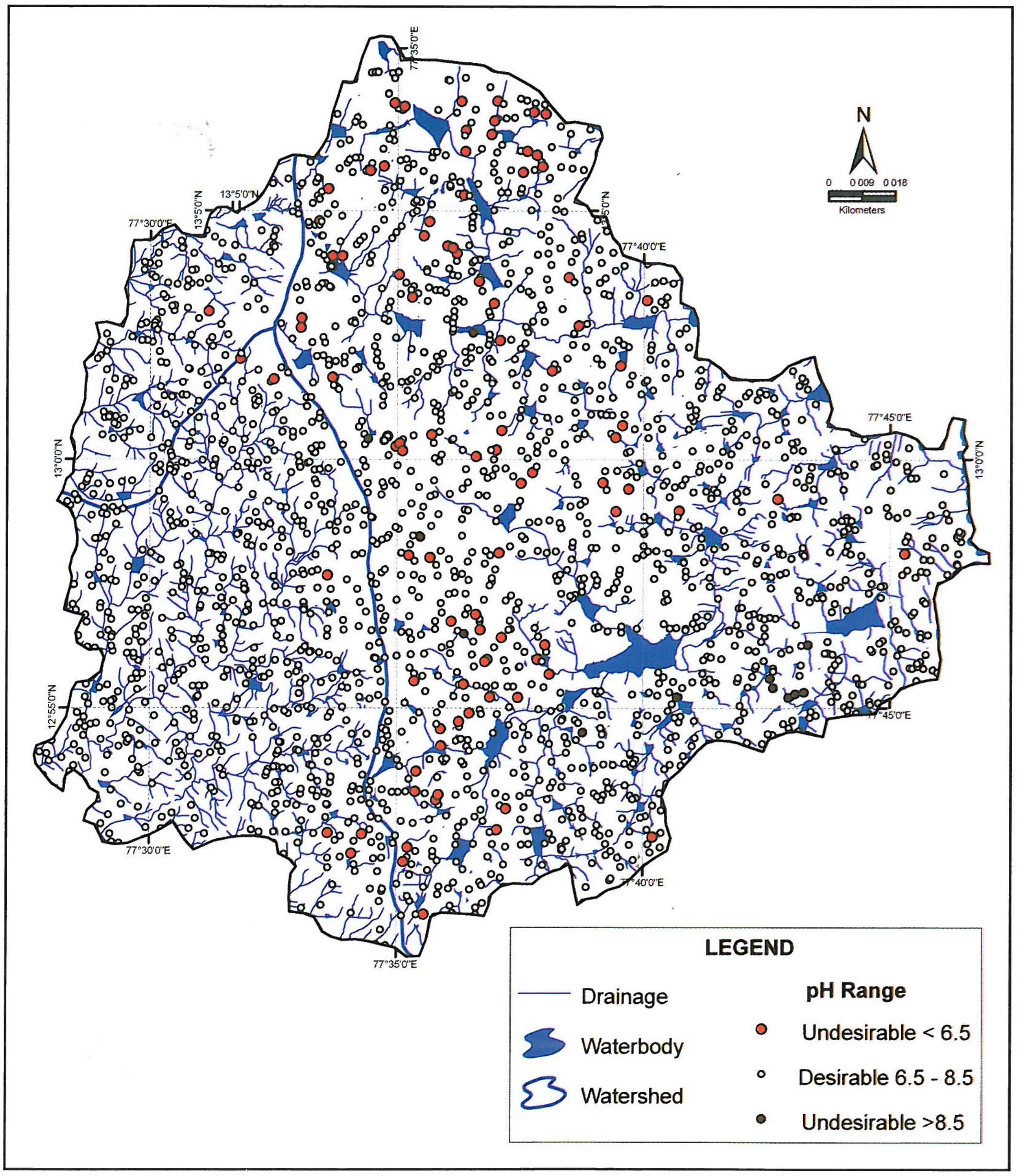



**Figure 8 : Groundwater pH, Bangalore City**

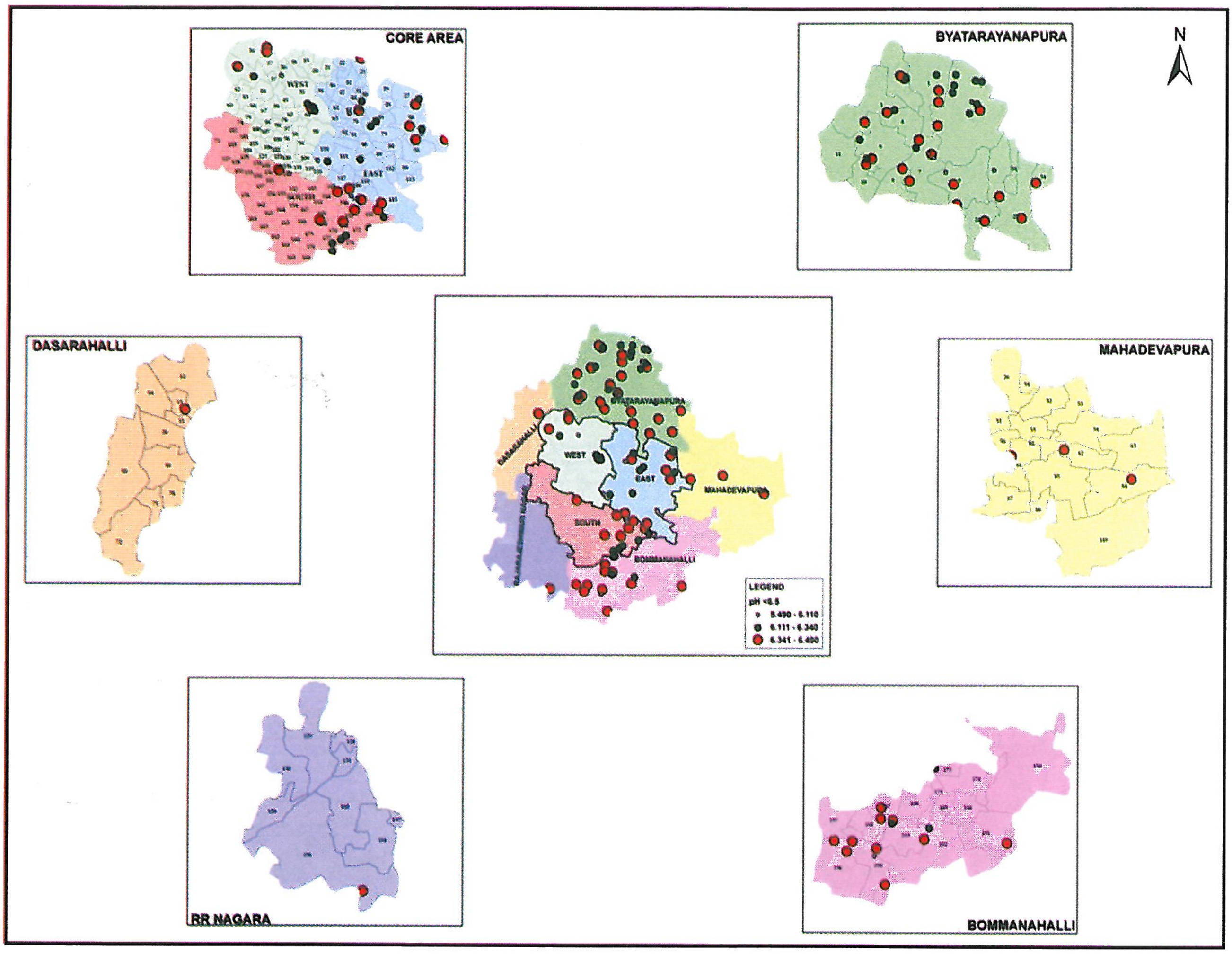



Figure 9 : Zone Wise Groundwater quality based on pH (<6.5)

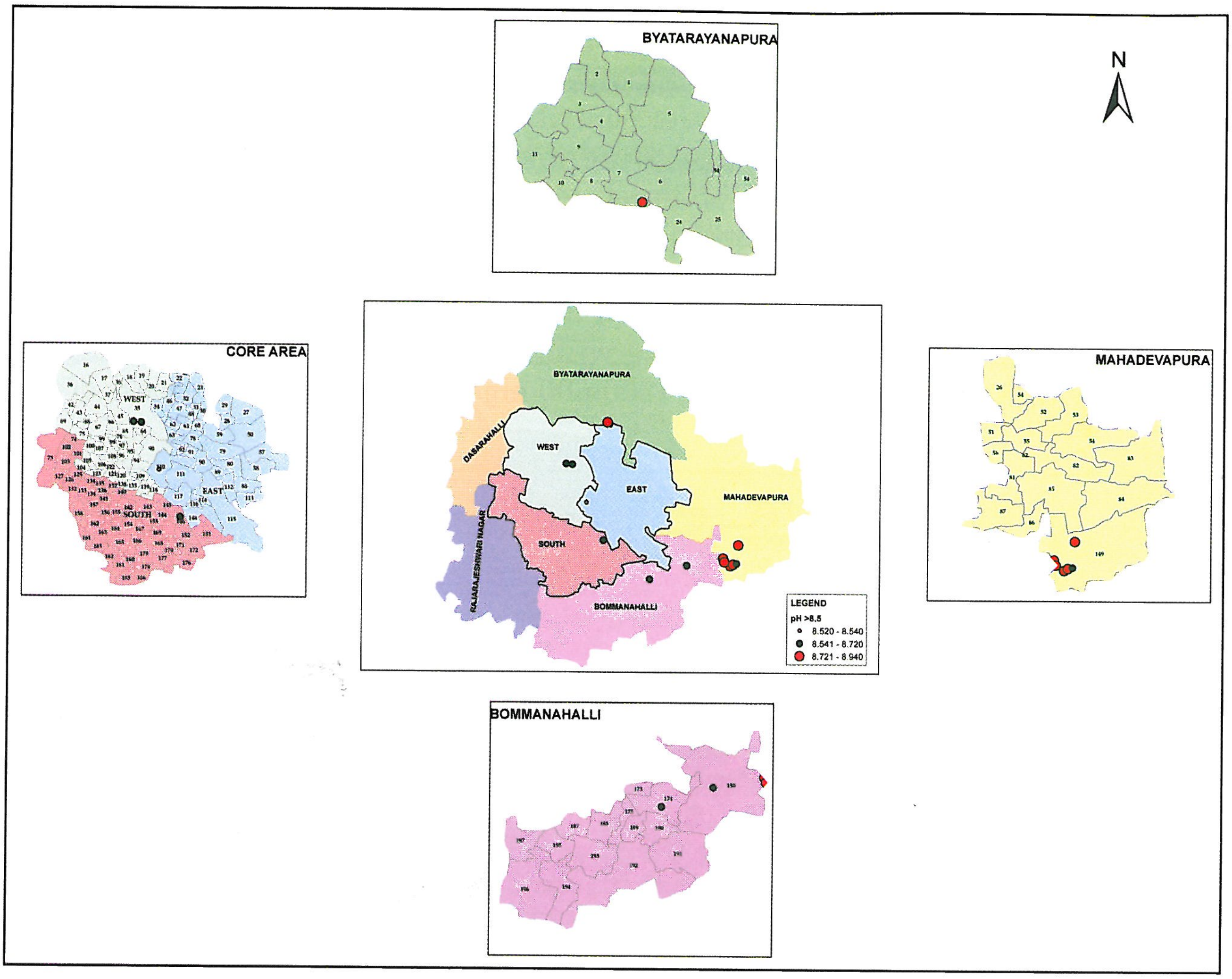



**Figure 10 : Zone Wise Ground Water Quality based on pH (>8.5)**

Fig. 9 and Fig. 10 show that the undesirable limits of pH (< 6.5 and > 8.5) shown in red color, are more seen in Ponnaiyar water shed at eastern part of the study area.

## Total Hardness (TH)

Hardness in water is mainly due to dissolved calcium and magnesium salts. The calcium and magnesium in hardwater contributes to the encrustation that may developed due to changes in temperature and pressure. The bicarbonate ions exist in groundwater as a result of dissolved carbondioxide. The bicarbonates of Ca and Mg cause carbonate hardness (temporary hardness) and the sulphate and chlorides cause non-carbonate hardness (permanent hardness). Total Hardness range from 16 to 2720 with an average of 354 (mg/L). Out of 2210 samples that were analysed, 45% of the samples are within the desirable limit (<300 mg/L), 46% are within the permissible limit (300-600 mg/L) and only 9% in excess of the

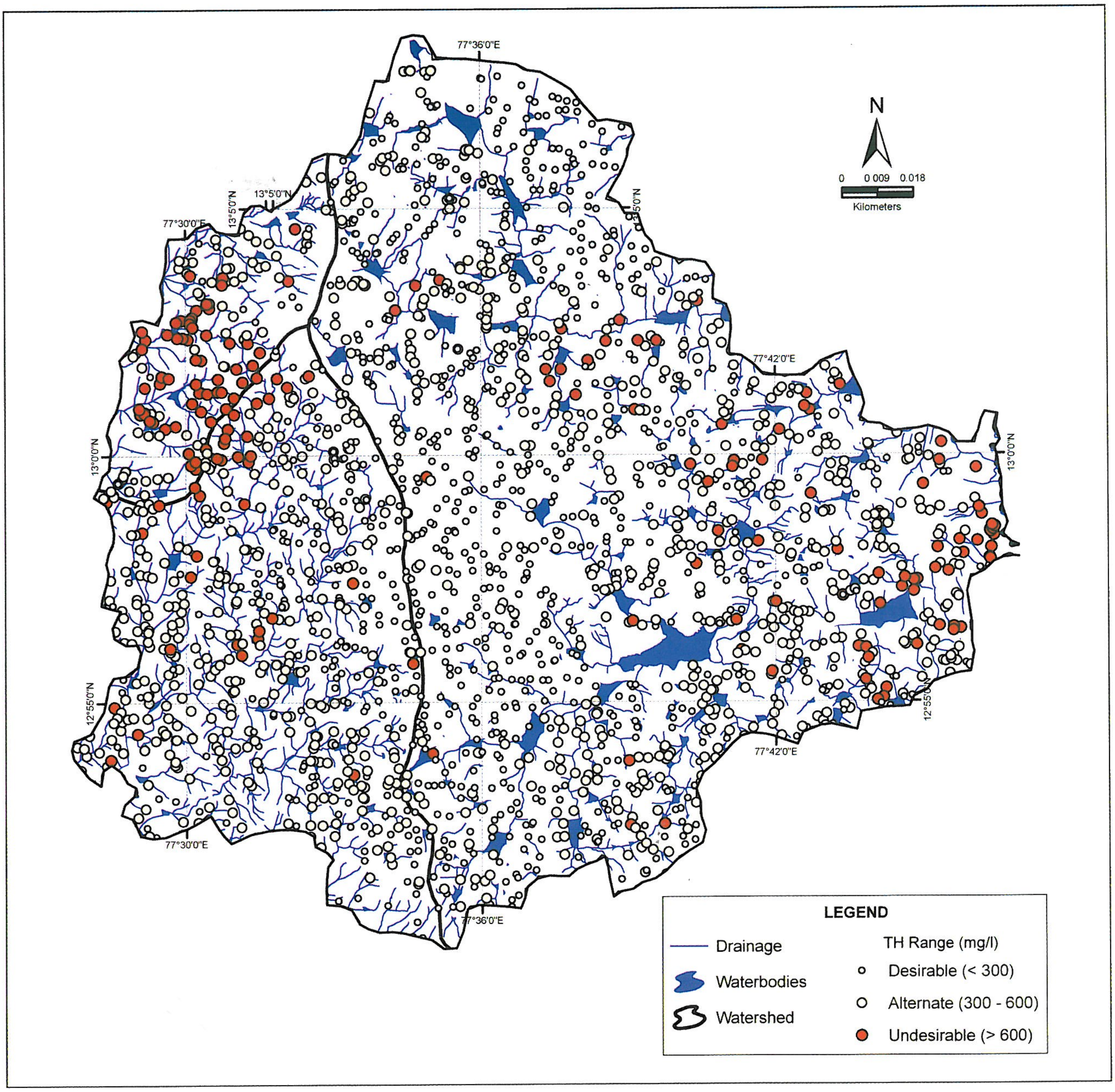



Figure 11 : Total hardness in Groundwater, Bangalore City

permissible limit (>600mg/L). The results reveal that the hardness of the water is due to bicarbonate (temporary hardness). Location wise and spatial distribution of TH in groundwater is given Fig.11 and Fig. 11.1.

The undesirable quality of groundwater based on total hardness attributable to rock-water interaction (temporary hardness-09% of the total samples) is at WNW and eastern boundaries of the study area. Further, 90% of the total samples analysed are within the permissible limit (300-600mg/L).

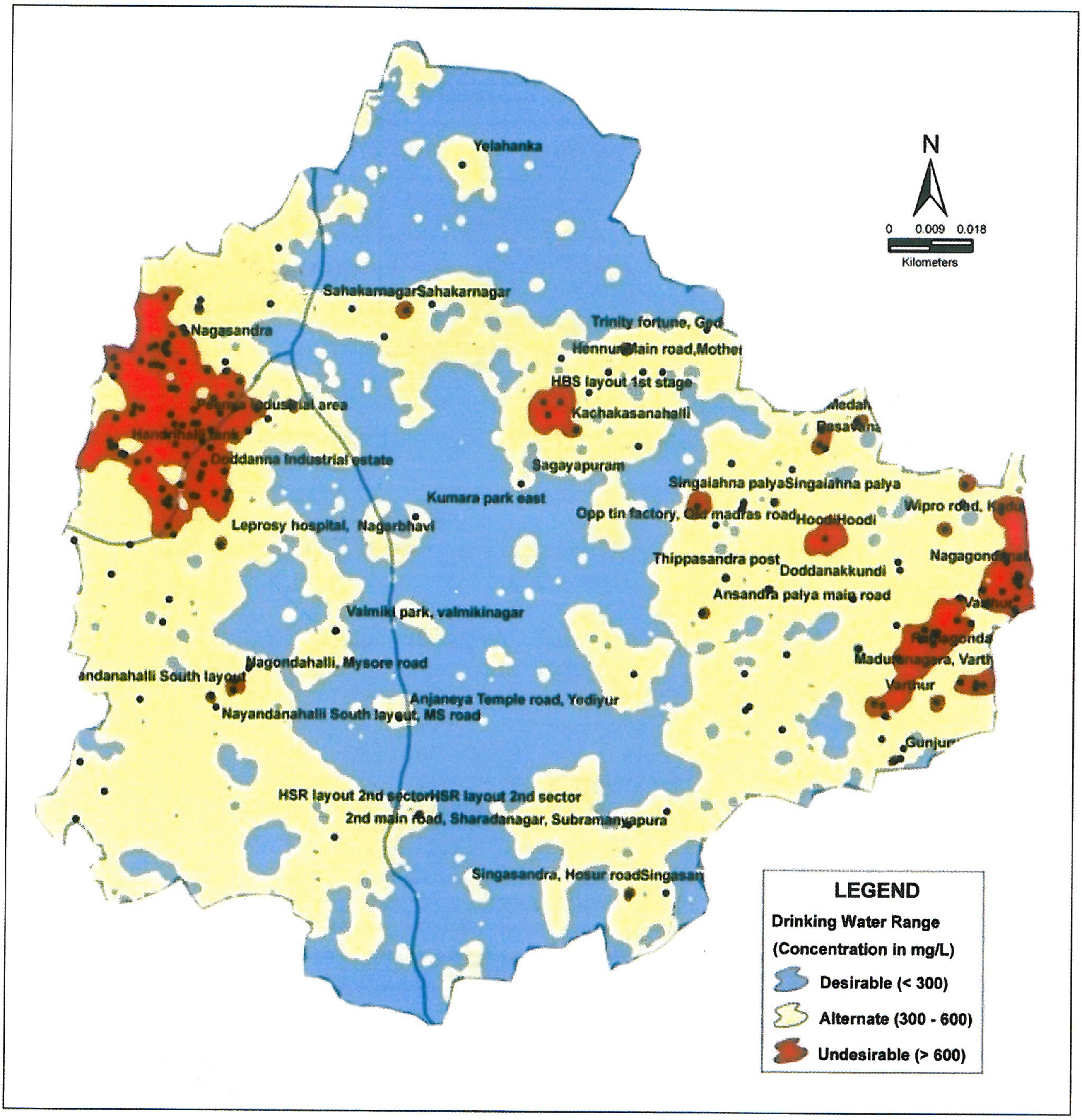



**Figure 11.1 : Spatial Distribution of Total hardness, Bangalore City**

## Total Dissolved Solids (TDS)

The total dissolved solids is the residue left after evaporation of a known volume of water at 1050c. It is approximately equal to the total content of dissolved substances in a water sample. TDS in the area range from 45 mg/L to 5970 mg/L with an average of 685 mg/L. Out of 2209 samples that were analysed, 31% are within desirable limit of 500 mg/L, and 68% within permissible limit of 2000 mg/L and only 13 samples (one percent) in excess of the prescribed Indian Standard.

Based on TDS content Davis and De Wiest (1966) classified water into Desirable for drinking (<500 mg/L), permissible (500-1000 mg/L). If to consider this

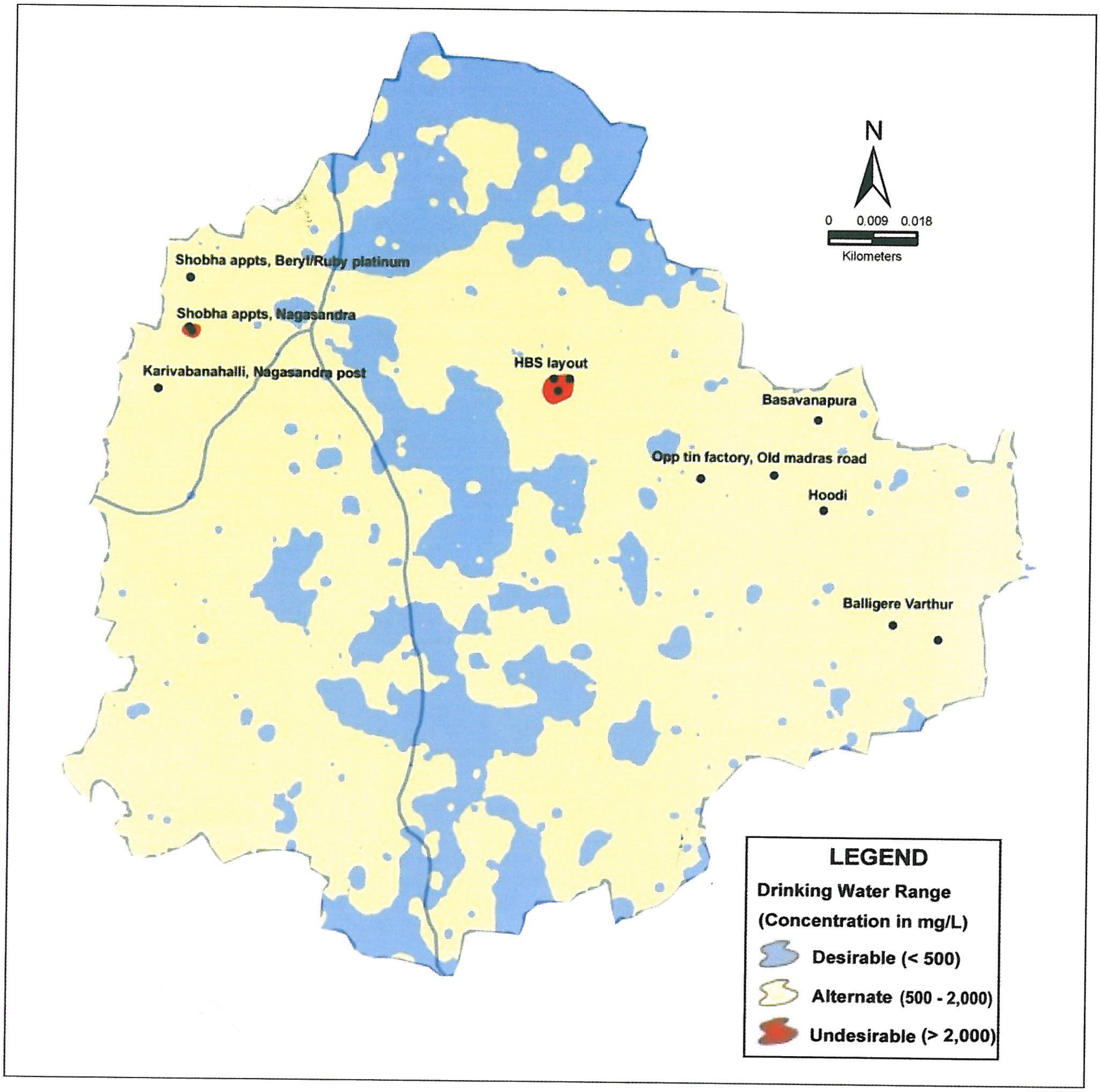



Figure 12 : Spatial Distribution of Total Dissolved Solids, Bangalore City

classification, 31% of the samples fall within desirable limit and 55% within permissible limit and only 14% above the permissible limit for drinking purpose. Where as according to IS-2003, desirable and permissible limits for drinking purpose are <500 mg/L and 500-2000 mg/L, respectively. As per this specification, 31% of the samples fall within the desirable limit and 68% within permissible limit and only 01% above the permissible limit for drinking purpose (Fig. 12)

Based on TDS content, Catroll (1962), classified water into four categories viz; fresh, brackish, saline and brine (Table 7).

**Table 7 : Water classification based on TDS values (Catroll, 1962)**

| TDS mg/L | Nature of water | Samples (%) |
|---|---|---|
| <1000 | Fresh water | 86 |
| 1000-10,000 | Brackish | 14 |
| 10,000-1,00,000 | Saline | - |
| >1,00,000 | Brine | - |

The data presented in Table 7 shows that 86% of water samples are fresh and the rest of 14% are brackish.

## Water Quality for Livestock

Hem's classification (1970) based on TDS for the livestock are furnished in Table 8.

**Table 8 : Upper limit for livestock (after Hem, 1970)**

| Sl. No. | Livestock | TDS(mg/L) |
|---|---|---|
| 1 | Poultry | 2860 |
| 2 | Pigs | 5290 |
| 3 | Horses | 6435 |
| 4 | Cattle(Dairy) | 7150 |
| 5 | Sheep(adult) | 12,900 |

As per this specification 99.50% of the groundwater of the study area is suitable for livestocks.

## Mechanism of Groundwater Chemistry

In order to ascertain the mechanism controlling the chemical composition of groundwater of Bangalore City, Gibb's ratio (Gibbs, 1970), calculated for (Na+K/Na+K+Ca) and anions ($Cl/Cl+HCO_3$) shows that 70% of groundwater samples are controlled by rock-water interaction and 30% by the process of precipitation. This supports the data obtained from positive chloro-alkaline index (Schoeller).

### (d) Total Iron (Fe)

The concentration of total Iron in Groundwater sample varies from 0.001 mg/L to as high as 48.50 mg/L with an average value of 0.53 mg/L. The high content

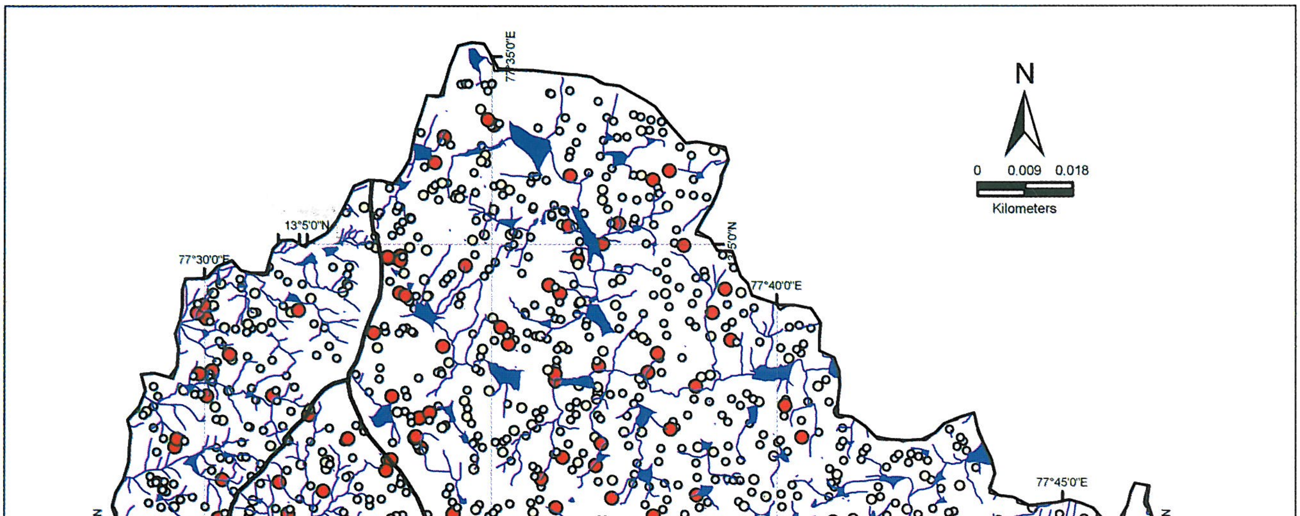



Figure 13 : Iron in Groundwater, Bangalore city

of iron in the groundwater samples is attributable to the corrosion of casing pipes of the bore wells. It is noted that 75% of the samples have shown Iron content within the desirable limit( 0.3 mg/L) and 15% of the sample are within permissible limit (1.0mg/L) and only 10% of the samples have Iron content in excess of permissible limit. Fig.13 and Fig.13.1 shows the distribution of Iron in groundwater of the study area.

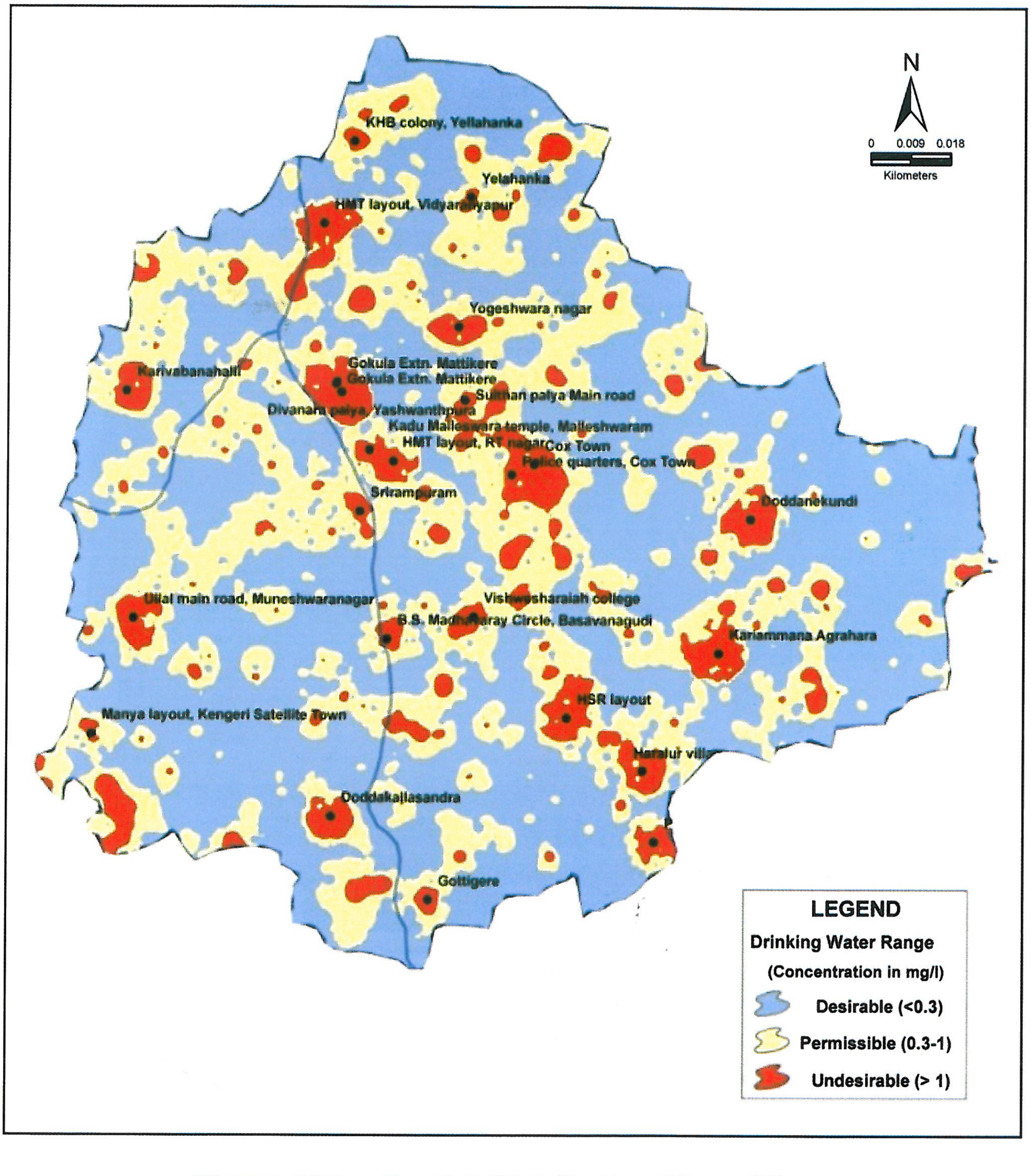



Figure 13.1 : Spatial Distribution Map of Iron

The iron concentration in excess of desirable limits affects the taste and colour of water and has adverse effects on long term consumption. This also promotes the growth of iron bacteria. When the iron contents of the water at the source is in excess of the specified limit, treatment for removal is necessary.

## (e) Nitrate ($NO_3$)

The nitrate content in groundwater varies from less than one mg/L to 554 mg/L with an average of 38.34 mg/L. Out of 2209 samples, 71% have nitrate content less than the desirable limit (<45 mg/L) and 29% (643 locations) have excess of nitrate content(>45 mg/L) rendering unfit for drinking As

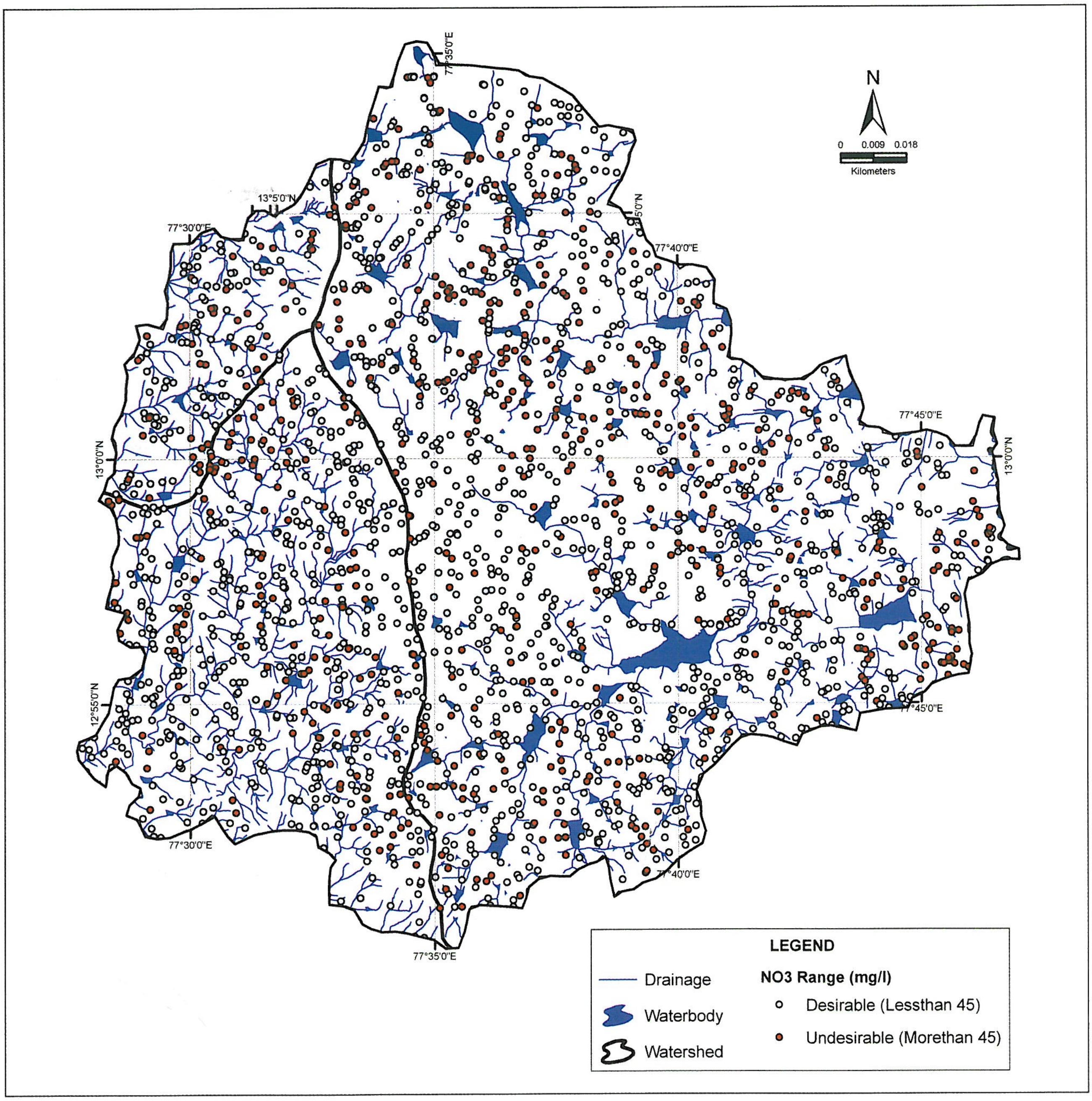



**Figure 14 : Nitrate concentration in Groundwater, Bangalore City**

Per Indian Standards (IS : 2003). Higher concentration indicates the effect of human activity (discharge of untreated sewage effluents) and a significant level of pollution.

The location of nitrate concentration and the spatial distribution maps are given in Fig. 14, Fig. 14.1 & Fig. 14.2 respectively.

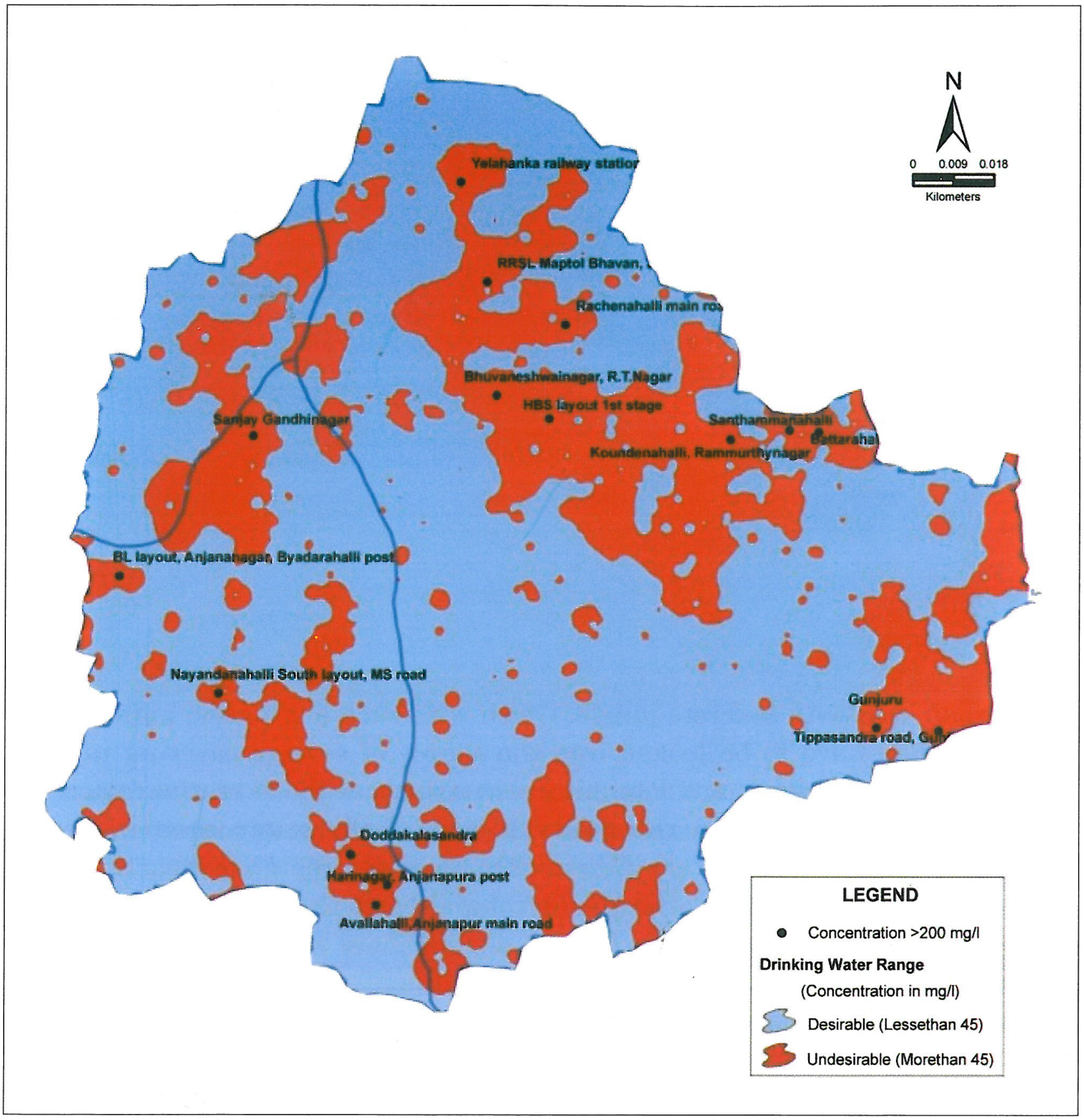



Figure 14.1 : Spatial Distribution of Nitrate in groundwater, Bangalore City

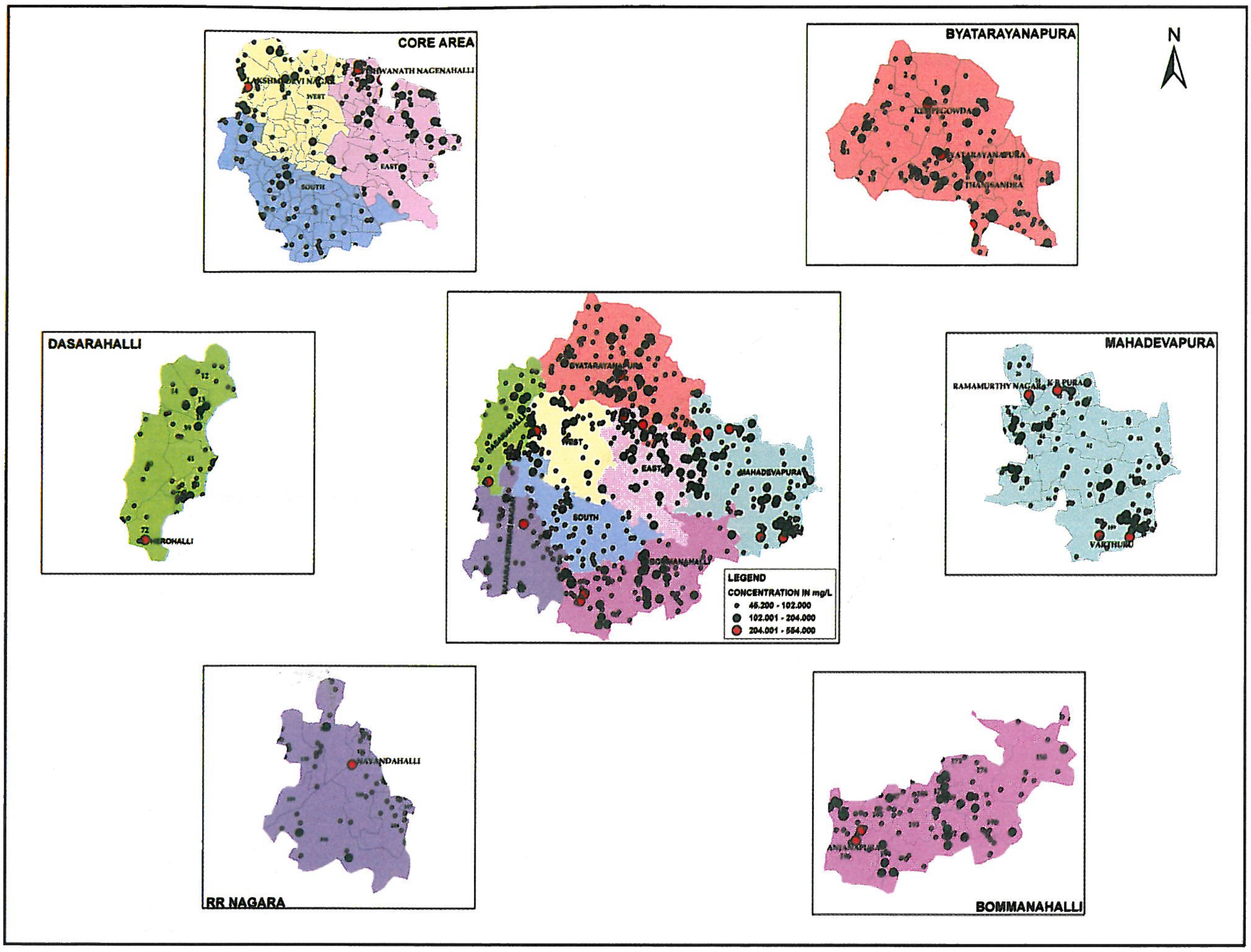



**Figure 14.2 : Zone wise Distribution of Nitrate (>desirable limit)**

Nitrate in groundwater cannot be due to rock-water interaction in the area. There is no major agricultural activity nor application of nitrogenous fertilizers since it is an urban area with concrete jungle. Given with such a situation high content of nitrate may have to be looked into the source of sewage carrying unlined channels of the Arkavathi and Ponnaiyar watersheds as the causative factors. In fact heavy sweage load in the western part of the study area is by the Vrushabhavathi river a tributary of Arkavathi. However, there are certain isolated pockets of high nitrate content in the peripheral parts that can be attributed to direct untreated, sewage disposals. Raju et al (1992) have observed that the nitrate content increases with the percolated sewage effluents as compared to the input of raw wastewater. Relatively higher content of nitrate in isolation in residential area, suggest local contamination due to improper sanitary conditions, leachate from animal wastes, sewage infiltration (in the absence of proof sewer system in the city) and solid waste dumps and kitchen garden manures/fertilizers.

The primary health hazard linked to excessive nitrate content in drinking water is methomoglobinemia, which affects infants. WHO has also stated that excessive consumption of nitrate rich water leads to carcinogenesis. Morales-Suarez-Varela et.al, (1995) have reported an increased mortality rates from gastric and prostate cancer with prolonged consumption of excess nitrate in drinking water in Spain. Grant et al (1996), identified a cluster of spontaneous abortions in India possibly related to ingestion of nitrate-contaminated well water.

The field study has revealed that the topographic depressions and local water bodies (many tanks/lakes in the city) are with domestic waste sewage effluents that are enriched in nitrogen (Fig. 15).

**Figure 15 : Domestic waste water/sewage effluents connected to the tank**

High contents of nitrate associated with high Cl and Na (Table-5), indicate contamination of groundwater possibly from septic tanks, sewage effluent or barnyard pollution. This feature is essentially noticed in the new Bhruhath Bangalore Mahanagara Palike peripheral parts, where there are no proper underground drainage facilities. As compared to the dug wells (unconfined aquifers), presence of nitrate in bore wells which have tapped semi confined aquifers are high.

## (f) Fluoride (F)

A Fluoride concentration of less than 1.0 mg/L in drinking water effectively reduces dental caries without harmful effects on health. Fluoride content in the groundwater samples varies from 0.03 mg/L to 5.54mg/L with an average of

0.65mg/L. It is significant to note that 99% of the samples contain fluoride less than of 1.0 mg/L and in rest of the samples the fluoride content is within the permissible limit (< 1.5 mg/L).

Having observed the concentration of fluoride content of more than 1.5mg/L in certain of the samples (Fig. 16), further sampling work was taken up exclusively for fluoride analysis. A total of 275 groundwater samples were collected and analysed. Of the 275 samples so analysed for fluoride only 16 samples revealed fluoride content of more than 1.5mg/L (Table 9). Samples having fluoride content of above 1.5 mg/L are shown in Fig. 16.1 Presence of fluoride content of 5.06 mg/L at Uttarahalli in the SW and 5.54 mg/L in Bellandur, in the SE part of the city is exceptionally high (Fig. 16.2).

**Table 9 : Fluoride in Groundwater (>permissible limit) of 1.5 mg/L**

| Sl.No | Location | Content (mg/L) |
|---|---|---|
| 1 | Uttarahalli | 5.1 |
| 2 | Sapthagiri layout, Sigehalli | 2.3 |
| 3 | Green Gleal layout | 4.2 |
| 4 | Bellandur | 2.3 |
| 5 | Bellahalli cross Yelahanka | 2.3 |
| 6 | Bellandur | 3.0 |
| 7 | Bellandur | 3.3 |
| 8 | Thirumanahalli Hegdenagar Mn. Rd | 1.6 |
| 9 | Bellandur | 1.7 |
| 10 | Bellandur | 5.5 |
| 11 | Bellandur | 3.6 |
| 12 | Green Gleal layout | 4.8 |
| 13 | Green Gleal layout | 5.0 |
| 14 | Bellandur | 2.4 |
| 15 | Maruthinagar Bellandur | 2.8 |
| 16 | Medahalli, Virunagar post | 1.9 |

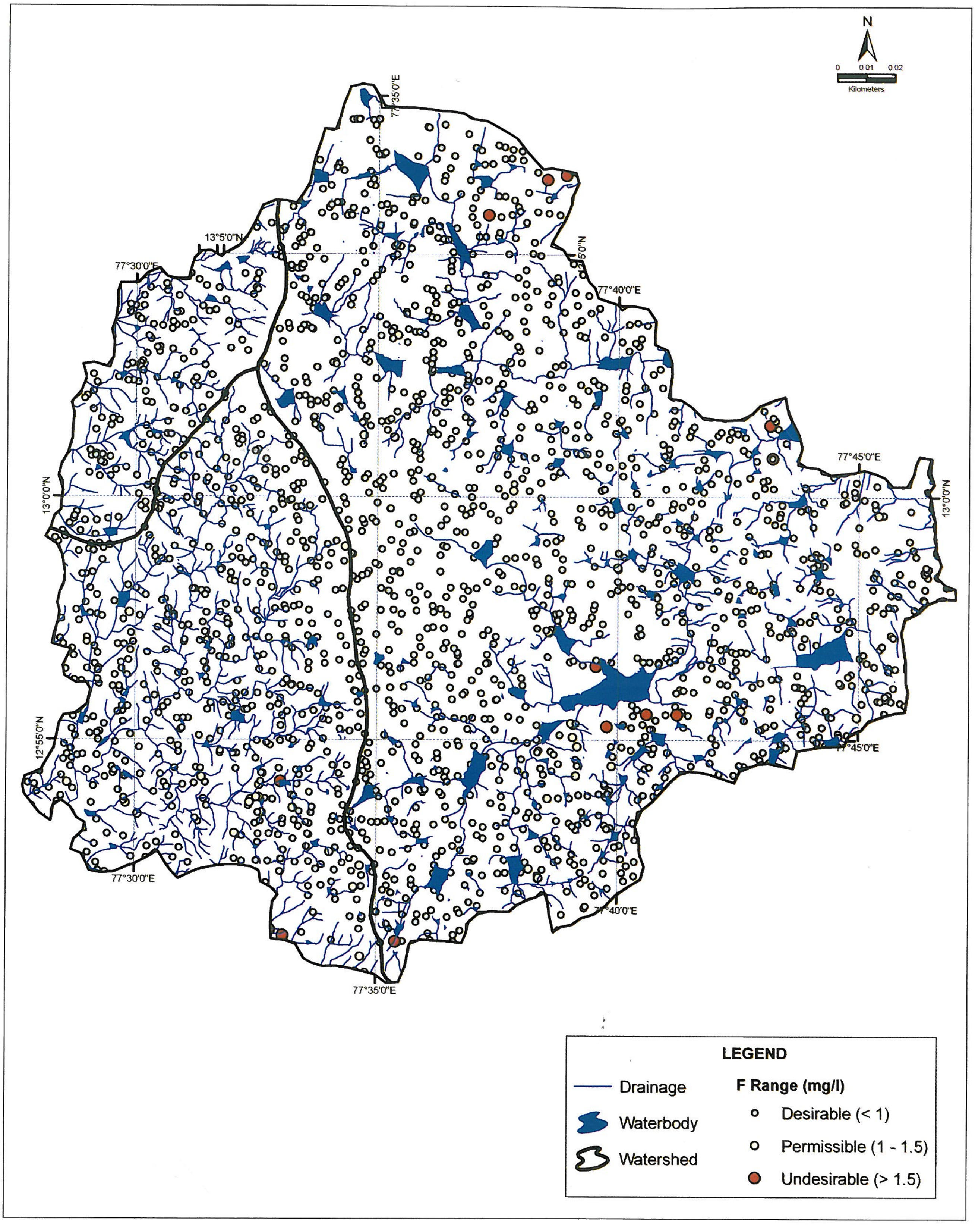



**Figure 16 : Fluoride concentration in groundwater, Bangalore city**

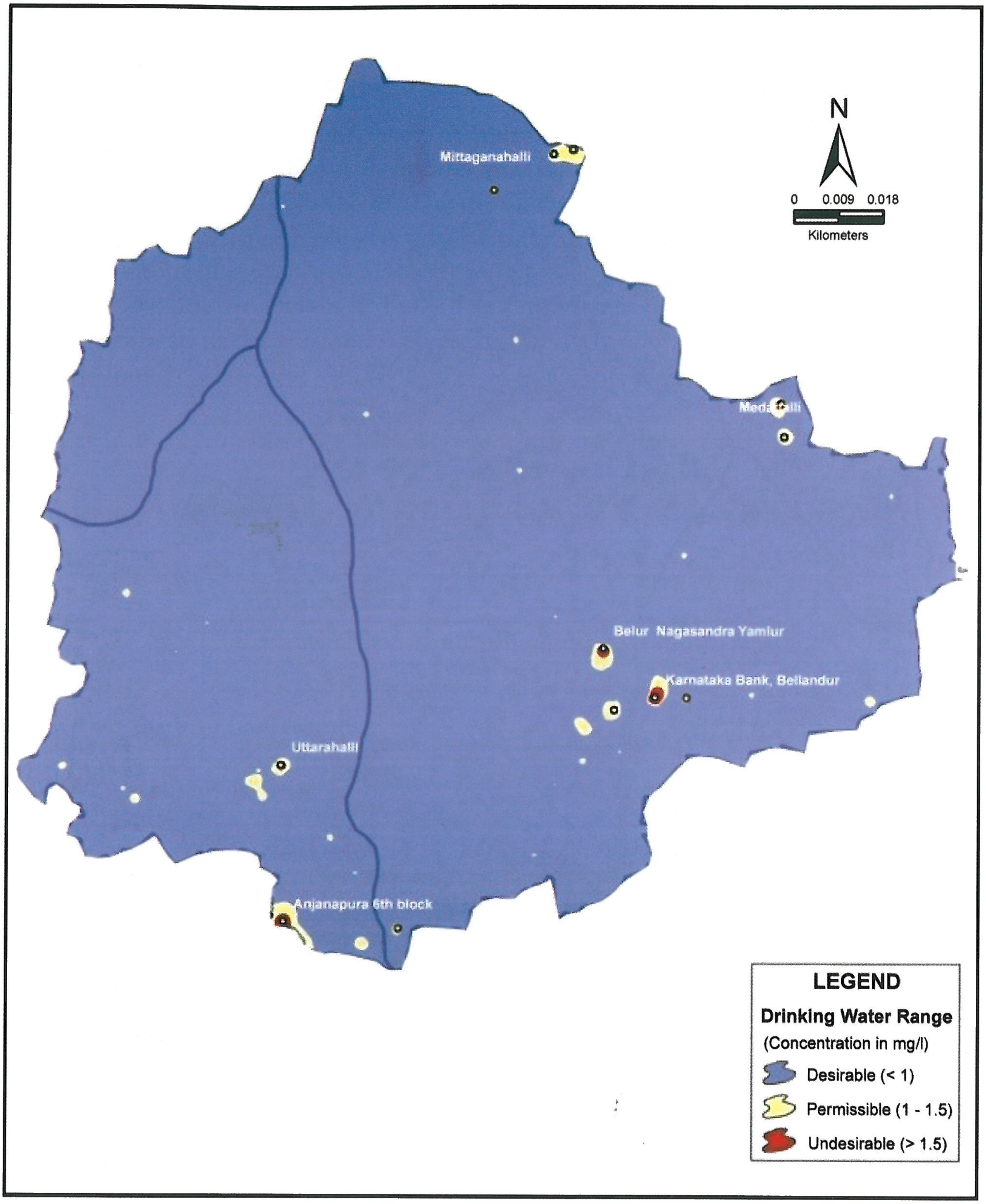



Figure 16.1: Spatial Distribution of Fluoride in Groundwater, Bangalore City

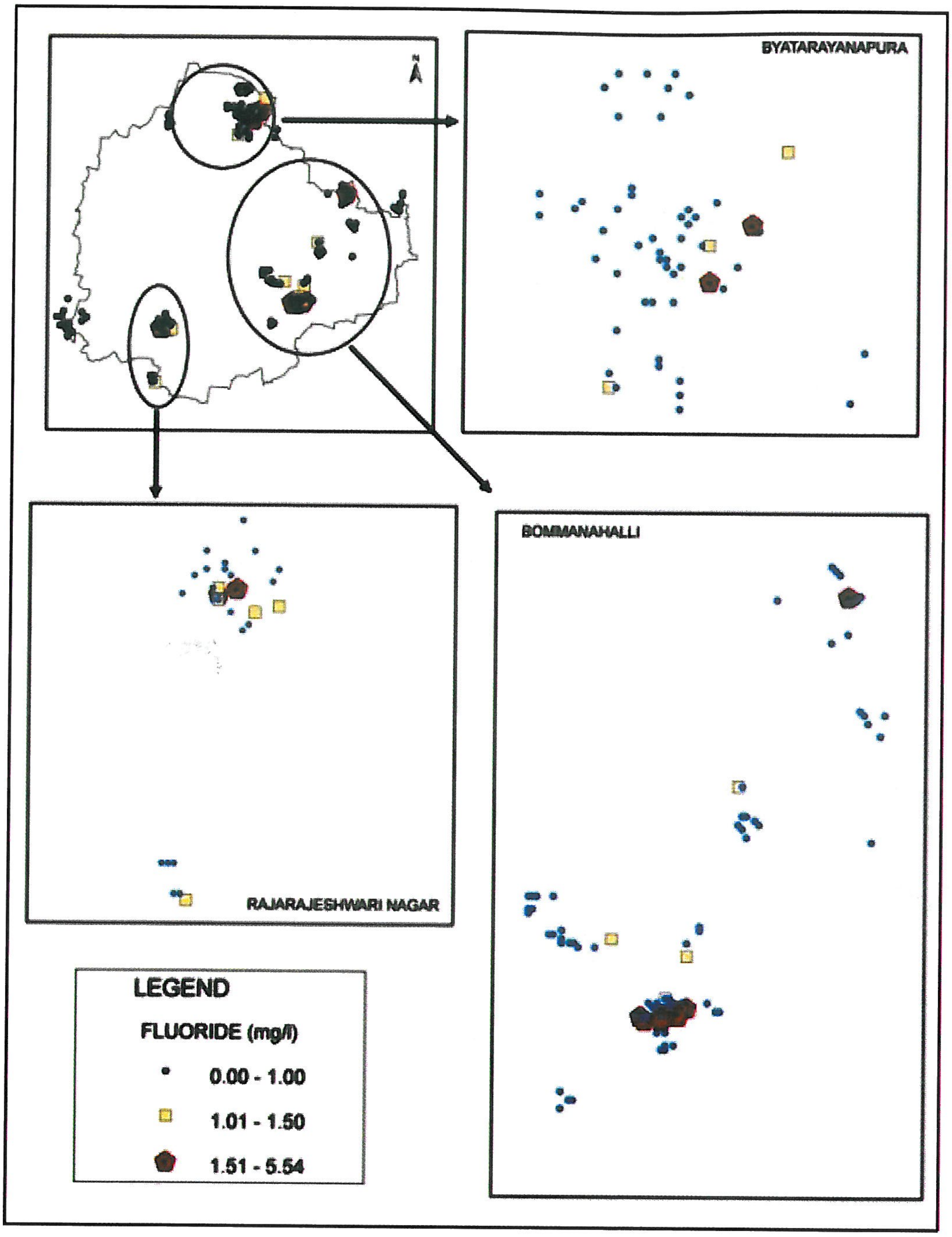



**Figure 16.2: Distribution of Fluoride in Groundwater, Bangalore City**

Though percentage wise occurrence of undesirable limit of fluoride in groundwater is negligible in the area (only 0.60 %), long term consumption of water containing excess fluoride results in "mottled enamel" in teeth, disfiguration of teeth, dental fluorosis and crippling of bones (skeletal deformities). Handa (1975) observed that groundwater with high level of fluoride contains low content of calcium and is positively correlated with bicarbonates. This is more so in the study area. Occurrence of fluoride in bore wells suggests the source of fluoride is geogenic. Granites/gneisses with intensive presence of pegmatites are the locations of high fluoride contents in borewells. The location of high content (above the permissible unit) of Fe, $NO_3$, pH and F are given in Table 10.

## Table 10 : Location of high content (above the permissible limit of Fe, $NO_3$, pH and F) in Groundwater, Bangalore City

| Fe > 1.0 mg/L | $NO_3$>45 mg/L | | TH > 600 mg/L |
|---|---|---|---|
| Bagalgunte | A.C. palya | Adgodi road | Anjananagar, |
| Doddakallasandra, | Abbigere | Adugodi | Annapurneshwari layout |
| Gangamma Circle, Jalahalli | Adugodi | Agrahara | Ansandra palya |
| Gangondanahalli | Ashwathnagar | Agrahara new layout | B.Narayanapura |
| High Court Building, | Bagalgunte | Akshyanagar | Bagalgunte |
| Immodihalli | Bale pete | Alahalli | Baligeri |
| J.P.nagar 7th phase | Battarahalli | Allalasandra | Basavanapura |
| Jakkur main road | Benniganahalli | Amruth nagar | Basaveshwaranagar |
| K.R.puram | C.V.Ramannagar | Amruthahalli, | Battarahalli |
| Kengeri | Devasandra | Anandapuram | Bellattur |
| Nagapura | Dodda Begur | Andrahalli | Bileshivale Village |
| Nyanappahalli | Dodda Kammanahalli | Anjananagar | Bommanahalli |
| Pillanagarden, | Doddadevasandra | Ansandra palya main road | Chalaghatta |
| Sidehalli | Dooravaninagar. | Arakere, | Channasandra |
| Tumkur road | Dubasipalya | Arkere Mico layout, | Devinagar |
| Ulsoor | Gollarahatti | Attur | Dimur village |
| V.V. puram | Hariappanapalya | Avalahalli | Dodda Banaswadi |
| Adugodi | Hebbal | B.Narayanapura | Doddabidarkallu, |
| Agrahara | Hosakerehalli | Babusahib palya | Doddabomma sandra |
| Ambedkarnagar | Ilyasanagar | Baligeri | Doddanakkundi |
| Ambedkarnagar | Jakkur | Balligere Gunjuru road | Doddanna Industrial estate |
| Amruthnagar | K.R. puram | Banasawadi | Dooravaninagar. |
| Anantapura Yelahanka | Kanakanagar | Bandepalya, | Ganapathi nagar |
| Annaiappa Block | Kariyanapalya | Bannerghatta road | Gangondanahalli Mn Rd |
| Annapurneshwari nagar | Kengeri | Basavanagar, | Geddilahalli |
| Babasahebpalya, | Kommagondanahalli | Basavanapura | GKW layout |
| Bairatti, | Kurudasonnenahalli | Basaveshwara nagar | Gorgunte palya, Y.pura |
| Bande road Kogilu layout | Munnakolalu, Marathahalli | Battarahalli | Gunjur |
| Bandemata Extn | Nandhini layout | Begur | Haggadur |
| Bapujinagar | Nyanappahalli | Bellahalli main rd | Handrihalli tank |
| Basavagrama, | Peenya 2nd stage | Bellary road | Haralur |
| Basavanagar, | Pillanagarden, | BEML layout R.R.Nagar | HBR layout, |
| Basavanagudi | R.T.Nagar | Benaganahalli | HBS layout 1st stage |
| Begur | Sidehalli | Benson town | Hegganahalli |
| Belur | Sri Gandada Kavalu | Bikasipura | Heggenahalli cross, Sunkadakatte |
| Benniganahalli | T.Dasarahalli | Bilekallu, | Hennuru cross |
| Bommanahalli | Ullal | Bileshivale | HMT layout, |
| BSK 2nd stage | Ullala Upanagara | Bommanahalli | Hoodi |
| BSK 6th stage | Varthur | BSK 2nd stage | Horamavu Agra |
| BTM layout | Vidyaranyapura | BSK 3rd phase | HSR layout 2nd sector |
| Chennapanahalli | Whitefield | BSK 6th stage | Immodihalli |
| Cooke town | HMT layout, | BTM 2nd stage | Inside Arabic college |
| Coxtown, Dodkunte | Hongasandra | BTm layout, | Jalahalli circle |
| Dasarahalli Agrahara | Horamavu village | Byadarahalli | Jnanabharathi |
| Devinagar | Horamavu, Agara | Byatarayanapura | K.R.puram |
| Divanara palya, | Horohalli, | Chakkanahalli | Kachakasanahalli |
| Doddakallasandra | Hosahalli cross | Chamrajpet | Kadugodi |
| Doddanekundi | Hosapalya | Chandralayout | Kariammana Agrahara |

| Fe > 1.0 mg/L | $NO_3$>45 mg/L | | TH > 600 mg/L |
|---|---|---|---|
| Doddekannalli Dinne, | HSR layout 3rd sector | Channasandra | Karivabanahalli, |
| Frazer town | Hudson Memorial Church | Chennapakanhalli palya, | Kaverinagar |
| Gollahalli, Kengeri hobli | Hundi | Chennapanahalli | Kengeri |
| Gottigere, | Indiranagar | Chikka Togur | Kittaganur |
| Gunjuru | J.C.Nagar, | Chikkabanawara | Kodi |
| Gunjurupalya | J.P.nagar | Chikkabellandur, | Kommagondanahalli |
| H. Siddaiah road | J.P.Nagar 8th phase | ChikkaBettahalli, | KS town |
| HAL 2nd stage, Indiranagar | J.Pnagar 9th phase | Chikkabommasandra | Kumara park east |
| HAL Rustumbagh | Jagadishnagar | Chikkalasandra | Kundalahalli |
| Handrihalli tank | Jagajivanramnagar | Chinnappanahalli, | Laggere |
| Haralur | Jakkur layout | Chokkanahalli | Magadi main road |
| Harikere, | Jalahalli | Chokkasandra | Mallasandra |
| HBR layout | Jalahalli circle | Cholanayakanahalli | Mallathahalli |
| Hegganahalli | Jambu savari dinne | Chunchunghatta | Mallathalli, Keregunte |
| Hennur Bagalur road | Jayanagar 4th Block | Dasarahalli | Medahalli, |
| Hennur cross | Jayanagar, | Devarachikkana halli | Nagagondanahalli Whitefield |
| Hirohalli | Jayanagara 9th block | Dimur village | Nagawara |
| HMT layout, | Jayanthi nagar | Dodda Banaswadi | Nagondanahalli, |
| Hoodi Rajapalya | Jeevanahalli | Dodda Togur | Nayandanahalli |
| Hosur main road | Jnanabharathi | Doddabasavapura | Nelagadaranna halli, |
| HSR layout | Jnanaganganagar | Doddabettahalli | Old madras road |
| HSR layout 2nd sector | Junnasandra | Doddabommasandra, | Panathuru |
| HSR layout 5th sector | Kachakasanahalli | Doddagubbi | Parappana Agrahara |
| Hulimavu | Kadugodi | Doddakallasandra | Pattandur, |
| Ideal homes layout | Kadugodi whitefield | Doddanekundi | Peenya 2nd stage |
| Indiranagar | Kaggadasapura | Doddekannalli Dinne, | Peenya Industrial area |
| Indiranagar 2nd stage | Kaikondanahalli | Domlur | Peenya Indl. area 3rd phase |
| J.P nagara 3rd phase | Kalkere | Dooravaninagar | Rajeshwari nagar |
| J.P.Nagar 1st phase | Kallipalya | Doriswamy palya | Rajiv Gandhi nagar |
| Jai Bharathi nagar | Kallyananagar | Dwarakanagar | Ramagondanahalli |
| Jakkur layout | Kalyan nagar, Mudalapalya | Electronic city | Rammurthynagar |
| Janabharthi 2nd stage, | Kamakshipalya | Frazer town | Sahakarnagar |
| Jayanagar 8th block | Kamakshipura | G.M.Palya | Sangeevininagar, |
| Jeevanahalli | Kammanahalli | Gangamma Circle | Sanjay Gandhinagar |
| K.G.Halli Jallahalli west | Kanakanagar | Ganganagar | Shingapura |
| K.P.Road | Kantirava nagar | Garebavi palya | Siddapura |
| K.R.Circle | Kariyanapalya | Garudacharyapalya | Sigehalli Road |
| K.R.puram | Kasavanahalli | Girinagar 1st stage | Singaiahna palya |
| Kalkere | Kaval Byrasandra | GKW layout | Singasandra, |
| Kanasandra, Kengeri | Kaveramma temple | Gokula | Srigandha Kaval, |
| Kanchanahalli, Yelahanka | Kaverinagar | Gollahalli | Subramanyapura |
| Kariammana Agrahara | Kempapura | Gollarapalya | Sumanahalli, Nagarbhavi |
| Karivabanahalli, Nagasandra post | Kodigehalli | Gorgunte palya, | Sunkadakatte, |
| Kasavanahalli | Kodipalya, | Govardhan | T. Dasarahalli |
| Kempapura Yamlur | Kogilu, Yelahanka | Govindapura | Thanisandra Mn Rd |
| Kengeri Upanagar | Konanakunte | Govindapura main road | Thimmandahalli, Hosakote |
| KHB colony, Yellahanka | Kothnur | Gunjuru | Thippasandra post |
| Kodipalya, | KR puram | H.V.R Layout | Tigalarapalya |
| Koramangala | Kudlu village, | Haggadur | Tippenahalli, |
| Kothunur | Kumara Krupa high Grounds | Hajagondanahalli | Tumkur road |
| Kudlu main road | Kumaraswamy layout | Hanumagiri nagar | Uttarahalli |
| Kundolahalli gate | Kumbena agrahara | Hanumanthanagar | Valmikinagar |

| Fe > 1.0 mg/L | $NO_3$>45 mg/L | | TH > 600 mg/L |
|---|---|---|---|
| L.N.Pura, | Kundalahalli | Haralur Varma Agra | Bellandur |
| Laggere Mn Rd | Kurubarahalli | Harinagar | Sigehalli |
| Laksandra Extn. | Kuvempunagar | HBR layout 3rd Block | Ulsoor road, Mallasandra |
| Lalbagh near Glass house | Kyalasanahalli | HBS layout 1st stage | Mitganahalli road |
| Lingarajpuram | LB Shastrinagar, | Hegdenagar | Mitganahalli road |
| Magadi road | Leggere | Hegganahalli | Gottigere |
| Mahadevpura | Lingarajpuram | Hegganahalli cross, | Mallasandra, Uttarahalli |
| Malleshwaram | Lottegollahalli | Hennur Bagalur road | Devarabisanahalli, Bellandur |
| Marappanapalya main road | Madeshwara main road | Hennur cross | Agrahara main road |
| Marathalli | Madiwala | Hesarghatta main road | Ibblur, Agara |
| Marenahalli 2nd phase | Magadi main road | Hirehalli Extn. | Anjanapura 6th block |
| Mariyannapalya | Nagadevanahalli, | Magadi road | Medahalli |
| Mathikere layout | Naganathpura, | Mahadevapura | Uttarahalli |
| Mattikere main road | Nagasandra, | Mallathahalli | Belur Nagasandra Yamlur |
| MRHB colony | Nagavara | Mallathalli, | Mittaganahalli |
| Muneshwaranagar | Narayanapura | Malleshwaram | Varthur |
| Munnekollalu | Nayandanahalli | Manrayanapalya | Vidyanagar, |
| Murugeshpalya Airport road | Nelagadaranna halli, | Marathahali | Vikara nagar, |
| Muthyala nagar | Nellurahalli | Marenahalli 2nd phase | Vinayaka nagar |
| Mysore road | New Timberyard layout | Mariyappanapalya, | Whitefield |
| Nagadevanahalli, Jnanabharathi | Old Byappanahalli | Maruthinagar | Yamlur |
| Naganathpura | Old madras road | Medahalli | Yediyur |
| Nagarbhavi main road | Old madras road, Indiranagar | Mical layout | Yelahanka |
| Osborne road | Osborne road | MS nagar | Yeshwanthpura, Inds. Area |
| Padmanabhanagar | Panathur | MSR Nagar | Yeshwanthpur |
| Panatturu Dinne | Paramara palya | Muddepalya | Tippenahalli, |
| Parallal road | Parappana Agrahara | Muneshwaranagar | |
| Parappana Agrahara | Peenya Industrial area | Murugeshpalya | |
| Parvathipura | Prime Rose road | Muthyala nagar | |
| Pattandur | Puttenahalli road, J.P. Nagar | Mysore road | |
| Pavathuru Dinne | R.M.Nagar | N.Naganahalli | |
| Peenya Industrial area | R.T.Nagar | Nadagondanahalli | |
| Prahantha nagar, | R.T.Nagar, Matadahalli | Sadanandanagar | |
| R.T.Nagar | Rachenahalli, | Sagayapuram | |
| Rajajinagar | Rajajinagar | Sahakarnagar | |
| Ramaswamy palya, | Rajeshwari nagar | Sanjaynagar | |
| Rampura, Virgonagar | Ramagondanahalli, | Sanjeevininagar | |
| Richmond road | Ramamoorthynagar | Sarakki village J.P.Nagar | |
| Ring road, Mariyappanapalya | Ramath Manzil | Sarapalya | |
| Sadashivanagar | Rameshnagar | Shampur | |
| Sahakarnagar | Rameshnagar | Shanthinagar | |
| Sanjevininagar | Rammurthy nagar | Shingapura | |
| Sarapalya Gate, | Richard town | Siddapur | |
| Sarjapura road | Richmond road | Sigehalli | |
| SB palya, New extn. | Roopena agrahara, | Singaiahna palya | |
| Sericulture Department GKVK | S.G.Palya, | Singanayakanahalli | |
| Siddapur | Sunkadakatte, | Singasandra | |
| Siddehalli | T.Dasarahalli | Singasandra Ind Area | |
| Singaiahna palya | T.R.Nagar | Sonnenahalli, | |
| Sri, M.V.Layout | Talagattapura | Srigandhanagar, | |
| Srinivaspura, Kengeri | Tejasvaramma nagar | Srinagara | |
| Srirampuram | Thambuchattipalya | Srirampuram | |
| Subbedar Chathram Road | Thanisandra | St.John's road | |

| Fe > 1.0 mg/L | $NO_3$>45 mg/L | | TH > 600 mg/L |
|---|---|---|---|
| Subedarpalya, | Thippenahalli, | St.Martha's Hospital | |
| Subramanya pura | Thyagarajnagar | Subbaiah palya, | |
| Sulthan palya Main road | Udayanagar | Subramanyapura | |
| T.Dasarahalli | Ulsoor | Subramanyapura | |
| Talagattapura, | umarnagar | Suddaguntepalya | |
| TERI, Domlur | Uttarahalli | Sudham nagar | |
| Thanisandra | V.H.C.S Layout, | Sulthanpalya, | |
| Tilaknagar | V.V. nagar | Veerabhadranagar | |
| Ulsoor | Valmikinagar | Venkateshpura | |
| Uttarahalli | Vasanthpura | Vidyaranyapura | |
| V.H.C.S Layout, | Vasthunagar, | Vijayanagar | |
| V.V. Puram, | Viveknagar | Vimanapur | |
| Varahasandra, Kengeri hobli | Yamlur | Vittasandra, | |
| Varanashi cross | Yediyur | Yelahanka new town | |
| Varthur | Yelachenahalli | Yeshwanth pura, | |
| Vasanth nagar | Yelahanka | Yeshwanth pura, Inds. Area | |
| Vidyapeeta Kengeri | | | |
| Vidyaranyapura | | | |
| Vikara nagar, | | | |
| Vishwesharaiah college | | | |
| Vivekanagar | | | |
| Yamlur | | | |
| Yelahanka | | | |
| Yeshwanthpur | | | |
| Yogeshwara nagar | | | |

## Heavy Metal Analysis

A total of 275 water samples were exclusively collected in and around the industrial area and were analysed for heavy metals such as zinc, copper, lead, manganese, chromium and aluminium in groundwater. The abstract of the analytical results are given in Table11 and the details of the contents of heavy metals in groundwater of the study area above permissible limit are in Table11.1. The locations where of heavy metals above the permissible limits are shown in Fig. 17. Three blocks namely, Byatarayanpura in the northern part of the city, Peenya in the northwest upto Jayanagar in the south, Bommanahalli-Mahadevapura in the SES part of the city have shown the presence of heavy metals above the permissible limits in groundwater Fig. 17.1.

**Table 11: Minimum, Maximum and Average values (mg/L) of Heavy metals in Groundwater**

| Constituent | Min. | Max. | Avg |
|---|---|---|---|
| Zinc | 0.01 | 285 | 2.4886 |
| Lead | 0.01 | 1.25 | 0.1823 |
| Copper | 0.01 | 1.17 | 0.148 |
| Manganese | 0.01 | 31.2 | 0.6016 |
| Aluminium | 0.44 | 0.97 | 0.638 |
| Chromium | 0.01 | 572 | 15.912 |
| Cl | 129 | 1057 | 541.82 |

**Table 11.1 : Location of Heavy Metals above the permissible limit**

| Sl. No. | Location | Zn | PB | CU | Mn | Al | Cr | TH | Cl |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Sarjapur road, Agara post | 0.44 | 0.00 | 0.11 | 0.39 | 0.00 | 0.00 | 0 | 0 |
| 2 | Kaikondanahalli, Sarjapur main road | 1.12 | 0.02 | 0.02 | 0.72 | 0.00 | 0.00 | 0 | 0 |
| 3 | Gollahalli, Hosapalya, Bommanahalli | 7.30 | 1.25 | 0.00 | 0.65 | 0.00 | 0.00 | 0 | 0 |
| 4 | 3rd phase, Peenya Ind area | 1.60 | 0.00 | 0.00 | 0.07 | 0.00 | 13.20 | 0 | 0 |
| 5 | 10th main 3rd phase, Peenya | 0.06 | 0.00 | 0.00 | 0.07 | 0.00 | 0.50 | 0 | 0 |
| 6 | 10th main 3rd phase, Peenya | 0.21 | 0.00 | 0.00 | 0.28 | 0.00 | 0.27 | 0 | 0 |
| 7 | 10th main 3rd phase, Peenya | 0.60 | 0.00 | 0.00 | 0.07 | 0.00 | 0.89 | 0 | 0 |
| 8 | Shivapura colony Ind area, Peenya 2nd stage | 0.10 | 0.00 | 0.00 | 0.63 | 0.00 | 0.00 | 0 | 0 |
| 9 | Shivapura 4th cross, Peenya 2nd stage | 0.09 | 0.00 | 0.00 | 0.62 | 0.00 | 0.00 | 0 | 0 |

| Sl. No. | Location | Zn | PB | CU | Mn | Al | Cr | TH | Cl |
|---|---|---|---|---|---|---|---|---|---|
| 10 | Sodekoppa main road, Shivapura, Peenya 2nd stage | 0.27 | 0.00 | 0.00 | 1.06 | 0.00 | 0.00 | 0 | 0 |
| 11 | Sodekoppa main road, Shivapura, Peenya 2nd stage | 0.25 | 0.00 | 0.00 | 0.91 | 0.00 | 0.00 | 0 | 0 |
| 12 | 6th cross, Shivapura main road, Peenya 2nd stage | 1.44 | 0.11 | 0.01 | 0.08 | 0.00 | 0.00 | 0 | 0 |
| 13 | Nellagadahalli road, Shivapura | 0.32 | 0.00 | 0.00 | 0.48 | 0.00 | 0.00 | 0 | 0 |
| 14 | Nellagadahalli road, Shivapura, Peenya 2nd stage | 0.94 | 0.00 | 0.00 | 0.87 | 0.00 | 0.00 | 0 | 0 |
| 15 | Maruthi nagar, Hegganahalli, Peenya 2nd stage | 0.01 | 0.00 | 0.00 | 0.01 | 0.44 | 0.02 | 0 | 0 |
| 16 | Maruthi nagar, Hegganahalli, Peenya 2nd stage | 0.02 | 0.00 | 0.00 | 0.03 | 0.97 | 0.03 | 0 | 0 |
| 17 | 5th main road, hegganahalli, Peenya 2nd stage | 0.00 | 0.00 | 0.00 | 0.00 | 0.62 | 0.03 | 0 | 0 |
| 18 | Sanjiveeni nagar, Hegganahalli, Peenya 2nd stage | 0.00 | 0.00 | 0.00 | 0.00 | 0.68 | 0.00 | 0 | 0 |
| 19 | Adrahalli main road, Peenya 2nd stage | 0.44 | 0.00 | 0.00 | 0.02 | 0.00 | 1.53 | 0 | 0 |
| 20 | Kaveri nagar, Andrahalli main road, Peenya 2nd stage | 0.11 | 0.00 | 0.00 | 0.35 | 0.48 | 1.84 | 0 | 0 |
| 21 | BTP area Tilaknagar | 0.01 | 0.00 | 0.00 | 0.66 | 0.00 | 0.00 | 0 | 0 |
| 22 | 28th cross, BTP area, Tilaknagar | 0.00 | 0.00 | 0.00 | 1.01 | 0.00 | 0.00 | 0 | 0 |
| 23 | 8th main road, 3rd Block, Jayanagar | 0.02 | 0.00 | 0.00 | 0.76 | 0.00 | 0.00 | 0 | 0 |
| 24 | 28th main road, Tilaknagar | 0.08 | 0.00 | 0.00 | 0.67 | 0.00 | 0.00 | 0 | 0 |
| 25 | 11$^{th}$ cross, 4$^{th}$ phase Peenya Ind area | 0.22 | 0.14 | 0.00 | 16.40 | 0.00 | 0.00 | 0 | 0 |
| 26 | Rajagopal nagar , Peenya 2nd stage | 0.25 | 0.01 | 0.00 | 0.03 | 0.00 | 10.15 | 0 | 0 |
| 27 | Rajeshwari nagar, Leggere | 0.35 | 0.02 | 0.00 | 1.39 | 0.00 | 0.02 | 0 | 0 |
| 28 | Rajagopal nagar , Peenya 2nd stage | 0.00 | 0.11 | 0.00 | 0.00 | 0.00 | 0.05 | 0 | 0 |
| 29 | Rajagopal nagar , Peenya 2nd stage | 0.28 | 0.00 | 0.00 | 0.00 | 0.00 | 0.06 | 0 | 0 |
| 30 | Ramaiah Extn. Peenya 2nd stage | 1.18 | 0.00 | 0.00 | 0.00 | 0.00 | 0.11 | 0 | 0 |
| 31 | Ramaiah Extn. Peenya 2nd stage | 1.25 | 0.00 | 0.00 | 0.00 | 0.00 | 0.07 | 0 | 0 |
| 32 | Ramaiah Extn. Peenya 2nd stage | 0.06 | 0.00 | 0.00 | 0.00 | 0.00 | 0.06 | 0 | 0 |

| Sl. No. | Location | Zn | PB | CU | Mn | Al | Cr | TH | Cl |
|---|---|---|---|---|---|---|---|---|---|
| 33 | Doddanna Ind estate, Hegganahalli, Peenya 2nd stage | 0.83 | 0.00 | 0.00 | 0.00 | 0.00 | 0.11 | 0 | 0 |
| 34 | Doddanna Ind estate, Peenya 2nd stage | 0.58 | 0.00 | 0.00 | 0.00 | 0.00 | 0.13 | 0 | 0 |
| 35 | Srigandha kaval, Kavisals layout | 0.26 | 0.00 | 0.00 | 1.28 | 0.00 | 0.31 | 0 | 0 |
| 36 | Srigandhanagar, Hegganahalli | 0.09 | 0.00 | 0.00 | 3.51 | 0.00 | 2.63 | 0 | 0 |
| 37 | Effluent, Srigandhanagar, Hegganahalli | 70.00 | 0.56 | 0.00 | 13.00 | 0.00 | 572.0 | 0 | 0 |
| 38 | Ambedkar statue, Tilaknagar | 0.00 | 0.00 | 0.00 | 0.33 | 0.00 | 0.00 | 0 | 0 |
| 39 | Haralakunte, HSR layout | 1.06 | 0.00 | 0.00 | 0.86 | 0.00 | 0.00 | 0 | 0 |
| 40 | Hosapalya | 7.10 | 0.00 | 1.17 | 1.25 | 0.00 | 0.00 | 0 | 0 |
| 41 | Srigandhanagar, Hegganahalli | 0.17 | 0.00 | 0.00 | 4.65 | 0.00 | 5.59 | 0 | 0 |
| 42 | HSR layout, 2nd sector | 0.06 | 0.00 | 0.00 | 1.83 | 0.00 | 0.00 | 1840 | 1057 |
| 43 | Somasundarapalya, HSR 2nd sector | 0.35 | 0.00 | 0.00 | 1.91 | 0.00 | 0.00 | 1660 | 966 |
| 44 | HSR 2nd sector | 0.13 | 0.00 | 0.00 | 0.08 | 0.00 | 0.00 | 1680 | 770 |
| 45 | HSR layout, 2nd sector | 0.11 | 0.00 | 0.00 | 1.19 | 0.00 | 0.00 | 1180 | 798 |
| 46 | Hosapalya | 0.07 | 0.00 | 0.00 | 0.07 | 0.00 | 0.00 | 300 | 238 |
| 47 | BBMP Nursery, Hosapalya | 0.22 | 0.00 | 0.00 | 9.70 | 0.00 | 0.00 | 960 | 938 |
| 48 | Nayar Rajkumar Farms, Hosapalya | 0.12 | 0.00 | 0.00 | 0.10 | 0.00 | 0.00 | 360 | 238 |
| 49 | Thirumalappa, Hosapalya | 0.08 | 0.00 | 0.00 | 0.23 | 0.00 | 0.00 | 300 | 294 |
| 50 | CMC water supply, Hosapalya | 11.20 | 0.00 | 0.00 | 0.71 | 0.00 | 0.00 | 340 | 266 |
| 51 | Krishna Reddy, Hosapalya | 0.06 | 0.00 | 0.00 | 0.10 | 0.00 | 0.00 | 360 | 266 |
| 52 | Yelahanka new town | 0.07 | 0.00 | 0.00 | 0.28 | 0.00 | 10.43 | 0 | 0 |
| 53 | Thippenahalli | 0.83 | 0.00 | 0.00 | 0.33 | 0.00 | 0.00 | 0 | 0 |
| 54 | HSR 2nd sector, Somasundarapalya | 18.58 | 0.00 | 0.00 | 0.15 | 0.00 | 0.00 | 0 | 0 |
| 55 | Somasundarapalya | 0.62 | 0.00 | 0.11 | 1.01 | 0.00 | 0.00 | 0 | 0 |
| 56 | ITI layout, Hosapalya | 1.79 | 0.00 | 0.00 | 1.25 | 0.00 | 0.00 | 0 | 0 |
| 57 | ITI layout, Hosapalya | 9.39 | 0.00 | 0.00 | 2.36 | 0.00 | 0.00 | 0 | 0 |
| 58 | ITI layout, Hosapalya | 19.20 | 0.00 | 0.00 | 2.36 | 0.00 | 0.00 | 0 | 0 |
| 59 | Swadesh Ind Supplier, Rajajinagar Ind Town | 0.44 | 0.00 | 0.00 | 0.26 | 0.00 | 4.07 | 0 | 0 |

| Sl. No. | Location | Zn | PB | CU | Mn | Al | Cr | TH | Cl |
|---|---|---|---|---|---|---|---|---|---|
| 60 | Swadesh Ind Supplier, Iron Ind, Rajajinagar | 0.67 | 0.00 | 0.00 | 1.35 | 0.00 | 9.89 | 0 | 0 |
| 61 | Anu polymers,Rajajinagar Ind Town | 285.00 | 0.06 | 0.00 | 31.20 | 0.00 | 1.28 | 0 | 0 |
| 62 | Sri washista masion,Rajajinagar | 1.70 | 0.00 | 0.00 | 0.29 | 0.00 | 0.05 | 0 | 0 |
| 63 | Rajajinagar Ind Town | 0.05 | 0.00 | 0.00 | 0.24 | 0.00 | 0.06 | 0 | 0 |
| 64 | Rajhans Enterprises,Rajajinagar Ind Town | 0.14 | 0.00 | 0.00 | 0.45 | 0.00 | 0.08 | 0 | 0 |
| 65 | Reshma Dyeing Factory, Rajajinagar Ind area | 5.29 | 0.00 | 0.00 | 0.54 | 0.00 | 0.10 | 0 | 0 |
| 66 | Rajajinagar Ind area | 2.29 | 0.00 | 0.00 | 0.66 | 0.00 | 0.00 | 0 | 0 |
| 67 | Bommanahalli Ind area | 2.24 | 0.00 | 0.00 | 0.36 | 0.00 | 0.03 | 0 | 0 |
| 68 | Viratnagar, Bommanahalli | 0.11 | 0.00 | 0.00 | 0.07 | 0.00 | 0.58 | 0 | 0 |
| 69 | Viratnagar, Kodichikanahalli | 0.06 | 0.00 | 0.00 | 0.96 | 0.00 | 0.05 | 0 | 0 |
| 70 | Colourline Clothing(I) Ltd, Whitefield | 1.65 | 0.00 | 0.00 | 0.14 | 0.00 | 0.06 | 0 | 0 |
| 71 | Printing press, Rajajinagar Ind area | 0.24 | 0.00 | 0.00 | 1.00 | 0.00 | 0.00 | 0 | 0 |
| 72 | Agrahara Dasarahalli, Rajajinagar | 0.13 | 0.00 | 0.00 | 2.18 | 0.00 | 0.00 | 0 | 0 |
| 73 | Old madras road, Ind area, Virgonagar | 0.13 | 0.00 | 0.00 | 1.67 | 0.00 | 0.00 | 0 | 0 |
| 74 | Bairasandra Kere, Jayanagar | 0.08 | 0.00 | 0.00 | 0.35 | 0.00 | 0.00 | 0 | 0 |
| 75 | Halima, Jayanagar | 0.08 | 0.00 | 0.00 | 0.35 | 0.00 | 0.00 | 0 | 0 |
| 76 | Hosapalya, Hosur road | 0.70 | 0.00 | 0.00 | 0.39 | 0.00 | 0.00 | 0 | 0 |
| 77 | Hosapalya lake, Somasundarapalya road | 0.61 | 0.00 | 0.00 | 0.36 | 0.00 | 0.00 | 0 | 0 |
| 78 | AES layout, Singasandra | 0.06 | 0.00 | 0.00 | 0.33 | 0.00 | 0.00 | 0 | 0 |
| 79 | Dhariwal Ind Ltd, Singasandra | 0.18 | 0.00 | 0.00 | 0.34 | 0.00 | 0.00 | 0 | 0 |
| 80 | Singasandra Main road | 0.09 | 0.00 | 0.00 | 4.00 | 0.00 | 0.00 | 0 | 0 |

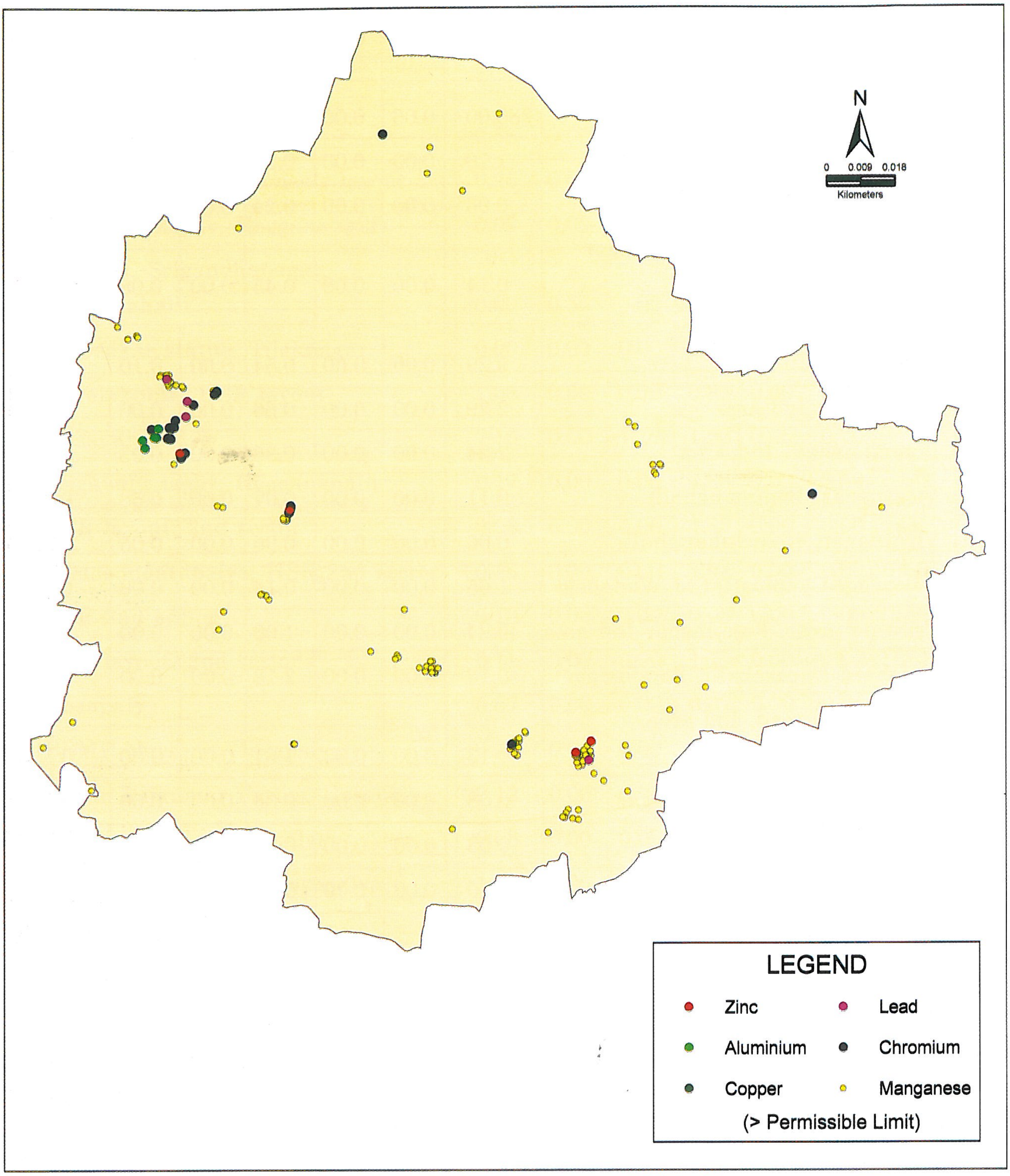



**Figure 17 : Heavy Metal Distribution in Groundwater, Bangalore City (above permissible limit)**

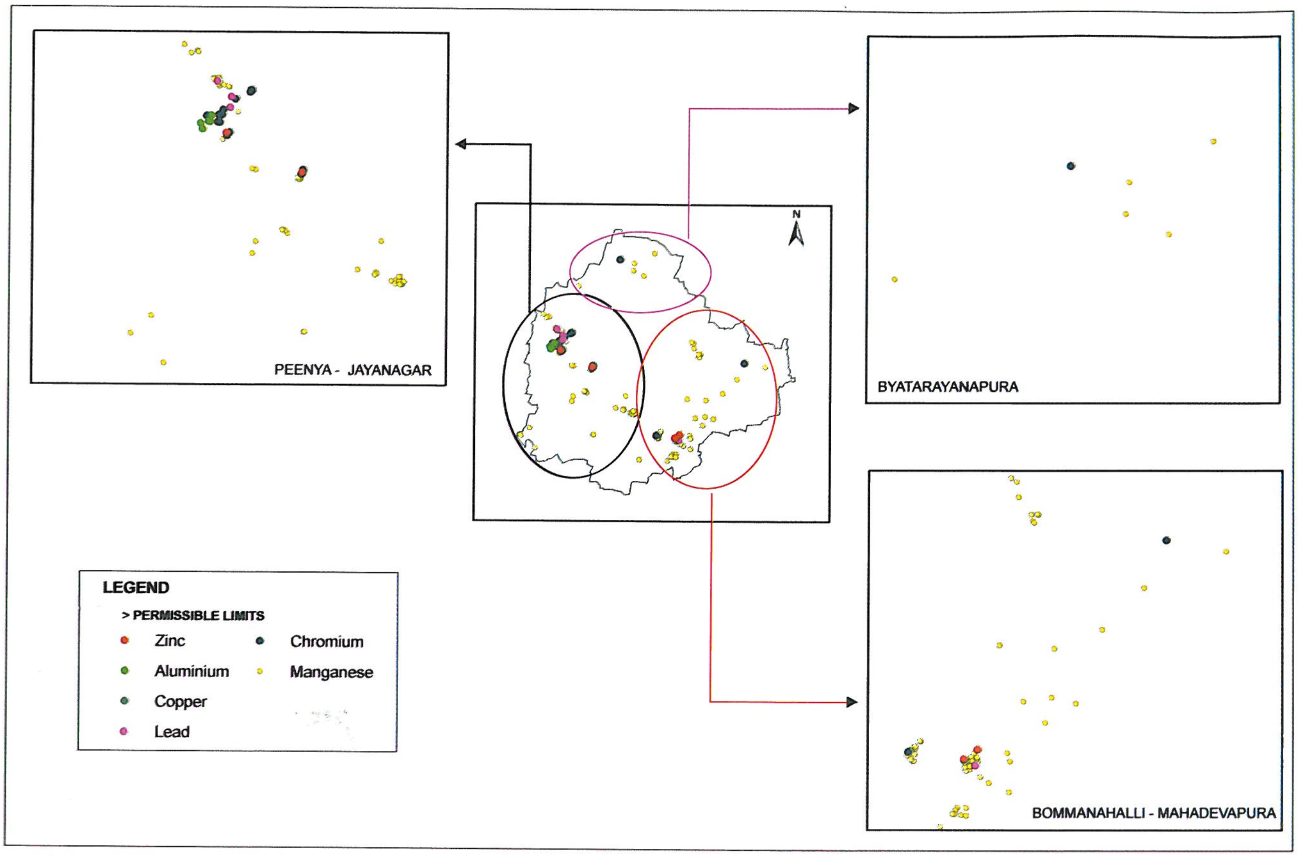



Figure 17.1: Distribution of Heavy Metals in Groundwater, Bangalore city

The details of heavy metal analysed are given below:

## 1. Zinc (Zn):

Normally zinc is not expected in natural groundwater. Zinc is an essential and beneficial element for human growth. The maximum permissible limit of zinc in drinking water is 15 mg/L. The analysis result (Table10 and Table10.1) indicate that of the 275 samples analysed 96% of the samples have the concentration of Zinc between 0.01 and 285 mg/L (averages 2.48 mg/L). The occurrence of Zinc in water samples of the study area are attributed to pollution from industrial effluents. Concentration above 5mg/L can cause a bitter astrignent taste

## 2. Copper (Cu):

Of the 275 water samples tested, only nine samples have detectable concentration of copper between 0.01 mg/L to 1.17 mg/L (average 0.148 mg/L). Among these six are within the desirable limit of 0.05 mg/L and rest of the three samples is within the permissible limit of 1.5 mg/L.

## 3. Lead (Pb):

Desirable/permissible limit of lead in groundwater for drinking purposes is 0.05 mg/L. In the study area, only 12 samples have detectable level of lead in them. The content varies between 0.01 mg/L to 1.25 mg/L (average 0.182 mg/L). Five samples have shown the lead content above the permissible limit rendering such water toxic for drinking.

Lead occur in rocks in sulphide and oxide forms. It also occurs in potasium feldspars. Lead in water may be from industrial and smelter discharges or from the dissolution of old lead plumbing. In sulphide form, lead gets into water if present in the rocks during rock water interaction. Higher concentration of lead in groundwater in the samples is attributable to industrial pollution.

## 4. Manganese (Mn):

Generally manganese in groundwater is present in soluble form. The detectable concentration of Mn is found to vary between 0.01 mg/L and 31.2 mg/L (average 0.601 mg/L). The desirable and permissible limit of manganese in drinking water is 0.10 mg/L and 0.30 mg/L, respectively. The analysis results reveal that 16% of the samples contain manganese above the permissible limit.

Manganese in groundwater particularly around the industrial area of the city (Fig.17 and Fig.17.1) is attributed to the pollution caused by industrial effluents. Higher content of chloride and total hardness in these samples support the contamination of groundwater due to industrial effluents and domestic wastewater.

## 5. Chromium (Cr)

Among the samples analysed, 41 have shown the presence of chromium (Hexavalent form) between 0.01 mg/L to 572 mg/L (average 15.91 mg/L). The content of chromium is above the desirable limit of 0.05 mg/L are in 51% of the 41 samples analysed which are to be rejected for it is carcinogenic.

Chromium salts are used extensively in industrial process and may reach groundwater locally through discharge of waste.

**Figure : 18**
**Chromium polluted groundwater (Peenya Industrial Area)**

**Figure : 19**
**Skin eruption due to longer consumption of Chromium polluted groundwater (Fig. 18)**

The higher content of Chloride, Total Hardness and low pH in association of higher concentration of heavy metals indicates industrial pollution and not lithogenic. The adverse effects like rashes, skin eruption etc., reported in the Peenya industrial area (Fig. 18 and Fig.19) is to be attributed to the long term consumption of water contaminated with chromium above the desirable limit.

## 6. Aluminium (Al):

Alluminium ranging from 0.44 mg/L to 0.97 mg/L (average 0.63 mg/L) is noted in five samples collected in Peenya industrial area. The desirable and permissible limit is 0.03 and 0.20 mg/L respectively. The long term consumption of water with aluminium above the permissible limit causes dementia. Since pH value ranges between 5.49 and 8.94, possibilities of alluminium in groundwater due to lithogenic source is remote

## Bacteriological Signature of Groundwater

Micro-organisms are the parameters that reflects about the usability or otherwise for drinking purpose. The quality of water is judged on the basis of the presence or absence of total coliforms. Presence of Faecal coliforms is used as indicator bacteria. The faecal coliforms are the part of a larger group known as total coliforms.

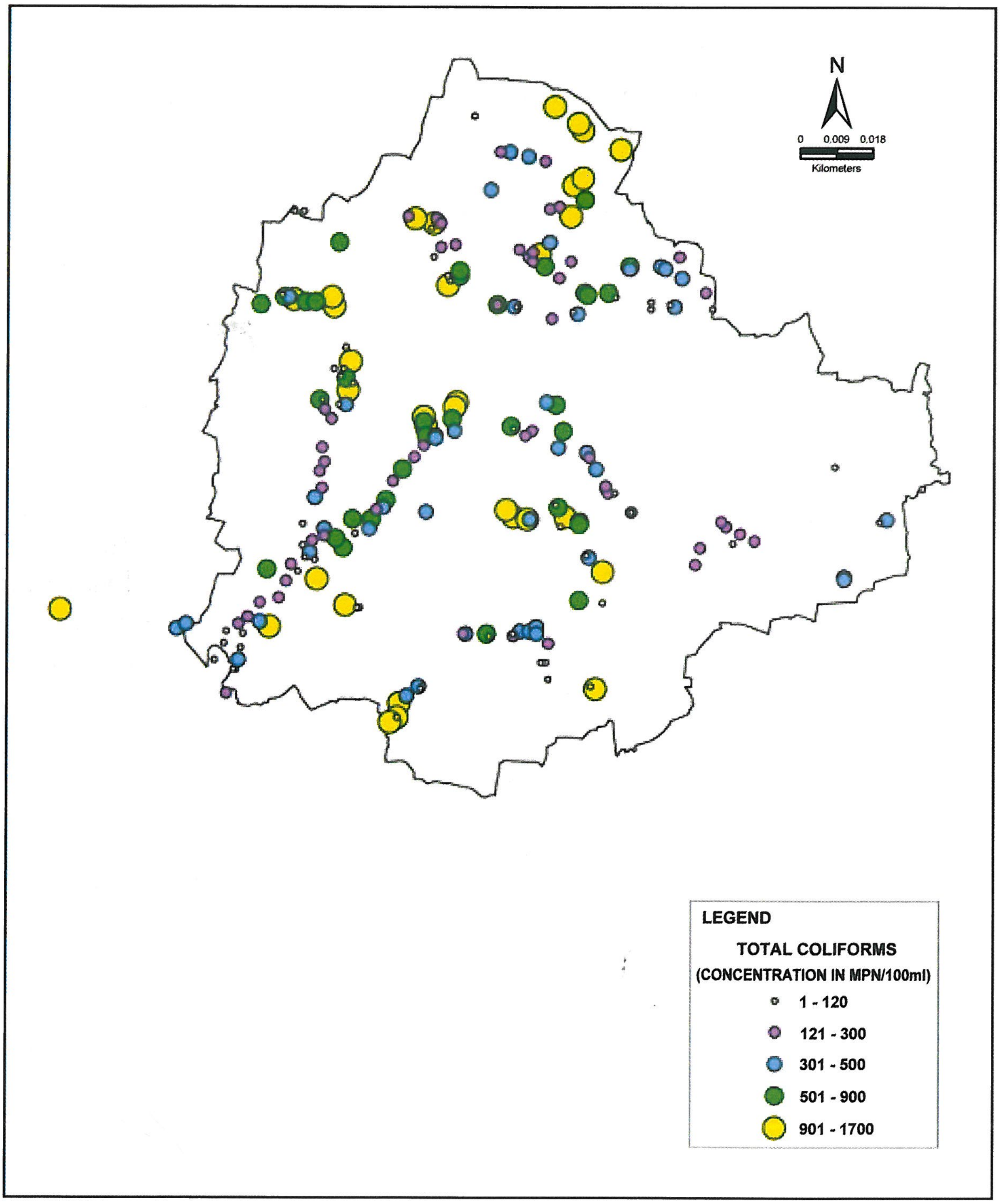



Figure : 20 : Total Coliform and E-coliform in Groundwater, Bangalore City

Groundwater sampling was carried out across major sewage drains for the determination of bacteriological contamination. Sampling locations are given in Fig. 20. The presence of coliforms in water samples was determined by observing there growth in special culture media. The content of coliform bacteria is determined statistically on the basis of analysis of different volume. Of the 259 water samples tested for E-coli and total coliform, 88 % of the samples have shown their presence.

The concentration varies between 1.1 and 1600 MPN/100 ml. The average value with respect to E-coli and total-coli are 488.17 and 489.44 respectively (Table 12).

**Table 12 : Minimum, Maximum and Average values of Coliforms in Groundwater samples (n=259)**

| Constituent | Min | Max | Avg |
|---|---|---|---|
| Totalcoliforms | 1.1 | 1600 | 489.44 |
| E-coliforms | 1.1 | 1600 | 488.17 |

The presence pathogenic bacteria (micro organisms of human origin) are believed due to anthropogenic activities. The presence of E-coli is due to sewage contamination whereas the total-coli suggest the pollution of groundwater due to soil and decaying plant matter. The difference in concentration between e-coli and total-coli in some samples indirectly suggest bacteriological contamination possibly from municipal waste water or leachate from garbage dumps.

## Groundwater Pollution in the vicinity of petrol bunks

Eleven groundwater samples were collected in the vicinity of petrol bunks in the western part of the city (Fig. 21 and Fig. 22) based on the public reports about the contamination. Water samples were tested for oil and grease in groundwater. The oil contamination could be noted in all the 11 samples so collected and analysed. Of 11 samples analysed the oil content vary from 33 mg/L to 91 mg/L. The desirable and permissible limit of mineral oil in drinking water is 0.01 mg/L and 0.03 mg/L. beyond which it gives undesirable taste and odour to the water.

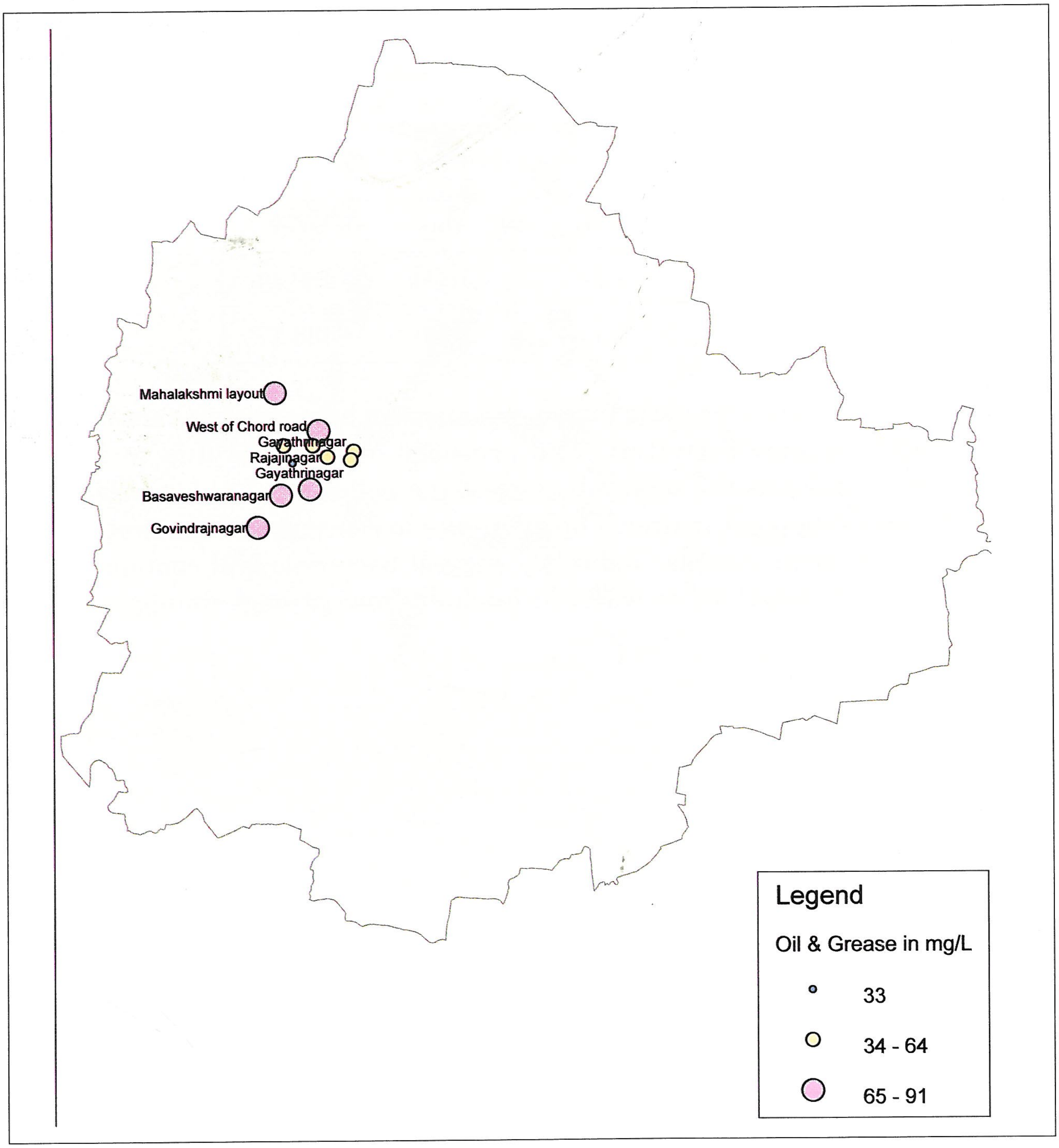



Figure 21 : Oil and Grease in Groundwater, Bangalore city

Figure 22 : Petrol Bunks and Service Stations

## Groundwater Pollution

As per the IS:2003 standards, considering the presence of various chemical constituents already discussed, different layers (over lays) of each of the parameter determined were superimposed and groundwater vulnerability map for drinking purpose in the study area was generated in the GIS environment and given in Fig. 23. The area indicated in red in the map is the one polluted by various constituents and not fit for human consumption. While the area indicated in blue is safe for drinking, the zone shown in yellow represents the constituents within the permissible limit though not in desirable limit.

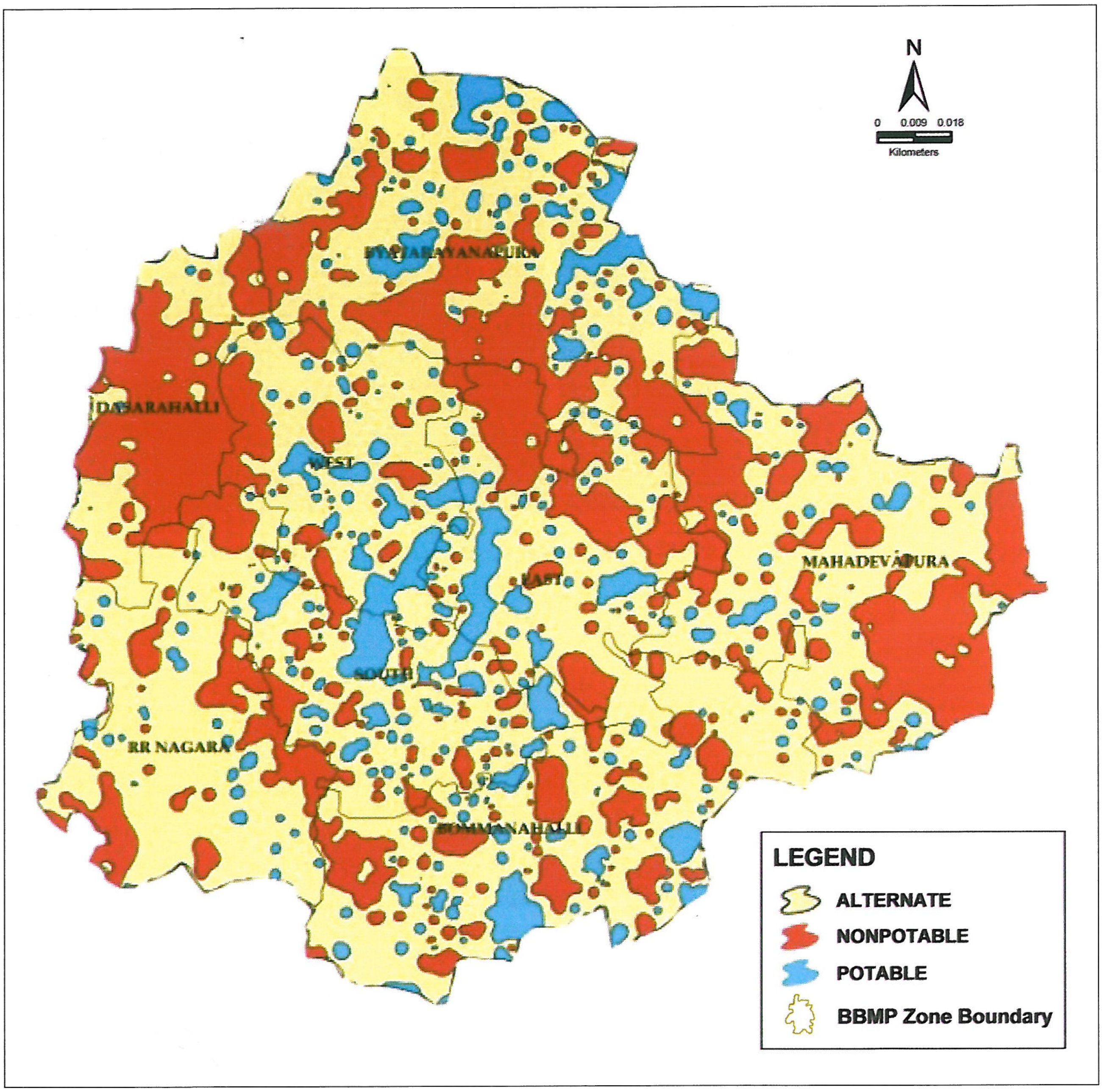



**Figure 23 : Groundwater Quality (drinking) map of Bangalore City (IS 2003, Drinking Water Standards)**

## Conclusions and Recommendations

From the foregoing account of groundwater quality studies carried out in Bangalore City the salient features that emerged out are:

- the groundwater is Na-Ca and $HCO_3$-Cl-$SO_4$ facies dominant
- Positive chlro alkaline index (CAI) values suggest that the sodium and potassium in water are exchanged by calcium and magnesium in the rock following Base Exchange reactions (chlro-alkaline equilibrium).
- The concentration above the permissible limits in case of pH, Total Hardness, Fe, F and $NO_3$, heavy metals and bacteriological contaminations indicate pollution due to anthropological activity.

- Measure be taken to prevent pollution from industrial and sewage effluents which are due to anthropological activities
- Priority be given for conservation of rain water through various rain water harvesting measures
- Bring awareness among the public towards judicious use of available potable water resources

PART – III

# Quality of Lake Waters, Bangalore City

Shashikantha Reddy

## Introduction

The Word 'Lake' and 'tank' denotes the collection of water through a barrier across the drainage in a given geomorphic set up. The nomenclature varies according to size and usage. The Word 'Lake' is more attributed to a large water body having a surface extent of more than 4 hectare and depth of more than 2 metres. A tank refers to that part of the water body useful for agrarian purpose of humans and animals. In the present context, the word 'lake' is largely referred even for tanks.

Bangalore was once referred to as city of 'lakes'. These lakes were constructed by the visionary chieftain Kempegowda and by the Maharaja of erstwhile Mysore State mainly for irrigation purposes. But, it also have served the drinking and fishing needs. These lakes helped replenishing groundwater resources in the vicinity. The terrain in and around old Bangalore, since characterized by undulating topography, could come handy for the construction of lakes across the drainages which are seasonal.

The present day Bangalore which here on shall be referred as Bruhat Bangalore Mahanagar Palike(BBMP) forms part of the catchment of Arkavati and South Pinakini river sub-basins. The drainage systems of these sub-basins cascades down to form three valley systems.

1. Hebbal valley
2. Kormangal chalaghatta valley
3. Vrishbhavathi valley

Part of these three valleys hosts the present day lakes of the BBMP area.

## Distribution of Lakes

Rapid urbanization and enlargement of the city without infrastructural facilities depleted the water resources of the lakes both qualitatively and quantitatively.

A look into the topographic maps published by the Survey of India for different periods has indicated that the 379 lakes that were existing in 1973 drastically got reduced to 246 in 1996. Presently there are only 201 lakes. The original course of natural drainages in most of the parts have been tampered, blocked and narrowed due to illegal enchrochment and bad planning while forming new layouts. The total extent of water spread of these 201 lakes is 2623 Hect. Among these 201 lakes 96 have water spread to its full extent during all the seasons, 82 lakes remain dry and the rest are seasonal. The smallest and the largest of the lakes are at Srigandada Kaval, Near Rajiv Gandhi Nagar (0.0941Hect) and Bellandur (307.35 Hect), respectively.

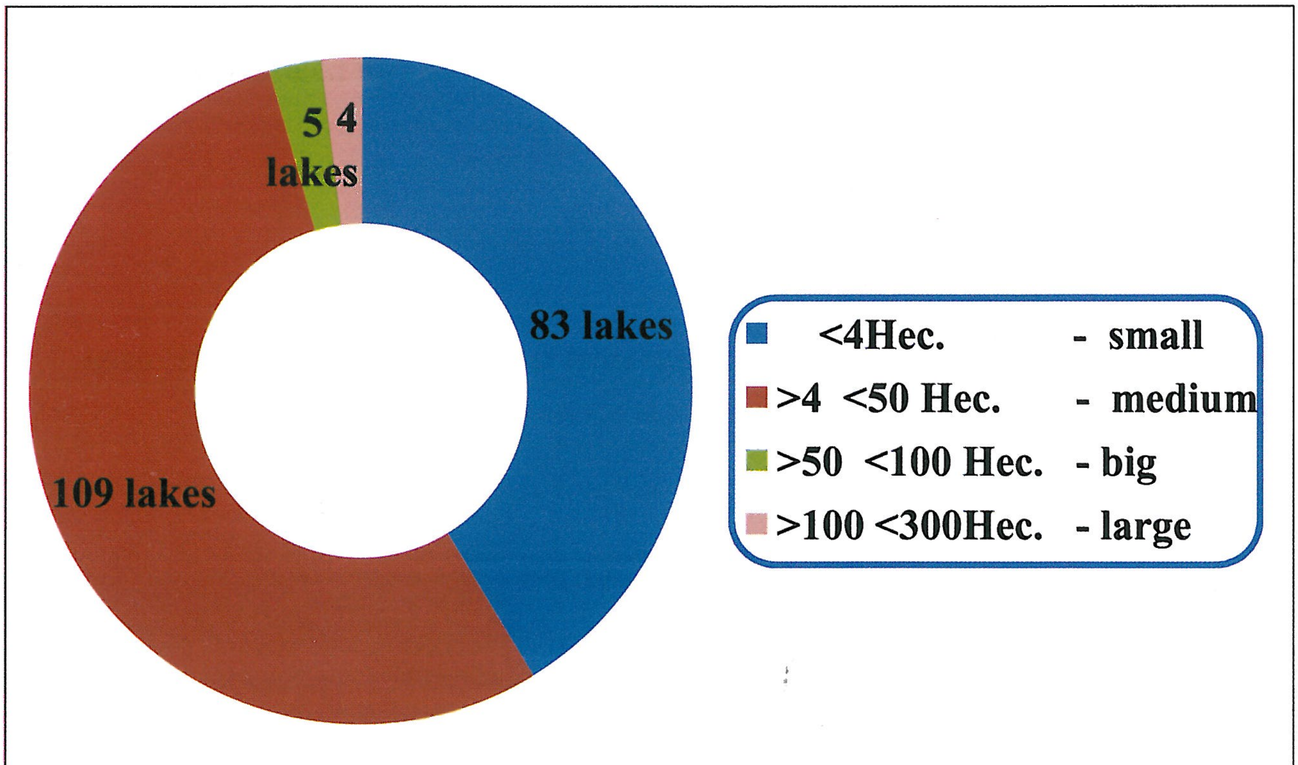



**Figure 1 : Classification of Lakes based on Extent in BBMP area**

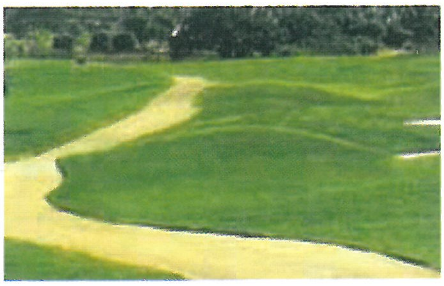
Following are some of the lakes that are no more existing due to urbanization effects over the years in BBMP area.

Figure 2 : Kempegowda Central Bus Stand constructed in the erstwhile Dharmambudhi Lake

- Sholay lake converted to football stadium
- Akkitimmanahalli lake converted to corporation Hockey stadium
- Sampangi lake converted to Kanteerava Sports Complex
- Dharmanbudi lake converted to Kempegowda Bus station.
- Challaghatta lake converted to Karnataka Golf Association
- Koramangala lake converted to National games complex
- Siddikatte lake converted to K.R.Market
- Karanji tank is now Gandhibazaar area
- Kempambuddi is now a sewerage collection tank.
- Nagashettihalli lake converted to Ambedkar Medical collect
- Domlur lake converted to BDA layout
- Millers lake converted to Gurunanak Bhavan Badminton Stadium
- Subashnagar lake changed to residential lay out
- Kurubarahalli lake converted to residential layout
- Kodihalli lake converted to residential layout
- Sirivaigalu lake converted to residential layout
- Marenahalli lake converted to residential layout
- Shivanahalli lake converted to Bus stand.
- Channamma tank changed to burial ground, Bangashakar II stage
- Puttenahalli tank converted to J.P.Nagtar 6th pHase

- Jakkarayanakere is converted into sports grounds
- Kamakshipalya lake converted into Sports ground
- Balayyankere is converted into sports ground
- Dasarahalli tank is converted into Ambedkar Stadium.

Sports village residential layout was once Koramangala Tank



Challaghatta Tank lost to Golf Course

Stadium complex was once Sampangi Tank.

**Figure 3 : Impact of Urbanisation on City Lakes**

## Ecology of Lakes

The lakes of Bangalore have attained important ecological status. The fresh water plants communities in the lakes have a large number of organisms like Periphytons, Flagella bodies, Insects, Mollusca etc. These lakes form an important eco-system in the city. The lakes of Bangalore host varieties of fauna & flora and fishes and birds. To name a few among them are:

**Birds** : King fisher, Pond Herons, Comorants, purple Moorhen Purple Heron, Pheasant tailed Jackhara

**Flora** : Typha,Citylotus,algae, tapegeass,terns reeds

**Fauna** : Fresh water turtle, frogs, crabs, molluses,

**Fish** : Common carp, cross carp, kafla, Rohu etc.,

# Quality of Lake Water

## Collection and analysis of water samples

Totally 161 lake water samples from 96 lakes of BBMP area were collected during the months of June and July 2010. Water samples so collected from the lake were mainly at the outlet point and where ever approachable, sample collection were made at inlet or outlet or mid points. The samples were collected in one litre white polythene containers as per the specified standards. Water temperature and other related physical properties were determined on spot.

For dissolved oxygen, Borosilicate Class bottles with preservatives like sodium oxide and Manganese sulphate and for the determination of presence of bacteria Borosilicate sterilized Class bottles were used. The samples so collected were got analyzed on the same day in the Laboratory at the Directorate of Mines and Geology. The chemical analysis includes determination of important chemical constituents, heavy metals and bacteria.

## Results and discussion

## On site analysis:

The temperature of lake water varied from 25°C to 30°C and the pH range from 6 to 8. Based on physical observation and physical properties in regard to color and turbidity the transparency of the lake water was recorded. None of the BBMP lake water is clear as they were associated with algal growth.

**Figure 4 : Pollution and algal growth in Varturu lake**

## Table 1 : Chemical analysis results of lake water samples, Bangalore City

| | | | Chemical constituents (mg/L) except pH | | | | | | | | | Heavy Metals (mg/L) | | | | | | Coliform Bacteria | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Name of the Lake | Extent in Hect. | Sample Location | Cl | $PO_4$-P | TSS | DO | COD | $NO_3$ | TH | F | pH | Zn | pb | Cu | Mn | Al | Cr | EC MPN/ 100 ml | TC MPN/ 100 ml |
| Amruthalli kere | 8.7 | Inlet | 156.8 | 5.11 | 37 | 2.2 | 19.2 | 4.45 | 272 | 0.32 | 7.9 | 0.11 | Nil | Nil | 0.5 | | | | |
| Amruthalli kere | | Middle | 131.6 | 2.55 | 16 | | 19.2 | 10.87 | 172 | 0.49 | 8.37 | 0.17 | Nil | Nil | 0.19 | | | | |
| Amruthalli kere | | Outlet | 131.6 | 2.09 | 23.5 | | 19.2 | 10.97 | 172 | 0.52 | 8.36 | 0.21 | Nil | Nil | 0.18 | | | | |
| Andrahalli kere | 5.44 | Inlet | 358 | 0.1 | 136.5 | 9.2 | Nil | 6.25 | 588 | 3.51 | 8.34 | 0.14 | Nil | Nil | 0.82 | 2.46 | | 160000 | 160000 |
| Andrahalli kere | | Outlet | 258 | 0.2 | 191 | 6.8 | Nil | 7.07 | 596 | 3.94 | 8.18 | 0.15 | Nil | 0.01 | 0.68 | 2.42 | | 160000 | 160000 |
| Anjanapura kere | 7.38 | Inlet | 190 | 0.2 | 67.5 | 6.2 | 40 | 4.715 | 224 | 0.54 | 8.12 | 0.17 | Nil | Nil | 0.24 | | | | |
| Arakere | 10.8 | Inlet | | | 5740 | Nil | | 5.46 | | 0.43 | 8.06 | | | | | | | | |
| Arehalli sanna kere I | 5.25 | Inlet | 44.9 | 0.05 | 39 | 6 | nil | 7.74 | 164 | 0.37 | 8.17 | 0.05 | Nil | Nil | 0.21 | | 0.05 | | |
| Arehalli sanna kere II | 0.5 | Inlet | 45 | 2.06 | 13 | 12.8 | Nil | 4.26 | 132 | 0.82 | 9.46 | 0.38 | Nil | Nil | 0.16 | | | | |
| Attur Lake | | Outlet | 34 | 0.1 | 65.5 | | | 26 | 84 | 0.46 | 7.22 | 0.19 | 0.11 | 0.1 | 0.61 | 68.9 | | | |
| Attur Lake | | Middle | 22 | 0.2 | 67.5 | | | 27 | 88 | 0.56 | 7.72 | 0.1 | 0.12 | 0.08 | 0.56 | 63.4 | | | |
| Attur Lake | 28.7 | Inlet | 25 | 0.05 | 76 | 7 | | 36.3 | 76 | 0.37 | 7.63 | | | | | | | | |
| Bagalkunte Kere | 3.94 | Inlet | 109 | 2.05 | 72.5 | 9 | 96 | 7.08 | 240 | 0.18 | 8.74 | 0.12 | Nil | Nil | 0.3 | | | | |
| Balajinagar Kere | 3.75 | Inlet | 123 | 0.2 | 8.5 | 5.8 | Nil | 4.31 | 260 | 0.65 | 7.47 | 0.06 | Nil | 0.01 | 0.41 | 0.79 | | | |
| Basapura kere(1) | 2.5 | Inlet | 412 | 0.55 | 1 | 5.4 | 57.6 | 8.02 | 500 | 0.52 | 8.36 | 0.07 | Nil | Nil | 0.05 | | | | |
| Begur tank | | Middle | 132 | 0.01 | 78 | | Nil | 2.34 | 184 | 0.48 | 8.35 | 0.06 | Nil | Nil | 0.1 | | | | |
| Begur tank | | Outlet | 185 | 0.11 | | | Nil | 2.62 | 316 | 0.48 | 7.97 | 0.07 | Nil | Nil | 0.07 | | | | |
| Begur tank | 49.8 | Inlet | 277 | 1.04 | 245 | Nil | 56.64 | 9.73 | 272 | 0.72 | 8.07 | 0.1 | 0.03 | Nil | 0.54 | | | | |
| Belandur Tank | | Outlet | 132 | 0.1 | 150 | Nil | 57.6 | 7.48 | 220 | 0.38 | 7.87 | 0.13 | Nil | Nil | 0.22 | | | | |
| Belandur Tank | | Middle | 134 | 0.1 | 192 | | 76.8 | 7.91 | 244 | 0.37 | 7.8 | 0.12 | Nil | Nil | 0.22 | | | | |
| Belandur Tank | 307.35 | Inlet | 109 | 5.05 | 498 | Nil | 96 | 9.73 | 208 | 0.4 | 7.51 | 0.19 | Nil | Nil | 0.23 | | | | |
| Belandur Tank | | Inlet - 2 | 148 | 5.11 | 363 | | 134.4 | 11.165 | 240 | 0.36 | 7.63 | 0.44 | 11 | 0.07 | 0.28 | | | | |
| Bhattrahalli Kere | 4.76 | Inlet | 476 | Nil | | 10 | 18.88 | 5.9 | 220 | 0.66 | 8.29 | 0.06 | 0.03 | 0.01 | 0.12 | 1.38 | | | |
| Bhattrahalli Kere | | Outlet | 468 | Nil | | | 18.88 | 6.1 | 208 | 0.61 | 8.67 | 0.09 | Nil | Nil | 0.13 | 2.42 | | | |
| Busegowdana kere | 5.79 | Inlet | 78.4 | 0.01 | 233 | 3.6 | 94.4 | 11.26 | 168 | 0.42 | 8.32 | 0.1 | Nil | 0.04 | 0.88 | | 0.03 | 900 | 900 |

| | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Busegowdana kere | | Outlet | 75.6 | 0.01 | 366 | | 56.64 | 12.71 | 166 | 0.42 | 8.44 | 0.16 | Nil | 0.04 | 0.84 | | 0.04 | | |
| Chikkabasavanapura Kere | | Outlet | 277 | Nil | | | 96 | 5.99 | 196 | 0.76 | 8.38 | 0.06 | Nil | Nil | 0.07 | 2.28 | | | |
| Chikkabasavanapura Kere | 5.11 | Inlet | 277 | Nil | | 9.2 | | 6.13 | 184 | 0.76 | 8.28 | 0.04 | Nil | Nil | 0.07 | 1.73 | | | |
| Chinnappanahalli Kere | | Middle | 252 | 0.1 | 7.5 | | Nil | 6.73 | 236 | 0.47 | 7.72 | 0.03 | Nil | Nil | 0.07 | | | | |
| Chinnappanahalli Kere | 2.63 | Inlet | 272 | 0.2 | 15.5 | 1.6 | 384 | 6.89 | 424 | 0.48 | 7.5 | 0.05 | Nil | 0.02 | 1.59 | | | | |
| Chinnappanahalli Kere | | Outlet | 230 | 0.01 | 3.5 | | 19.2 | 7.17 | 192 | 0.51 | 7.68 | 0.6 | Nil | Nil | 0.21 | | | | |
| Devara Beesanahalli Kere | 4.64 | Inlet | 442 | 5.21 | 145.5 | 3.6 | | 4.51 | 316 | 0.44 | 8.51 | 0.2 | Nil | 0.04 | 0.09 | | | >1600 | >1600 |
| Devara Beesanahalli Kere | | Middle | 291 | 5.16 | 191 | | | 12.08 | 368 | 0.45 | 8.11 | 0.12 | Nil | 0.03 | 0.07 | | | | |
| Devarakere | | Middle | 171 | 0.01 | 809 | | 38.4 | 2.72 | 232 | 0.63 | 8.82 | 0.58 | | Nil | 0.07 | | | | |
| Devarakere | 1.88 | Inlet | 168 | 0.01 | 1261 | 7.4 | 38.4 | 3.01 | 232 | 0.65 | 8.76 | 0.04 | | Nil | 0.06 | | | | |
| Doddakalsandra kere | 5.75 | Inlet | 423 | 5.06 | 15 | 2.2 | | 4.94 | 476 | 0.54 | 8.26 | 0.06 | Nil | Nil | 0.26 | | | | |
| Doddakalsandra kere | | Outlet | 431 | 5.03 | 4.5 | | 18.88 | 7.37 | 480 | 0.56 | 8.35 | 0.06 | Nil | Nil | 0.24 | | | | |
| Doddanekkundi Lake | | Outlet | 202 | 2.55 | 12 | | 18.88 | 4.65 | 360 | 0.37 | 7.97 | 0.12 | Nil | 0.01 | 0.58 | 1.18 | | | |
| Doddanekkundi Lake | 45.29 | Inlet | 305 | 0.55 | 9 | Nil | 56.64 | 14.09 | 460 | 0.46 | 7.65 | 0.17 | Nil | 0.02 | 0.67 | 1.19 | | | |
| Doraikere | | Outlet | 132 | 0.51 | 4 | | 38.4 | 5.35 | 444 | 0.55 | 7.67 | 0.05 | | Nil | 0.26 | | | | |
| Doraikere | 11.67 | Inlet | 148 | 5.33 | 9 | 2 | Nil | 5.47 | 404 | 0.72 | 7.59 | 0.06 | | 0.01 | 0.28 | | | | |
| Dubasipalya kere | | Outlet - 2 | 120 | 0.05 | 16.5 | 3.8 | 38.4 | 13.73 | 116 | 0.5 | 8.22 | 0.09 | Nil | Nil | 0.36 | | | | |
| Dubasipalya kere | 5.98 | Inlet | 123 | 0.05 | 10.5 | | 38.4 | 14.94 | 124 | 0.49 | 8.18 | 0.01 | Nil | Nil | 0.37 | | | | |
| Garepalya Kere | 7.3 | Inlet | 1148 | 2.11 | 82.5 | 2.2 | 288 | 51.38 | 564 | 0.42 | 8.39 | 0.06 | 0.02 | Nil | 0.21 | | | | |
| Gottigere Kere | 12.93 | Inlet | 204 | 0.01 | | 2 | | 5.62 | 320 | 0.41 | 7.89 | 0.04 | Nil | Nil | 0.72 | 0.89 | | Pre sent | Pre sent |
| Halagevaderahallikere | 2.85 | Inlet | 64.4 | 0.2 | 20 | 7.2 | 19.2 | 3.83 | 196 | 0.35 | 7.74 | 0.05 | Nil | Nil | 0.26 | 0.11 | | | |
| Haralakunte Kere (Somasandrakere) | 5.03 | Inlet | 736 | 5.11 | 4190 | Nil | 321 | 23.96 | 672 | 0.37 | 8.14 | 0.21 | 0.04 | Nil | 0.84 | | | | |
| Haralur Kere | 9.58 | Inlet | 269 | 0.01 | 107 | 4.6 | 38.4 | 3.09 | 196 | 0.59 | 8.25 | 0.08 | Nil | Nil | 0.11 | | | | |
| Hebbal Kere | | Outlet | 185 | 0.01 | 39 | | 18.9 | 3.53 | 212 | 0.36 | 8.56 | 0.08 | Nil | Nil | 0.18 | | | | |
| Hebbal Kere | 52.81 | Inlet | 126 | 1 | 20 | 3.2 | 18.9 | 5.22 | 264 | 0.33 | 7.65 | 0.18 | Nil | Nil | 0.26 | | | >1600 | >1600 |
| Hemmigepura Kere | 5.93 | Inlet | 109 | 0.2 | 15 | 2.8 | 19.2 | 2.46 | 368 | 0.56 | 8.32 | 0.06 | Nil | Nil | 0.08 | | | | |
| Hemmigepura Kere | | Outlet | 87 | 0.1 | 12 | | 19.2 | 3.09 | 184 | 0.39 | 8.47 | 0.05 | Nil | Nil | 0.13 | | | | |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Herohalli Kere | 12.26 | Inlet | 249 | 0.2 | 89 | 9.6 | 151 | 6.35 | 296 | 0.6 | 8.46 | 0.19 | 0.08 | 0.08 | 0.95 | | | 160000 | 160000 |
| Horamavu Agara Kere | | Outlet | 602 | 0.01 | 49 | - | 132 | 6.36 | 288 | 0.6 | 8.83 | | | | | | | | |
| Horamavu Agara Kere | 17.3 | Inlet | 596 | 0.01 | 50 | 5.8 | 113 | 7.01 | 292 | 0.61 | 8.81 | 0.05 | Nil | 0.04 | 0.18 | | | 1600 | 1600 |
| Hosakere kere | 15.54 | Inlet | 210 | 1 | 5.5 | 2.8 | 94.4 | 2.64 | 440 | 0.44 | 8.07 | 0.13 | Nil | 0.01 | 0.45 | | | >1600 | >1600 |
| Huchappana palya kere | | Outlet | 118 | 0.53 | 21 | | Nil | 18.23 | 260 | 0.51 | 7.93 | | | | | | | | |
| Huchappana palya kere | 2.06 | Inlet | 115 | 0.55 | 62.5 | 7.2 | Nil | 19.64 | 252 | 0.92 | 8.18 | | | | | | | | |
| Hulimavu kere | 44.26 | Inlet | 221 | 0.2 | 18 | Nil | Nil | 2.69 | 276 | 0.43 | 8.09 | 0.06 | Nil | 0.01 | 0.47 | 0.87 | | | |
| Hulimavu kere | | Outlet | 176 | 2.51 | 15 | | Nil | 9.56 | 372 | 0.56 | 7.81 | 0.46 | Nil | 0.01 | 0.28 | 2.23 | | | |
| Ibbalur Kere | | Periphery | 218 | 5.05 | 77 | 4 | - | 7.55 | 348 | 0.87 | 7.96 | 0.07 | Nil | 0.02 | 0.43 | | | >1600 | >1600 |
| Ibbalur Kere | 3.16 | Inlet | 213 | 5.09 | 160 | | | 8.63 | 340 | 0.88 | 8.13 | 0.08 | Nil | 0.01 | 0.11 | | | | |
| Ittamadu | 0.5 | Inlet | 148 | 5.03 | 505 | | Nil | 8.22 | 364 | 0.71 | 8.31 | 0.2 | Nil | Nil | 0.72 | | | | |
| Ittamadu | | Periphery | 140 | 5.03 | 4.5 | 11.2 | Nil | 8.81 | 372 | 0.63 | 8.22 | 0.14 | Nil | Nil | 0.57 | | | | |
| Jakkur kere | 58.97 | Inlet | 213 | 0.11 | 10 | | | 5.701 | 148 | 0.71 | 9.49 | 0.06 | Nil | Nil | 0.08 | | | | |
| Jakkur kere | | Outlet | 316 | 0.11 | 4.5 | 6.2 | | 7.78 | 516 | 0.46 | 8.33 | 0.05 | Nil | Nil | 0.047 | | | | |
| Janardhankere | 1.57 | Inlet | 185 | 0.01 | 728.5 | 5.8 | 38.4 | 3.31 | 312 | 0.68 | 8.43 | 0.05 | | Nil | 0.07 | | | | |
| Jattigarahalli kere | | Outlet | 19.6 | 0.01 | 93.5 | | Nil | 4.2 | 44 | 0.35 | 9.92 | 0.12 | Nil | Nil | 0.17 | | | | |
| Jattigarahalli kere | 2.46 | Inlet | 16.8 | 0.01 | 12 | 4 | Nil | | 48 | 0.34 | 9.52 | 0.1 | Nil | Nil | 0.09 | | | | |
| Jimkenahalli Kere | 2.35 | Inlet | 129 | 0.01 | 32 | | 40 | 4.29 | 144 | 0.41 | 8.49 | 0.13 | Nil | Nil | 0.23 | | | | |
| JP Park ( Mattikere) | | Inlet | 151 | Nil | 69 | 3.6 | 37.76 | 3.47 | 172 | 0.61 | 8.45 | 0.17 | Nil | Nil | 0.76 | | | 160000 | 160000 |
| JP Park ( Mattikere) | 33.9 | Outlet | 154 | Nil | 4.5 | | 37.76 | 3.81 | 184 | 0.63 | 8.74 | 0.18 | Nil | Nil | 0.4 | | | | |
| Kalena Agrahara kere | 2.06 | Inlet | 109 | 0.01 | 27 | 10.8 | 20 | 2.397 | 200 | 0.34 | 8.13 | 0.12 | Nil | Nil | 0.35 | | | | |
| Kalkere Agara Kere | 63.37 | Inlet | 204 | 2 | 2.5 | 1.4 | 37.76 | 7.23 | 340 | 0.42 | 7.63 | 0.13 | Nil | 0.04 | 0.21 | | | 1600 | 1600 |
| Kamgondanahalli Kere (Ragavendra Lyt) | 11.94 | Inlet | 221 | 5.11 | 23 | 2.4 | 38.4 | 5.3 | 468 | 0.37 | 8.11 | 0.31 | Nil | Nil | 0.31 | | 0.05 | | |
| Kasavanahalli Kere | 15.83 | Inlet | 230 | 0.01 | 175.5 | 8.2 | 57.6 | 3.48 | 196 | 0.51 | 8.51 | 0.08 | Nil | Nil | 0.17 | | | | |
| Kattiganahalli Kere | 8.08 | Inlet | 61.6 | 0.01 | 13 | 4.4 | 19.2 | 4.59 | 108 | 0.45 | 8.42 | 0.04 | Nil | Nil | 0.1 | | | | |
| Kembathanahalli kere | 3.06 | Inlet | 140 | 0.21 | | | 20 | 4.85 | 164 | 0.72 | 7.22 | | | | | | | | |
| Kembathnalli kere III | 1.79 | Inlet | 30.8 | 0.11 | | | 20 | 63.11 | 128 | 0.27 | 7.21 | | | | | | | | |
| Kengeri kere | 10.09 | Inlet | 238 | 0.2 | 280 | 8 | 113.3 | 6.54 | 200 | 0.71 | 9.65 | 0.07 | Nil | 0.02 | 0.19 | | | >1600 | >1600 |
| Kodagi Singasandra kere | 4.21 | Inlet | 274 | 0.01 | 29 | 12.2 | 37.76 | 6.796 | 192 | 0.92 | 9.14 | 1.08 | Nil | Nil | 0.09 | | | | |
| Konnapana agrahara | 1.88 | Inlet | 190.4 | 0.01 | 9 | 4.2 | Nil | 4.83 | 184 | 0.68 | 8.32 | 0.05 | Nil | Nil | Nil | | | | |
| Kottanurkere | 6.86 | Inlet | 199 | 0.05 | 7.5 | 6.2 | 40 | 2.74 | 188 | 0.68 | 8.35 | 0.16 | Nil | Nil | 0.25 | | Nil | | |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| KR Puram (BEML) | | Outlet | 157 | 2.55 | 15 | | 76.8 | 4.715 | 284 | 0.54 | 8.19 | 0.06 | Nil | Nil | 0.18 | | | | |
| KR Puram (BEML) | 10.81 | Inlet | 154 | 5.11 | 1.5 | 4.8 | | 6.88 | 272 | 0.51 | 8.23 | 0.08 | Nil | Nil | 0.2 | | | | |
| Kudlu dodda kere | 19.79 | Inlet | 297 | 2.01 | 99 | | 38.4 | 2.35 | 248 | 0.43 | 8.87 | 0.14 | Nil | Nil | 0.22 | | | | |
| Kudlu dodda kere | | Outlet | 288 | 2.5 | 6723 | 7.6 | 480 | 5.41 | 284 | 0.45 | 9.27 | 0.09 | Nil | Nil | 0.07 | | | | |
| Kundala Halli Kere | | Outlet | 255 | 0.2 | 435.5 | | | 3.03 | 216 | 0.64 | 8.64 | 0.05 | Nil | 0.02 | 0.03 | | | | |
| Kundala Halli Kere | | Middle | 224 | 0.5 | 1590 | | 18.88 | 4.74 | 264 | 0.34 | 7.99 | 0.04 | Nil | 0.02 | 0.04 | | | | |
| Kundala Halli Kere | 9.52 | Inlet | 224 | 0.5 | 865 | 2.6 | 0 | 4.96 | 248 | 0.33 | 8.2 | 0.05 | Nil | 0.02 | 0.02 | | | >1600 | >1600 |
| Lalbagh Kere | 16.04 | Inlet | 67 | 0.01 | 43.5 | 4.8 | Nil | 2.14 | 136 | 0.53 | 9 | 0.05 | Nil | Nil | 0.03 | | | | |
| Lingadeeranahalli kere | 1.98 | Inlet | 16.8 | 0.2 | 20.5 | 4.4 | Nil | 5.02 | 172 | 0.32 | 7.51 | 0.06 | Nil | Nil | 0.45 | | | | |
| Lingadeeranahalli Kere(Andrahalli) | 1.96 | Inlet | 358 | 0.2 | 118 | | 18.88 | 7.34 | 596 | 4.41 | 8.26 | 0.25 | Nil | 0.01 | 0.6 | 1.29 | | 160000 | 160000 |
| Lingadeeranahalli Kere(Andrahalli) | | Outlet | 339 | | | | | | 396 | | | 0.01 | 0.01 | 0.02 | 0.4 | 1.13 | | | |
| Madivala tank | | Middle | 140 | 0.01 | 10 | | 18.88 | 4.21 | 212 | 0.36 | 8.36 | 0.06 | Nil | Nil | 0.12 | | | | |
| Madivala tank | | Outlet | 151 | 0.2 | 6 | | 56.64 | 5.06 | 204 | 0.37 | 7.37 | 0.07 | Nil | Nil | 0.11 | | | | |
| Madivala tank | 94.7 | Inlet | 112 | 1 | 265 | Nil | 227 | 15.83 | 220 | 0.36 | 7.16 | 0.5 | Nil | 0.08 | 0.24 | | | 160000 | 160000 |
| Mailasandra kere (Sunakal palyakere) | | Outlet | 67.2 | 0.05 | 45 | | 18.88 | 8.08 | 92 | 0.90 | 0.3 | 0.06 | Nil | 0.01 | 0.24 | | | | |
| Mangammana Palya Kere | 1.97 | Inlet | 372.4 | 0.05 | 71 | 12.2 | 153.6 | 13.3 | 144 | 1.23 | 8.99 | 0.05 | Nil | Nil | 0.11 | | | | |
| Munnekolalu Kere | | Outlet | 207 | 1 | 159 | | 56.64 | 5.29 | 268 | 0.31 | 7.49 | 0.17 | Nil | 0.04 | 0.13 | | | | |
| Munnekolalu Kere | 4.1 | Inlet | 168 | 0.4 | 127 | 1.2 | 37.76 | 15.68 | 296 | 0.31 | 7.69 | 0.21 | Nil | 0.04 | 0.12 | | | >1600 | >1600 |
| Nagarabhavi kere | 1.17 | Inlet | 36.4 | 0.05 | 77 | 4 | 19.2 | 18.7 | 204 | 0.38 | 7.37 | 0.05 | Nil | Nil | 0.54 | | | | |
| Nagasandra Kere | 13.07 | Inlet | 378 | 5.01 | 363 | Nil | 153.6 | 7.48 | 612 | 0.32 | 7.37 | 0.26 | 0.27 | Nil | 0.6 | | | | |
| Nagavara Kere (Lumbini Garden) | | Outlet | 207 | 0.05 | 6 | | Nil | 4.17 | 180 | 0.56 | 7.89 | 0.05 | 0.02 | 0.02 | 0.12 | 1.24 | | | |
| Nagavara Kere (Lumbini Garden) | 20.33 | Inlet | 204 | 0.05 | 16.5 | 5 | 18.88 | 4.2 | 188 | 0.56 | 7.96 | 0.05 | 0.02 | Nil | 0.11 | 0.82 | | | |
| Nallurahalli Tank | 11.61 | Inlet | 314 | 2.26 | 27.5 | 7.6 | 57.6 | 6.75 | 416 | 0.41 | 8.04 | 0.08 | Nil | Nil | 0.21 | | | | |
| Nallurahalli Tank | | Outlet | 316 | 1.22 | 14 | | Nil | 8.31 | 400 | 0.42 | 7.43 | 0.05 | Nil | Nil | 0.24 | | | | |
| Nallurahalli Tank | | Middle | 294 | 1.1 | 90 | | 19.2 | 8.37 | 408 | 0.42 | 7.92 | 0.05 | Nil | Nil | 0.12 | | | | |
| Narasapanhalli kere | 19.16 | Inlet | 650 | 2.09 | 77.5 | 1.6 | Nil | 7.05 | 768 | 0.94 | 8.33 | 0.08 | | | 0.45 | | | | |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Thalaghattapura chikka kere | 0.69 | Inlet | 11.2 | 0.01 | 21.5 | 5.8 | Nil | 6.71 | 48 | 0.2 | 7.36 | 0.13 | Nil | Nil | 0.08 | | | | |
| Thindlu Lake | 41.77 | Inlet | 95.2 | 0.2 | 6.5 | 7.2 | 56.64 | 6.08 | 184 | 0.26 | 7.84 | 0.15 | Nil | 0.02 | 0.21 | | | 1600 | 1600 |
| Thindlu Lake | | Outlet | 106 | 0.1 | - | - | - | 7.55 | 240 | 0.44 | 8.37 | 0.12 | Nil | 0.01 | 1.05 | | | - | - |
| Ulsoor Kere | 43.81 | Inlet | 92 | 0.01 | 42 | 11.2 | 113.3 | 3.87 | 100 | 0.37 | 8.73 | 0.1 | Nil | Nil | 0.1 | | | | |
| Ulsoor Kere | | Outlet | 101 | 0.05 | 22 | | 75.52 | 3.87 | 100 | 0.37 | 8.58 | 0.07 | Nil | Nil | 0.19 | 1.12 | | | |
| Ulsoor Kere | | Middle | 92 | 0.05 | 6 | | 75.52 | 4.81 | 108 | 0.37 | 8.93 | 0.08 | Nil | 0.01 | 0.21 | | | | |
| Uttarahalli kere | 4.51 | Inlet | 45 | 0.5 | 21.5 | 4.2 | Nil | 7.97 | 184 | 0.77 | 7.03 | 0.71 | 0.01 | 0.02 | 0.34 | | | | |
| Vajarahalli kere | 0.43 | Inlet | 25 | 0.2 | 35.5 | 11.2 | 38.4 | 4.82 | 112 | 0.24 | 8.66 | 0.13 | Nil | Nil | 0.04 | | | | |
| Varahasandra kere | 6.02 | Inlet | 86.8 | 0.1 | 5 | 5.2 | Nil | 6.29 | 204 | 0.35 | 7.84 | 0.07 | Nil | Nil | 0.08 | | | | |
| Varturu Tank | | Outlet | 134 | 0.1 | 13 | - | Nil | 7.43 | 252 | 0.43 | 8.13 | 0.1 | Nil | 0.01 | 0.57 | 1.17 | | | |
| Varturu Tank | 166.87 | Inlet | 137 | 2.5 | 12 | 3.8 | 56.64 | 8.02 | 276 | 0.46 | 8.13 | 0.14 | Nil | 0.02 | 0.67 | 1.21 | | | |
| Vengaiah Kere | 21.66 | Inlet | 246 | 0.1 | 81 | 10 | 94.4 | 6.77 | 204 | 0.33 | 8.81 | 0.07 | Nil | 0.01 | 0.15 | | | 160000 | 160000 |
| Vengaiah Kere | | Outlet | 241 | 0.2 | 226 | | 56.64 | 7.88 | 200 | 0.33 | 8.92 | 0.09 | Nil | Nil | 0.15 | | | | |
| Venkatala Lake | 22.9 | Inlet | 58.8 | 0.01 | 11.5 | 4.2 | 19.2 | 7.72 | 100 | 0.35 | 8.77 | 0.05 | Nil | Nil | 0.13 | | | | |
| Venkojirao kere (Agarakere) | | Inlet | 860 | 0.05 | 27 | 12.6 | 37.76 | 6.79 | 292 | 0.71 | 9.67 | 0.07 | Nil | Nil | 0.06 | | | 1600 | 1600 |
| Venkojirao kere (Agarakere) | 40.11 | Outlet | 812 | 0.05 | 5.5 | | 75.5 | 8.01 | 292 | 0.75 | 9.02 | 0.06 | Nil | Nil | 0.06 | | | 900 | 900 |
| Vidyaranyapura Lake 2 | | Outlet | 81.2 | 0.2 | 63 | | 75.52 | 4.41 | 204 | 0.25 | 7.83 | 0.06 | Nil | 0.01 | 0.13 | | | | |
| Vidyaranyapura Lake 1 | 6.64 | Inlet | 101 | 0.2 | 25.5 | 4.8 | 75.52 | 7.31 | 204 | 0.27 | 8.05 | 0.25 | Nil | 0.01 | 0.17 | | | >1600 | >1600 |
| Yediyur Kere | | Outlet | 47.6 | 0.1 | 2 | | 0 | 2.01 | 140 | 0.3 | 8.54 | 0.04 | Nil | 0.03 | 0.06 | 4.78 | | | |
| Yediyur Kere | 4.54 | Inlet | 56 | Nil | 1.5 | 7.4 | 0 | 2.33 | 128 | 0.31 | 8.72 | 0.05 | Nil | 0.03 | 0.07 | 2.22 | | >1600 | >1600 |
| Yediyur Kere | | Middle | 64.4 | 0.05 | 47 | | 0 | 2.57 | 140 | 0.32 | 8.78 | 0.05 | Nil | 0.04 | 0.31 | 1.16 | | | |
| Yelahanka Kere | | Outlet | 431 | 0.23 | 52 | | 211 | 9.44 | 216 | 0.68 | 8.96 | 0.08 | 0.02 | Nil | 0.35 | | | | |
| Yelahanka Kere | 115.8 | Inlet | 428 | 0.01 | 96 | 6.8 | 249.6 | 11.35 | 180 | 0.74 | 9.05 | 0.07 | Nil | Nil | 0.25 | | | | |
| Yelahanka Kere | | Middle | 406 | 0.01 | 88 | | 211 | 11.79 | 188 | 0.69 | 9.02 | 0.08 | Nil | Nil | 0.27 | | | | |
| Yellamallappa chetty kere | 159.5 | Inlet | 185 | 1.09 | 4 | | 40 | 6.43 | 352 | 0.37 | 7.95 | 0.16 | Nil | Nil | 0.35 | | | | |
| | | Outlet | 213 | 0.1 | 247.5 | | 75.52 | 5.78 | 172 | 0.65 | 10.08 | 0.11 | Nil | 0.03 | 0.05 | | | >1600 | >1600 |

## Lake water pollution and impact on Groundwater

The Dissolved Oxygen (DO) level in lake waters is important as low level of DO indicates organic pollution. The presence of DO is necessary for maintaining favorable conditions for growth of fish and other aquatic life. DO is a measure of oxygen dissolved in water. If the oxygen level falls below 4 ppm then the aquatic life like fish will die, oxidation of dead plant material takes place and lakes goes from oligotrophic (Low Productivity) state to Eutrophic (high productivity). The Chemical Oxygen Demand (COD) test indicates about any possible pollution by industrial effluents. COD of unpolluted water is normally lower than 20 mg/L. But, the COD values in all the lake waters analysed are more than 20 mg/L indicating the pollution from industrial and municipal wastes.

Municipal and some industrial effluent discharges may contain nitrate and phosphates. This may result in algal boom or eutrophication. This is not desirable for a balanced aquatic eco-system. Out of 96 lake water samples, only four samples have phosphorous and nine samples have nitrate concentration higher than the permissible limits.

The presence or absence of coliform determines the bacteriological quality of water. Its presence indicates contamination from sewage and possible presence of pathogenic organisms. The total count of coliforms in unpolluted lake waters may vary between 10 to 100 MPN/100 ml. All the 23 lake water samples analysed confirmed the presence of E-coli (more than 1,600 MPN/100 ml), indicating these waters are highly polluted (Table 1).

The study has revealed that there is an impact of polluted lake water on groundwater in the vicinity. From the data presented in Table 1, the concentration of heavy metals viz. Zinc, Lead, Copper, Manganese and Coliform bacteria in the lake water samples and groundwater samples in the vicinity of such lake have been compared and given in Tables 2a and 2b.

**Table 2a : Heavy Metals in Lake and Groundwater Samples (in the vicinity of lakes) Please refer to Table 1**

| Sl. No. | Lakes | Concentration of Heavy Metals in Lake water (mg/L) | | | | Concentration of Heavy Metals in Borewell water near Lakes (mg/L) | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Zn | Pb | Cu | Mn | Zn | Pb | Cu | Mn |
| 1. | Agara lake | 0.07 | Nil | Nil | 0.11 | 0.44 | Nil | 0.11 | 0.39 |
| | | | | | | 1.12 | 0.02 | 0.02 | 0.72 |
| 2. | Bellandur lake | 0.19 | Nil | Nil | 0.23 | 0.04 | Nil | 0.01 | 0.25 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 3. | Kundalahalli lake | 0.05 | Nil | 0.02 | 0.02 | 0.02 | Nil | 0.01 | 0.17 |
| 4. | Puttenahalli lake | | | | | 0.36 | Nil | Nil | Nil |
| 5. | Hulimanakere | 0.06 | Nil | 0.01 | 0.47 | 0.06 | Nil | Nil | 0.28 |
| 6. | Begur | 0.07 | Nil | Nil | 0.54 | 0.16 | Nil | Nil | 0.18 |
| 7. | Kodagi Singasandra | 1.08 | Nil | Nil | 0.9 | 0.06 | Nil | Nil | 0.08 |
| 8. | Yelahanka Kere | 0.07 | Nil | Nil | 0.25 | 0.01 | Nil | Nil | 0.08 |
| 9. | Bandepalya | 0.21 | Nil | Nil | 0.84 | 0.02 | Nil | Nil | 0.02 |
| 10. | Sankey tank | | | | | 2.55 | Nil | Nil | Nil |
| 11. | Nagasandra | 0.26 | 0.27 | Nil | 0.60 | 0.07 | Nil | Nil | 0.22 |
| 12. | Shivalikere | | | | | 0.06 | Nil | Nil | Nil |
| 13. | Hosahalli | | | | | 0.15 | Nil | Nil | Nil |
| 14. | Kudulukere | | | | | 0.06 | Nil | 0.01 | 0.22 |
| 15 | Kuduludoddakere | 0.09 | Nil | Nil | 0.07 | 0.06 | Nil | Nil | 0.08 |

## Table 2b : Coliform Becteria in Lake and Groundwater Samples (in the vicinity of lakes)

| Sl.No. | Lake | Contamination of lake water | | Contamination of Borewell water near lake | |
|---|---|---|---|---|---|
| | | E-Coliforms MPN/100 ml | Total Coliforms MPN/100 ml | E-Coliforms MPN/100 ml | Total Coliforms MPN/100 ml |
| 1. | Kodigehalli Kere | >1600 | >1600 | 900 | 900 |
| 2. | Hebbal Kere | >1600 | >1600 | 130 | 130 |
| 3. | Bellandur Lake | >1600 | >1600 | 130 | 130 |
| 4. | Halasur lake | >1600 | >1600 | 900 | 900 |
| 5. | Allalsandra lake | >1600 | >1600 | 500 | 500 |
| 6. | Yelahanka lake | >1600 | >1600 | 350 | 350 |
| 7. | Nelurhalli lake | >1600 | >1600 | 9.2 | 9.2 |