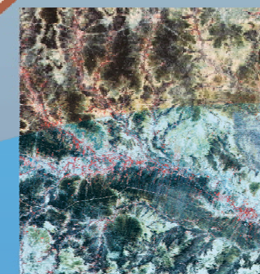
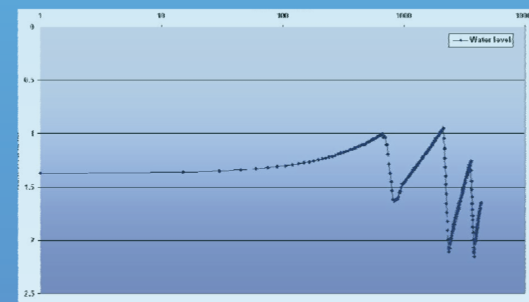
Hydrogeological studies for improved groundwater management strategies in the dryland areas underlain by Deccan basalts: an initiative in Purandar taluka

A detailed action research in ten villages of eastern Purandar of Pune district, Maharashtra





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ACWADAM

Advanced Center for Water Resources Development and Management

August 2009

Hydrogeological studies for improved groundwater management strategies in the dryland areas underlain by Deccan basalts: an initiative in Purandar taluka

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Chapter 1: INTRODUCTION

In rural India, groundwater provides approximately 80% of the water used for domestic purposes, and more than 50% of that used for irrigation. *(World Bank and MoWR, 1999)* Statistics for the State of Maharashtra reveal that 55% to 60% of irrigation is by groundwater.*(Pers. comm. with water and irrigation experts)* These statistics, however underplay the larger role of groundwater within both, natural resources and socio-economic frameworks. Access to groundwater means reduced agricultural risk and an avenue for economic development. At the same time, increasing use of groundwater has resulted in various environmental concerns, the foremost being the depletion of groundwater resources.

Extreme events like 'high intensity' rainfall spells leading to floods and increased frequency of droughts in large parts of the country compound the problem of groundwater over-abstraction. Drying up of wells supplying water for irrigation and household needs is one clear-cut indicator of such over-exploitation. At the same time, wells may dry up simply because they do not fully penetrate the underlying aquifer(s). Hence, only a proper hydrogeological analysis of a problem or situation can confirm the precise cause-effect relationship behind groundwater problems. The problem of groundwater over-exploitation is sometimes further compounded by the inherently low groundwater storage capacity of underlying rocks and the lack of enough rainfall to effectively recharge aquifers under such situations. Moreover, haphazard use of groundwater has also led to deterioration of groundwater quality in many areas. Water quality too is a subjective matter, depending upon whether the cause is geogenic or anthropogenic.

The report of the Expert Group on Groundwater Management and Ownership (*Planning Commission, 2007*) notes that in 2004, an alarming 28% of the blocks in the country were in the category of critical, semi-critical or overexploited as compared to 7% in 1995. In some states, including Maharashtra, the percentage was as high as 54%. The situation has certainly not improved since. In fact, with continued exploitation, it is expected that by 2020 more than 50% blocks in the country will be critical.*(Planning Commission, 2007)*

Purandar taluka in Pune district of Maharashtra is one such example where groundwater over-abstraction has created serious problems in many villages. The 20 odd villages in eastern Purandar have been included in the dark zone by the Groundwater Survey and Development Agency (GSDA). There are thousands of dug wells and bore wells in Purandar through which exploitation of groundwater is taking place for the last fifteen years or so. The Government has been trying to regulate groundwater use through

Groundwater dependent agriculture

instruments like ban of drilling, regulated supply of electricity, especially during low-rainfall years and so on. Such regulation, being on a regional scale, has led to the exclusion of villages with untapped aquifers, from access to resources; and therefore, to limited agricultural productivities and therefore unsustained agicultural livelihoods. In such villages too, community based groundwater management efforts get decelerated as operationalisation of energy delivery is at least partly constrained by the regional paradox of “over-exploited' areas. Other villages face problems of groundwater quality, for instance, severe problems of groundwater salinity. Poor quality groundwater which has high concentration of inorganic solvents has severely affected land, water and the livelihoods of the community, in such pockets.

All these issues are directly related to the underground geology and the overall hydrogeological settings in a region. In Purandar, there was no scientific study on hydrogeology or geology before the current effort was taken up. Gram Gaurav Pratishthan (GGP), which is a local NGO working in this area for the last 30 years had done work on the social mobilization of communities for improved equity on water resources. GGP approached Advanced Center for Water Resources Development and Management (ACWADAM) to undertake a long-term study which would not only help in improved understanding of groundwater for the region, but would also provide a platform for improved action on the ground (through GGP's own work). The main aim of this project was to undertake a comprehensive hydrogeological study of the focus area and to obtain a good understanding of groundwater resources. This understanding would help establish a “knowledge base” for implementing agencies like GGP to take up various water resources programmes in the region as well as to advocate the ‘typology’ of groundwater problems that require specific approaches for mitigation.

ACWADAM and GGP are working in Purandar taluka since last five years

1.1: Organisations involved

Advanced Center for Water Resources Development and Management (ACWADAM): Established in 1997, ACWADAM is a non-profit organization based in Pune. ACWADAM has embarked upon a long-term endeavour of developing into a premier Research and Training Centre that will cater to action oriented research aimed at finding solutions to current and future problems pertaining to water resources. ACWADAM's goal is to help achieve Sustainable Management of Water Resources in all domains: rural - urban, industrial, agricultural and domestic. It has been striving to achieve this goal through scientific application of the sciences of Geology, Hydrogeology & Hydrology at all scales in the water resources sector, keeping in mind its focus on groundwater resources. ACWADAM has been able to develop local-level understanding of geology and groundwater resources through intensive engagement with various partners from different parts of the country. In doing so, it has provided key inputs to projects like watershed development, groundwater resources development, drinking water projects, and most importantly in developing strategies on community-based groundwater management.

Gram Gaurav Pratishthan (GGP): Gram Gaurav Pratishthan (GGP) was formed in 1972-73 as a trust registered under the Bombay Public (Charitable) Trusts Act 1950. The Naigaon village temple trust donated a barren plot of land to GGP to demonstrate a workable solution for the woes of dry-land farmers practicing rain-fed agriculture in the Purandar taluka of Pune district. By end of 1978, GGP through the efforts of Late Shri Vilasrao Salunkhe, evolved a practically successful model wherein water conservation structures were constructed after scientifically studying the rainfall and water run off patterns. GGP worked along with the villagers of Naigaon in finalising the water conservation, distribution and sharing principles for the wide scale application of the Pani Panchayat model. This model involves villagers collectively deciding about water conservation, distribution and sharing amongst themselves. The sharing is on an equitable basis, with a minimum per capita water entitlement based on available water rather than on the ownership of land; hence, there is a clear provision for including the landless under the framework of Pani Panchayat. GGP has been instrumental in spreading this model not only in Maharashtra but also in other parts of India.

1.2: Study area

Eastern talukas of Pune district like Purandar, Baramati and Shirur are the drought prone talukas which fall in the rain shadow zone of the Western Ghats. The average annual rainfall in this area is around 500 mm or less. Purandar taluka can be divided into two parts on the basis of rainfall, where western Purandar receives around 1000 mm of rainfall while its eastern counterpart receives less than 500 mm of rain. The study area includes 10 villages of eastern Purandar namely, Amble, Waghapur, Rajewadi, Pisarve, Tekwadi, Pimpri, Pandeshwar, Naigaon, Malshiras, and Pondhe which are distributed in the five watersheds. The total area covered under this study is around 150 km^2. The climate of Purandar taluka is semi-arid tropical with average annual temperatures ranging between 18°C. in winter to 35°C in summer. June to September is the rainy season which receives rains from the southwest (SW) monsoon.

1.3: Purandar Taluka

Purandar taluka derives its name from the historically important fort of 'Purandar', which was a strategic location for the Maratha kingdom established by Shivaji Maharaj in the 16th century. Saswad is the taluka headquarters of Purandar. The approximate distance from Pune city is around 60 km. Saswad is a historical city having number of old Wadas and Rajwadas (old palatial houses) built during the Peshwa rule, subsequent to

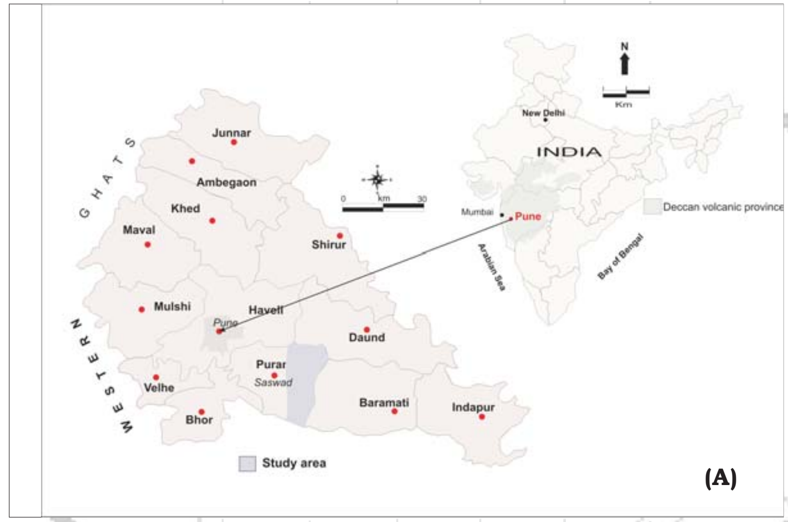
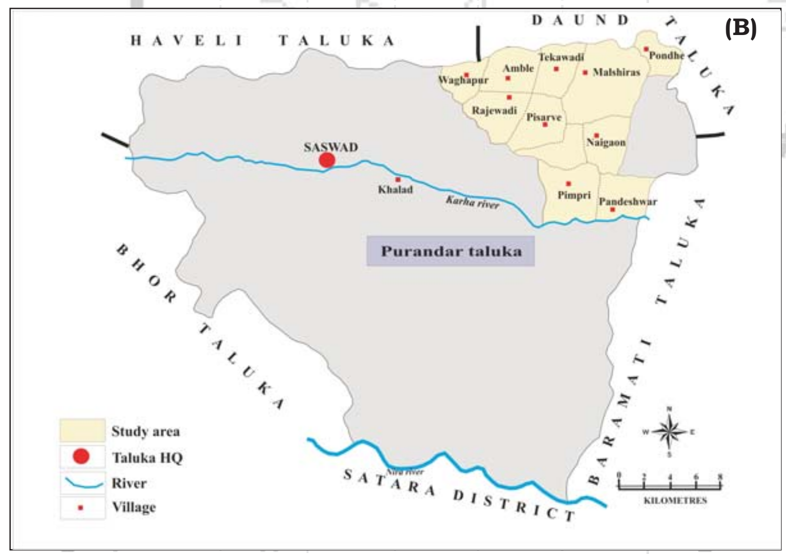


Figure 1.1(A &B): Location of study area



the Shivaji dynasty. The Saswad Nagar Parishad was established in 1859. The taluka is surrounded by Haveli and Daund talukas to the north, Baramati taluka to the east and Bhor taluka to the west. All these talukas fall under Pune district. Purandar taluka lies close to the boundary of Pune and Satara district as the river Nira separates Pune district from Satara district, which is located to the south of Purandar. The total area of Purandar taluka is 1103 km2 and the total population is 223,428.(*Census data 2001*) Saswad is well connected with Pune by road and majority of the villages of the study area are well connected with Saswad. *Figure 1.1(A)* indicates the location of study area with respect to India and Maharashtra.

Karha and Nira are the two main rivers flowing through the area. Most of the streams of the study area drain into Karha river while water from the Pondhe watershed drains into Mula river. There are anumber of small and medium irrigation dams constructed on Karha river. Nazare dam is one such medium irrigation dam constructed near Pandeshwar village. The total capacity of this dam is 22.32 MCM. *(Irrigation Department Report 2006-2007)* There are 4960 irrigation wells in the taluka having 52 diesel pumps. (Directorate of Agriculture, 2000-2001)

The study area is located at a distance of 20 km east of Saswad. The Amble watershed is located about 14 km from Saswad and can be best approached by the Saswad-Malshiras road which eventually leads to Uralikanchan and joins the Pune-Solapur highway (NH9). The Tekwadi watershed is located 16 km from Saswad town. Villages like Rajewadi, Tekwadi, Malshiras and finally, Pondhe lie on the same road and the road connectivity is exceptionally good with most roads being metalled. Villages like Pisarve and Naigaon are well connected with Saswad by a metalled road, while Pimpri Pandeshwar and Romanwadi villages can be approached via Jejuri - Nazare road. *Figure 1.2* indicates location of study villages.

The geographic location of the area is 18°15' N to 18°30' N and 74°E to 74°20'E. The area is covered under toposheet no. 47 J/3 and 47 J/7. The total population of the study area is around 19487 (Census data, 2001). Major crops grown in the area are sorghum (Jowar), pearl millet (Bajra), pulses and onion. Horticulture and floriculture are also practiced by many farmers.

The highest point in the study area is Dhawaleshwar temple, with an elevation of 892 m. above mean sea level. The average elevation of the area is between about 900 m. above mean sea level in the North to 620 m. above mean sea level in the South. The general direction of slope is from North to South. The soil type found in the area is red to reddish brown silty soils and black clayey soils (alfisols and vertisols respectively).

Five main watersheds are identified for this study, namely: Amble, Tekwadi, Naigaon, Pimpr-Pandeshwar and Pondhe. The average area covered under each watershed is given in *table 1.1.*

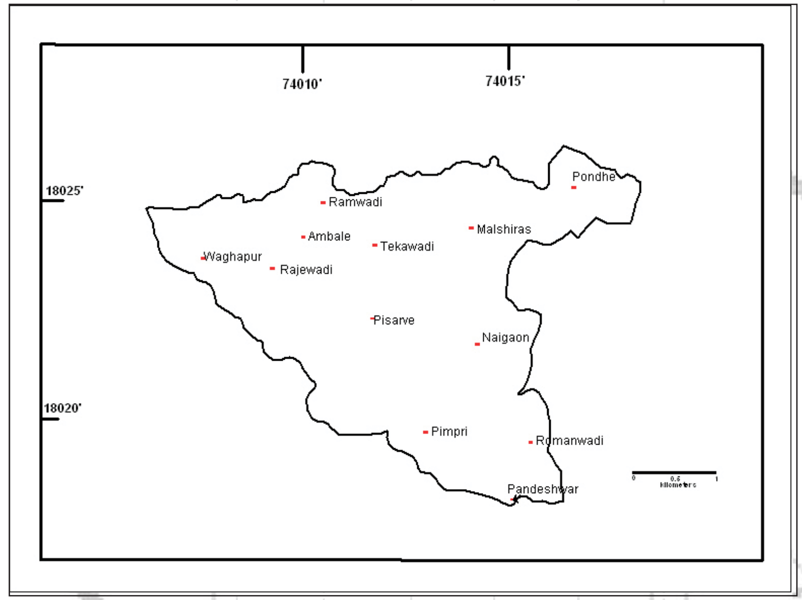


Figure 1.2: Location of study villages

Watershed	Area in Km^2	Area in hectares
Amble	46.66	4666
Tekwadi	20.74	2074
Naigaon	54.46	5446
Pimpri Pandeshwar	9.93	993
Pondhe	9.03	903
TOTAL	140.85	14085

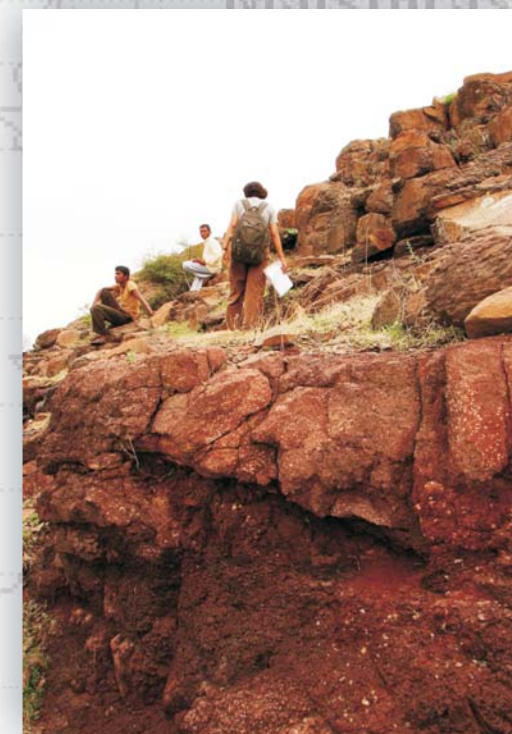
Table 1.1: Watershed areas

1.4: Objectives

The main objective of the project was to generate baseline data on hydrogeology and to compliment it with allied information such as weather data and socio- economic information. Another objective of this project was to prepare thematic maps with the intention of depicting different types of information in a pictorial format. The project also aimed at sharing this scientific information with the implementing agency (GGP) from time to time, which improved their understanding about groundwater and gave them a scientific vision in their implementation programme. Similarly, ACWADAM hoped to dovetail information and experiences from this project with those from its other projects and disseminate it to different individuals and organizations in the water sector in India. Moreover, ACWADAM also aimed at using the fieldwork component of the project to build capacities of undergraduate students by involving them in specific field-related tasks and data-collection. The students were then exposed to analytical tools like water level data plotting and interpretation, pumping test analysis and water quality analysis. The data generated by the students was included in the ACWADAM's study under the project in Purandar and the students produced technical reports regarding their work during each year.

The five broad objectives of the project are listed below.

1. To identify and describe the aquifers in the five watersheds.
2. To understand the quantitative and qualitative aspects of groundwater.
3. To study groundwater use and the recharge-discharge relationship, both in space and time.
4. To help in initiating groundwater management practice through the implementing organization (GGP) and community based efforts.
5. To provide a laboratory in nature for students of Earth Sciences, specifically in the subjects of geology and hydrogeology, through projects that enhance the knowledge base that is currently restricted largely to the theory taught in classroom sessions.



Basalt Flow contact in Diveghat

1.5: Methodology

ACWADAM strongly believes in generating its own data by establishing a simple yet strategic monitoring network. This rationale primarily stems from the fact that existing (secondary) data are too regional to be representative of groundwater conditions, especially in localized groundwater systems in hard-rock regions. Moreover, there is little recognition of the proper units "aquifers" in most of the secondary data framework. In other words, the non availability of accurate hydrogeological data at the micro watershed level implied that ACWADAM's major thrust in the project area was to generate primary hydrogeological data using various methods and instruments. Some secondary data was also used for this study, wherever found relevant. Most of the secondary information was in the form of socioeconomic data generated by government sources like Directorate of Agriculture and Irrigation Department as well as GGP for their own study. ACWADAM was also able to fall back on some primary data for parts of the area, developed during an earlier research project on community management of groundwater *(COMMAN 2005)*. The methodology used for this study involved the following components.

1. Establishing a monitoring network
2. Generation of data through extensive field work and ground truthing of primary/secondary data
3. Analysis of data
4. Interpretation and recommendation including inputs to action plans by GGP, through their project implementation

Apart from the above four aspects, one additional important aspect emerged as a consequence of the study. This included the articulation of the groundwater typology concept across target audiences, implying significant inputs at the advocacy level, especially with regard to groundwater law and water policy.

Data generation
Detailed hydrogeological maps were prepared by adopting all the three methods mentioned above. Extensive field work was undertaken by the ACWADAM team to prepare the geological maps of the five watersheds. Instruments like clinometer compass, global positioning system (GPS), altimeters, tape measures were used for the geological mapping. Remote sensing data (IRS P6 merged PAN + LISS III) was also used for identifying the lineaments in the field and for understanding changes in land-use patterns. The Survey of India Topographic Sheets at 1:25000 scale (47J/3 and 47J/7) were used as base maps for mapping the geology. The actual field mapping and thematic outputs were on scales of 1:10000 or higher. Surveys including resistivity soundings were conducted to determine the subsurface configuration of the basalt units. Similarly, detailed studies pertaining to the hydrogeology of the Deccan basalts were brought to bear on this study through earlier works *(Deolankar 1980, Peshwa et al, 1987, Kale and Kulkarni 1992, Kale et al 1992, Kulkarni et al 2000)*. Detailed hydrogeological maps were prepared for the five watersheds using software like MAP Info Professional 8.5 and Surfer 8, available with ACWADAM.

Monitoring network
ACWADAM set up a monitoring network to generate primary data for ground water levels and weather parameters. ACWADAM-GGP team identified 221 dug wells in the five watersheds. Initially the water level data was acquired on a monthly basis. In the last one and half years, the frequency was reduced to once in two months which seemed a practical frequency of monitoring for this

Mapping of alluvium at Ramwadi

Preparation of well inventory

particular area. Around 10% of the total wells from each watershed were selected in a way that they were sufficiently representative to capture the overall situation in the study area. A well inventory was prepared for each well taking into consideration the well depth, well diameter, land use, geology, pumping hours, pump details etc. Insitu water quality was also measured for most of the wells to ascertain any anomalies in the water quality. Four volunteers from GGP, Mr. Dattu Itkar, Mr. Subhash Waghale, Mr. Dnyaneshwar Nale and Mr. Dhole measured the water level data during the project period.

The ban on any drilling imposed by GSDA meant preclusion of observation bore hole drilling in the project area. It was also planned that an automatic water level recorder (AWLR) would be installed in one of the deeper/ shallow bore holes, which would give an accurate data about the aquifer behaviour during the course of the project. In the absence of observation bore holes, the AWLR was installed in the Naigaon well (N1) to give accurate water level data at a 15 min. interval. The AWLR was installed in January, 2008 and it continues to give water level data for the dug well on a regular basis. It has also provided valuable information about the pumping effects and the recovery of the well. Impact of the check dam on the well water level could also be studied through this recorder.

An automatic weather station was installed at Naigaon to obtain information about the six major weather parameters. Hourly data was generated for wind speed, wind direction, temperature, relative humidity, solar radiation, rainfall and evaporation. The installation was completed in November 2006 and then onwards, data became available. As the entire weather station is electronically operated there are a few data gaps due to technical problems with the sensors and instrument. The main problem occurred during September 2007 to November 2007 when the temp-humidity sensor had to be changed due to damage from lightening. For most of the other period, continuous data was obtained from the weather station. The ACWADAM student interns actively participated in the weather station installation process which gave them a unique 'in-field experience'. Besides the automatic weather station at Naigaon, five rain gauges and one evaporimeter were installed in the study area, to obtain an idea regarding the spatial variation of rainfall and evaporation. The rain gauges were installed in Amble, Tekwadi, Pandeshwar, Pondhe and Khalad. An additional evaporimeter was also installed in Khalad to gauge if there was significant variability from the western parts of Purandar to the eastern ones. Local volunteers collected data during the three years, ensuring technical capacity building at various locations.

A V-notch was installed in the Pondhe stream, to measure the inflow from the stream. The stream is not perennial and has water till early summer. The inflow from this stream was measured on a fortnightly basis. Based on this data, some inferences were drawn about the volume of water generated in the

Automatic water level recorder installed in Naigaon well

Automatic weather station in Naigaon

watershed.

Field measurements

Aquifer delineation and understanding aquifer properties were the two main objectives of this study. The aquifer delineation was achieved primarily through hydrogeological mapping. Water level data was analysed and plotted as hydrographs and water table contours. This data, in conjunction with the hydrogeological mapping helped delineate aquifers in the project area. Pumping tests were conducted to determine aquifer characteristics like transmissivity and storativity. Conducting a pump test is a time consuming job and is dependent upon the externalities like availability of electricity, availability of enough water in the well, farmers pumping schedule etc. Therefore it is not always easy to conduct a pump test on each and every well. However, ACWADAM was able to conduct tests on 50 dug wells, some of them repetitive. The major role in this exercise was played by the student interns who consequently picked up the art of conducting a pumping test and analyzing data. Around 25 pump tests were conducted by them in five watersheds. Maximum number of tests were conducted in the Amble and Tekwadi as these are the two major overexploited watersheds. Similarly, ACWADAM conducted tests on wells in Pondhe, most of which would be used as sources for the community-managed groundwater system being implemented in Pondhe village.

The water quality samples were collected from 15 different sources in the five watersheds. The analysis was done twice every year; once in summer (April-May) and once in the post monsoon season (November-December) to understand the impact of recharge on groundwater along with the quality type. In situ measurement of pH, TDS, conductivity and salinity was done for every sample in the field. Additionally, Dissolved Oxygen was also measured in the field during the last water quality analysis. All the samples were collected in a 2 litre bottle provided by the laboratory where analyses were carried out. All these samples were filtered to remove impurities. None of the samples were acidified. Samples were sent to the laboratory within 8 to 10 hours of collection. The samples were analyzed by Polytest laboratory which is an ISO certified laboratory from Pune. The samples were analyzed for the parameters given in *table 1.2*.

As detailed water quality analysis was not feasible for more than 15 samples per year from the study area, in situ water quality measurement was done for additional 20 samples of water per year. This helped obtain a broad picture of the water quality distribution in the area.

A couple of socioeconomic surveys were carried out by the ACWADAM-GGP team in the study area. The first survey was conducted in December 2007. In this survey, a six page questionnaire was prepared in Marathi with water as a central theme. Several questions regarding the economic status, social status, land and water assets, water requirement, quality of water, crops

Water quality analysis conducted in a well in Pandeshwar

General Parameters	Anions	Cations	Trace elements
pH	Chlorides	Calcium	Arsenic
Electrical Conductivity	Fluoride	Magnesium	Iron
	Sulphate	Potassium	Manganese
	Nitrate	Sodium	
	Bicarbonate		

Table 1.2: Parameters selected for the water quality analysis

grown, changes in livelihood pattern, impact of watershed development work and the need for groundwater management were discussed in the questionnaire. A survey was conducted for 125 families in five watershed areas. The data obtained in this survey was compiled and later analyzed. A second socioeconomic survey was conducted in December 2008 - January 2009. The main focus in this survey was on the mechanisms of groundwater management in the study area. Ten volunteers were selected for this short survey; these volunteers were sensitized to the needs of the survey before sending them out to the field.

Understanding groundwater in a drought prone area like Purandar is aherculean task, which needs understanding of scientific, social and economic factors. In this three year study, an attempt has been made to understand this complex issue by setting up a monitoring network and by gathering data which is useful in understanding the complexities of groundwater related issues. This report describes and analyses, in detail, some of these processes and results from the study. The report also attempts to capture the salient impacts from the study.

A survey being conducted in Purandar

Chapter 2: FRAMEWORK FOR ACCUMULATION AND MOVEMENT OF GROUNDWATER

The increasing problems of water scarcity, deteriorating quality and conflicts over water are clearly evident from many parts of the world. In many regions of India, water scarcity is a regular phenomenon. In other regions, despite water availability, drinking water is brought from afar since local water sources are contaminated and are therefore not potable. Groundwater constitutes a major source of water supply, especially in rural India. It has clearly proved to be a resource that has contributed significantly to the agricultural development of the country. At the same time, many regions of India are facing problems of groundwater overexploitation, increased salinity and serious health risks from fluoride and arsenic contamination.

Large scale mitigation measures like artificial recharge, rainwater harvesting, fluoride and arsenic mitigation are required to address problems of groundwater on a national scale. However, unlike surface water, groundwater is a hidden resource. Groundwater is also a resource with characteristics that often change over short distances. This is because the accumulation and movement of groundwater is governed by the nature and structure of the rocks within which it occurs. The openings in the rocks and the interconnectivity between these openings define the porosity and hydraulic conductivity (permeability) of the rocks. These two properties of rocks decide how much water the rock can store and how quickly it can transport it from one point to another. Therefore, whether it is scarcity or quality, it becomes necessary to understand the “hydrogeological” properties of rocks and rock material while tackling any groundwater-related problem.

Water level in GGP’s Naigaon well(N1) after the monsoon

Hydrogeology is the science which mainly deals with groundwater. It includes some reference to the altitude, slope and the morphology of land; however, its main component is the study of geology and its influence on the accumulation and movement of groundwater. Hydrogeological investigations are the primary exercise to dealing with any groundwater-related problem and responses are often tailored to the hydrogeological context of a problem. Hence, the current project also used basic hydrogeology as the “core piece” in understanding groundwater resources in the Purandar area. The following sections describe how different elements such as drainage analysis, geology and hydrogeology play an important role in movement and accumulation of groundwater.

2.1: Drainage analysis

Drainage analysis helps reveal the nature of contributing surfaces, both to surface drainage as well as to the infiltration component of a water balance; the infiltration component is the main input to the groundwater storage in an aquifer. Drainage analysis also helps gauge the nature of water flow in a regime and provides indications on the relationship between underlying geological features and the facilitation or resistance to the process of infiltration.

In the study area the regional drainage pattern is generally sub-dendritic in nature, indicating the dominance of impermeable surfaces and slopes. Drainage of each watershed is plotted along with the wells in the area. This drainage and wells have are plotted based on field inventories. The drainage analysis for all the watersheds was undertaken using *Strahler's method (1952)* of stream ordering, where first order drainage represents the streams originating in head region; two first order streams form a second order; two second order streams form a third order and so on. Most of the stream channels were inventoried in the field to check whether major alterations to natural drainage were made. Unlike many other areas underlain by the Deccan basalt in western Maharashtra, where natural streams are "trained" to skirt agricultural fields, the streams in the project area still maintain their natural courses.

Three parameters are crucial in establishing a link between surface drainage geometry and the underlying geology. This link, in turn, helps in pointing towards areas that facilitate infiltration and the relative nature of surfaces – facilitating or resisting infiltration. These parameters are drainage density, stream frequency and bifurcation ratio *(Wisler and Brater, 1959; Kulkarni, 1992; Pakhmode et al, 2003).*

Drainage density represents the texture of a drainage basin or watershed. It is the ratio of stream length to the basin area, indicating the basins carrying larger volumes of surface runoff. The length of a stream, which is a dimensional property, indicates the hydrological nature of the contributing surfaces of the drainage network. Permeable media support fewer streams that are longer. Stream frequency data indicates the number of streams required to drain the area. Bifurcation ratio helps in understanding the drainage pattern of the area and provides an index to understand the degree of structural control on the drainage lines. A bifurcation ratio greater than 5 and less than 2.5 indicates structurally controlled development of the drainage network *(Strahler, 1957)*. All this information provides indicators on variability of the infiltration characteristics (and consequently, recharge) within a drainage basin, and on a relative scale, across contiguous basins on the surface. *Table 2.1* and *table 2.2* indicate the drainage analysis of five watersheds based on Strahler's method.

The drainage analysis of the five watersheds indicates that the drainage density in Amble and Tekwadi watershed is around 2.5 km/km^2 while the drainage density of Naigaon watershed is 1.2 km/km^2 indicating lower to moderate relief and better permeability of the surface in case of the latter. The Pimpri Pandeshwar watershed is a lower part of a larger watershed which includes all the micro watersheds like Amble, Tekwadi and Naigaon and also

Baseflow in the Pondhe stream- May

Basin	Stream order	No. of streams	Bifurcation ratio	Total stream length (in kms)	Average stream length (in kms)	Length ratio
Amble	1	142	3.736	76.12	0.5360	-
	2	38	3.8	27.40	0.7210	0.7434
	3	10	5	19.31	1.931	0.3733
	4	2	2	13.90	6.95	0.2778
	5	1	-	2.05	2.05	3.3902
Tekawadi	1	89	4.045	51.67	0.5805	-
	2	22	7.333	15.79	0.7177	0.8088
	3	3	3	11.26	3.7533	0.1912
	4	1	-	5.29	5.29	0.7095
Naigaon	1	147	3.97	38.7	0.2632	
	2	37	5.28	15.575	0.4209	0.6253
	3	7	3.5	4.7	0.6714	0.6268
	4	2	2	4.15	2.075	0.3235
	5	1	-	5.625	5.625	0.3688
Pondhe	1	29	3.2	26.25	0.24	-
	2	9	4.5	8.59	0.37	0.64
	3	2	2	8.02	0.73	0.50
	4	1	-	2.27	2.27	0.32

Table 2.1: Drainage analysis of four watersheds based on Strahler's method

Landscape of eastern Purandar

Stream flow in Malshiras during monsoon-2006

streams from the villages like Mavdi, Pimpri and Pandeshwar. Overall it represents the drainage of eastern Purandar draining into the Karha river. The drainage density of this entire watershed (of which Pimpri Pandeshwar is a small part) is 2.52 km/km^2 which indicates moderate relief and better permeability. The drainage density of Pondhe is around 5.43 km/km^2, indicating slightly greater relief and mediocre permeability of the surface. This is also supported by the fact that the stream frequency in Amble, Tekwadi and Naigaon watersheds is less than 4 streams per km^2 while Pondhe has a significantly higher stream frequency of 16.76 streams per km^2.

Figure 2.1 indicates the hydrogeological maps for Amble, Tekwadi, Naigaon and Pondhe watershed and Pimpri Pandeshwar area.

Fracture controlled drainage in Pondhe

Basin	No. of streams (N)	Basin area A (sq km)	Total length of streams L (km)	Drainage density Dd = L/A (km/sq km)	Stream frequency F = N/A (per sq km)
Amble	193	57.5	138.78	2.4135	3.3565
Tekwadi	115	33	84.01	2.5457	3.4848
Naigaon	194	53	68	1.2830	3.6226
Pondhe	41	8.41	45.13	5.43	4.88

Table 2.2: Drainage characteristics of four watersheds

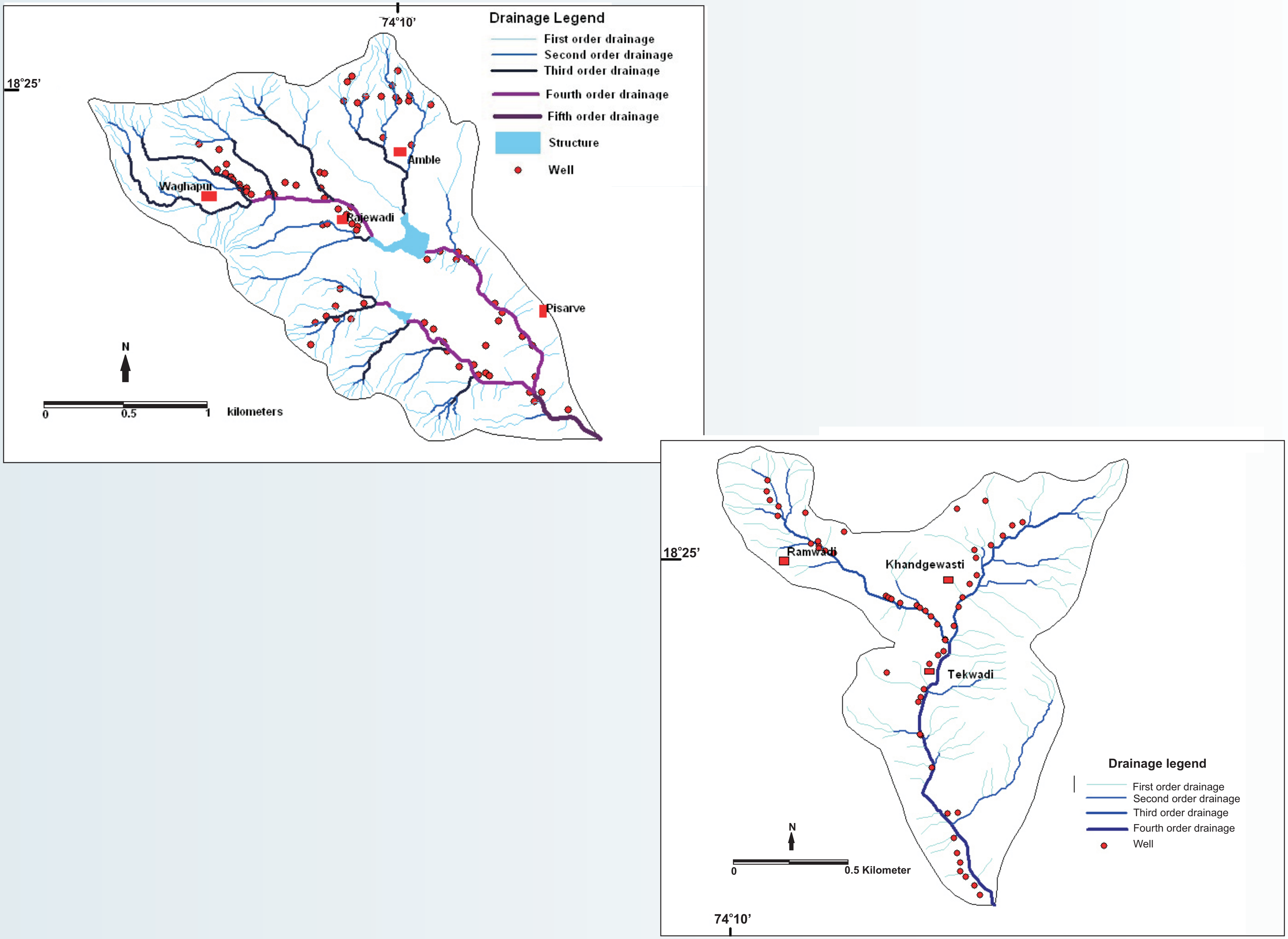
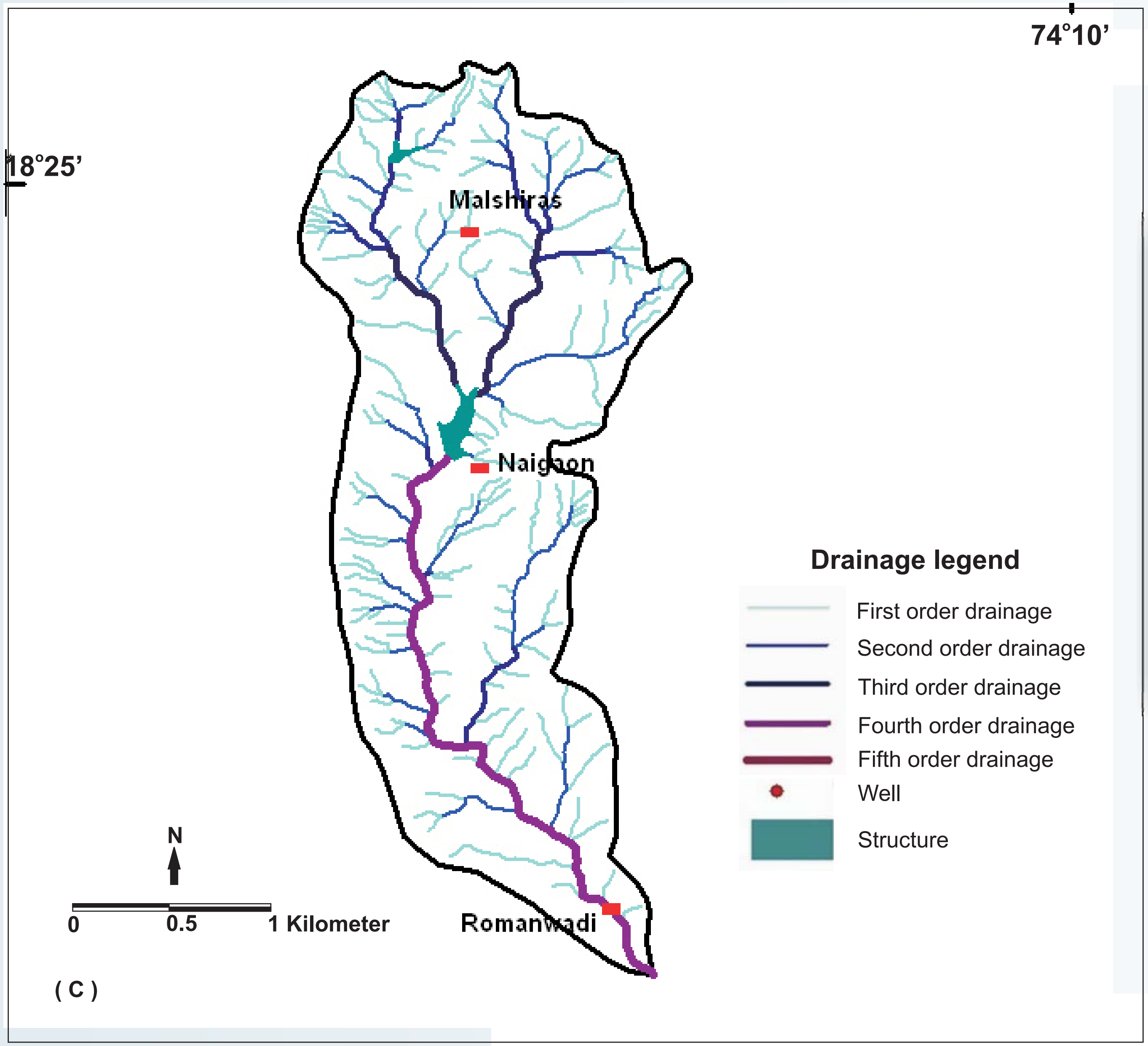
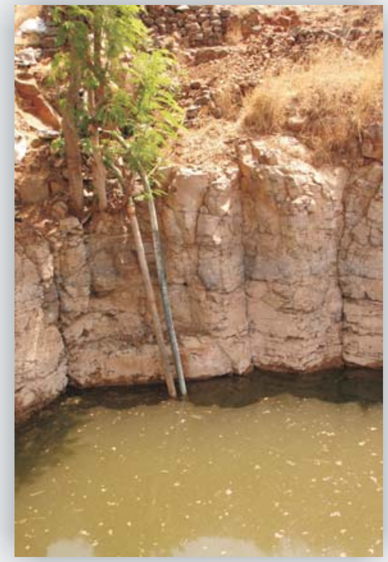


Figure 2.1(A & B): Hydrogeological map of (A)Amble and (B)Tekawadi watersheds





A well in Naigaon

Figure 2.1(C): Hydrogeological map of Naigaon watershed

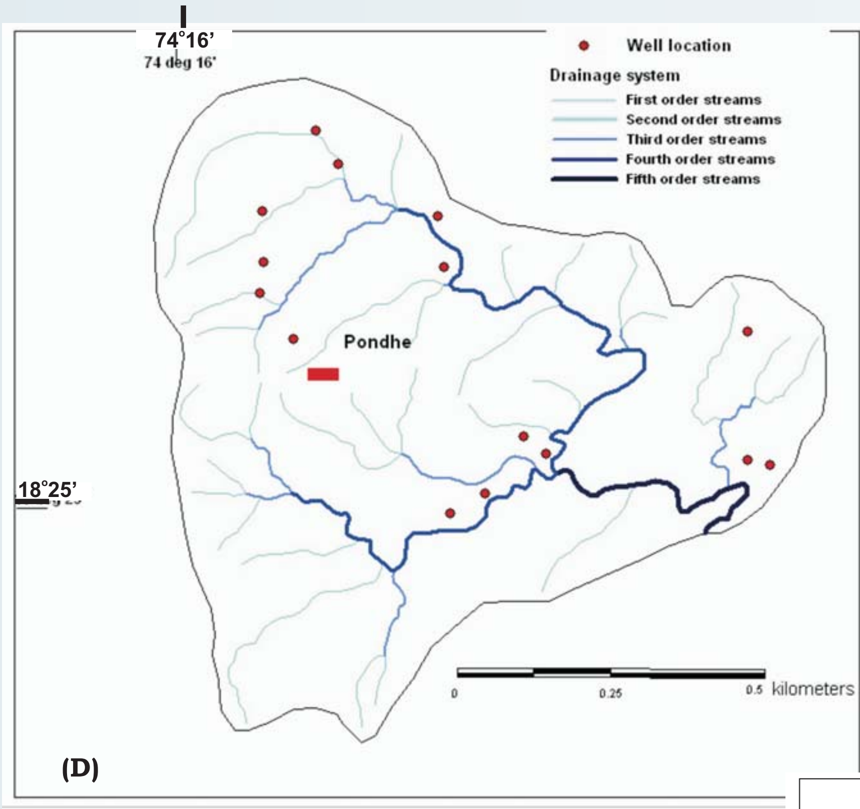
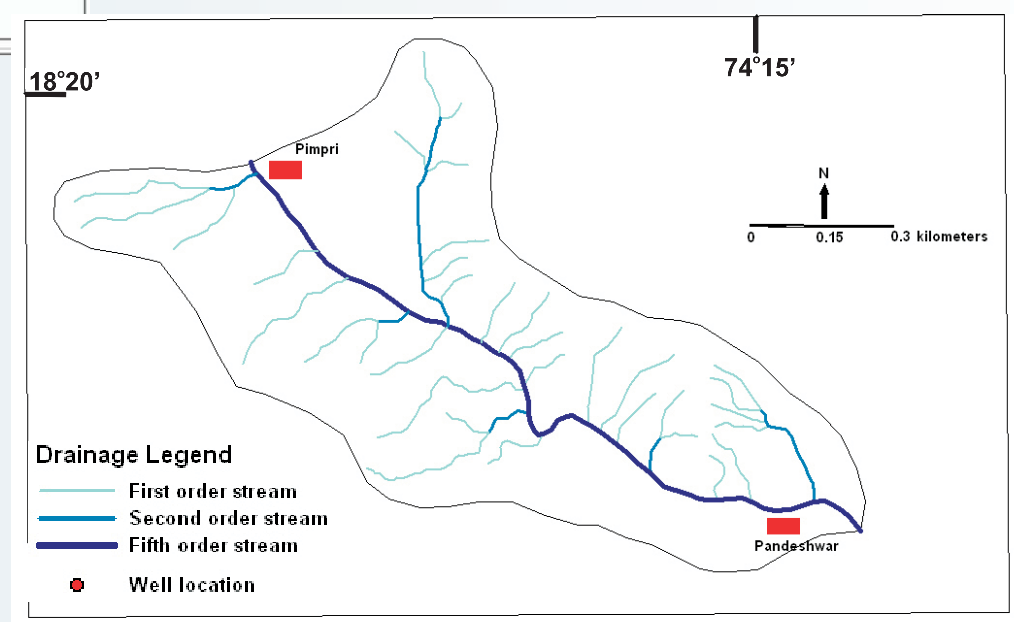


Figure 2.1(D &E): Hydrogeological map of (D)Pondhe watershed and (E)Pimpri Pandeshwar area



2.2: Geology

The three main watersheds in the project area are underlain entirely by the Deccan basalts (also referred to as Deccan Traps or Deccan Trap Basalts), formed from the eruption of lavas some 65 million years ago. These lava 'flows' vary in thickness from a few meters up to tens to hundreds of meters. Each lava flow can further be divided into units and sub-units. In general, the Deccan basalts can be grouped into two categories, 'simple' or 'compound', depending on the viscosity of the primary lava *(Deshmukh, 1988; Kale and Kulkarni, 1992).*

The simple basalt flows equate to classic flood basalts formed by effusive eruption of very large quantities of low viscosity lava from open fissures. The compound flows are either the product of explosive activity from more viscous lavas or can be formed at the distal portion of simple flows where there is an increased viscosity from cooling and de-gassing. Both types of basalt flows tend to weather variably even across small outcrops. Basalt lavas from the project area have been depicted dominantly as “aa'' lava flows belonging to the Diveghat formation *(GSI, 2001).*

The compound flow basalts result from lavas, which lose much of their volatile gases prior to extrusion and hence are more viscous. This greater viscosity causes the remaining volatile gases to be trapped within the rapidly solidifying lava. The lava is characterized by upper and lower surfaces that resemble “rubble”. Fragmentation of the upper surface results from the disruption of the viscous crust by the movement of the flow beneath it. Some compound flows may be devoid of a compact middle layer. Although distinction is made between the two flow types, gradations between simple and compound flows are not uncommon since the effects of the loss of volatiles and cooling will increase the viscosity of the lava and cause a change in physical characteristics *(Macdonald et al, 1995).*

The project area has been divided into two types of basalt units, namely the vesicular-amygdaloidal basalt units and the compact basalt units, based on hydrogeological work in the Deccan basalts by some of ACWADAM's team members. A comprehensive narrative of these experiences and the development of a systems approach to Deccan basalt hydrogeology is provided in *Kulkarni et al (2000).* Nine basalt units have been mapped in the project area based on this classification. The classification includes division of a verical pile of basalts into Vesicular-amygdaloidal basalts (capped by red tuffaceous layers) and compact basalts . These units are essentially mappable portions of the lava sequence with a geometry that takes into consideration the weathering and fracture patterns in units, and more importantly, avoids any semantics debate regarding the formation of the rock itself, i.e. debates surrounding volcanological classification of the basalts. In other words, the classification used here is based upon factors controlling groundwater accumulation and movement in these basalts, rather than on the genetics of

Lithified alluvium in Pandeshwar area

Tekwadi

their formation. *Figure 2.2* is a geological map of the project watersheds showing the disposition of horizontal basalt units.

Further, regional linear features in the form of fracture zones and dykes often transect a sequence of basalt lavas. These lineaments in the project area were identified through field checks, although remote sensing data was procured subsequently and cross-checked with field observations. The geological map also shows the lineaments, most of which are in the form of fracture zones. The geology of each watershed is briefly described further in this chapter.

The other important geological feature that contributes to the hydrogeology of the project area is the presence of alluvial (sediments) deposits, in different parts of the area. Alluvial deposits are found in local pockets, almost across all the watersheds, but their presence at a certain scale is apparent in the Pandeshwar area where they constitute a significant portion of the watershed, overlying the basalt sequence for much of the downstream portion. The deposits include course sand and gravel, often cemented together by a calcareous matrix. At places, they are consolidated into a lithified mass, whereas at other places, they remain unconsolidated. They attribute unique hydrogeological characteristics to the areas where they occur– anomalous to the otherwise basalt dominated hydrogeology of the area.

The interconnectivity between units and the fracture openings within each unit, control the storage and transmission of groundwater in these basalts. Compact basalts have very little storage and transmission capability, except when jointed or fractured. Even then, the permeability of the fractured portion of compact basalts is quite limited as compared to that of weathered vesicular-amygdaloidal basalts / compound basalts *(Kale and Kulkarni, 1992; Kulkarni et al, 2000)* as compact basalts tend to be more vertically fractured than horizontally. Hence, due to their horizontal sheet jointing (related to the degree of weathering) and greater lateral interconnectivity, the vesicular-amygdaloidal basalts form a better medium for the storage and transmission of groundwater.

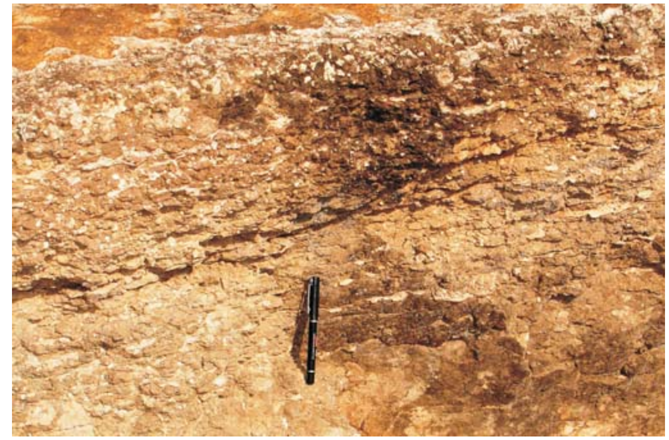
The alternate sequence of vesicular-amygdaloidal basalt units and compact basalt units encompasses a compounded thickness of some 190 m over the project area. Individual units show thicknesses that vary from a few metres to tens of metres. The vesicular amygdaloidal basalts are usually quite weathered and sub horizontally sheet jointed. Each vesicular-amygdaloidal basalt unit is underlain by a denser, compact basalt subunit that is commonly sub-vertically jointed in its upper portions. These upper jointed parts grade downward into more unjointed, dense portions marking the base of the major aquifers in the area. *Figure 2.3* is a conceptual diagram showing the cross section of basalt units from the project area.

The regional fractures representing 'fracture zones' are traceable for considerable distances along certain preferred orientations. Three sets of

Typical compact basalt found in Western Maharashtra

regional fractures predominate. One set representing NNW-SSE, the second set NE-SW and a third set in E-W direction. The implications of these fractures on the overall hydrogeology of the project area needs a more detailed and rigorous effort as these may be of some importance, especially in the recharge processes and in the interconnectivity between different aquifers or groundwater systems. However, the sequence of alternate vesicular-amygdaloidal and compact basalt units has a more dominating control on the occurrence and movement of groundwater in the region.

Figure 2.2 indicates the geological map prepared for four watersheds and Pimpri Pandeshwar area, prepared using extensive field work and well lithologs



Typical vesicular amygdaloidal basalt

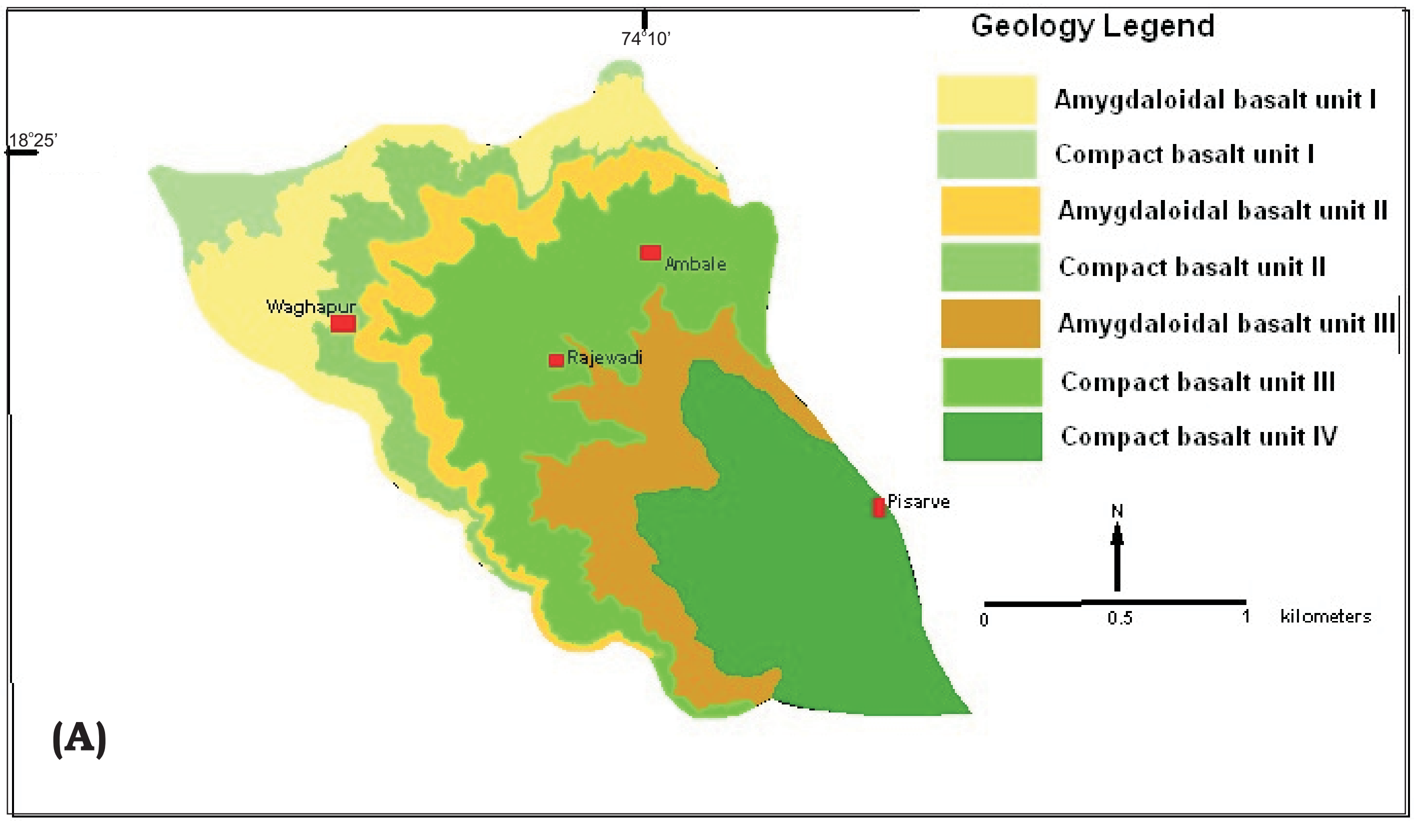


Figure 2.2(A): Geological map for Amble watershed

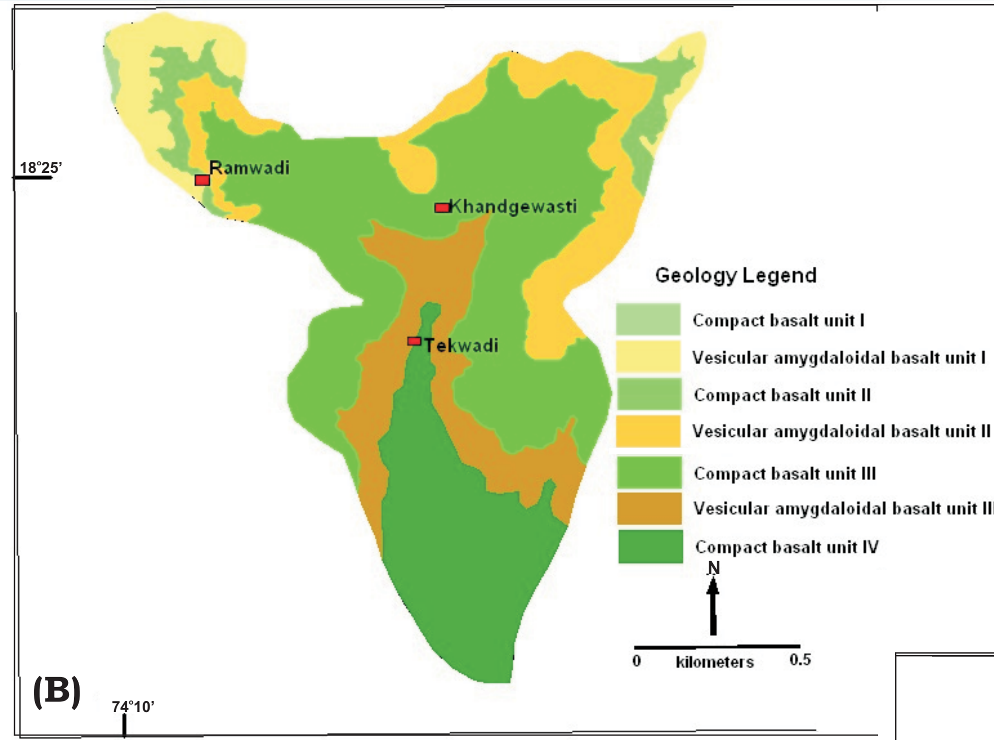
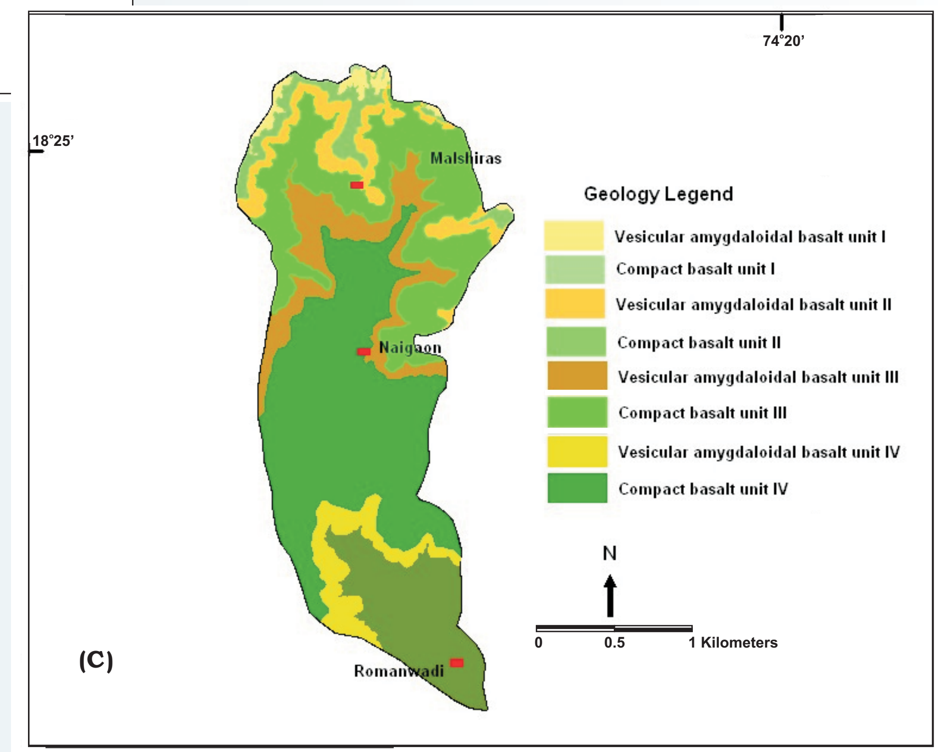


Figure 2.2(B): Geological map for Tekawadi watershed

Figure 2.2(C) : Geological maps for Naigaon watershed



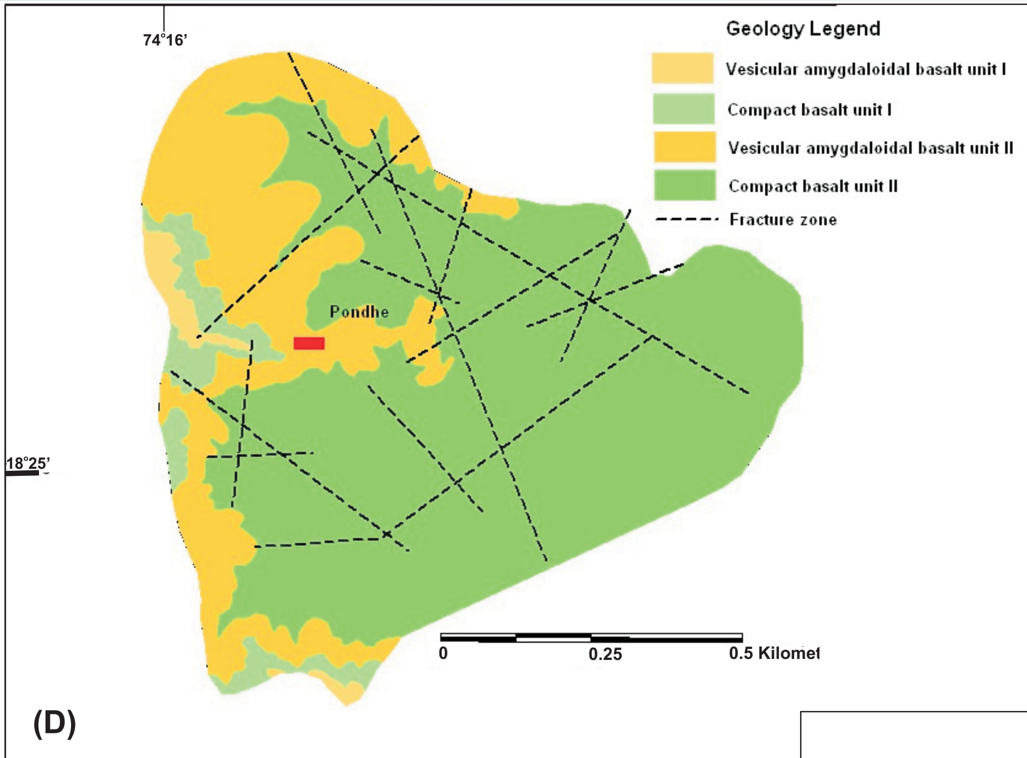
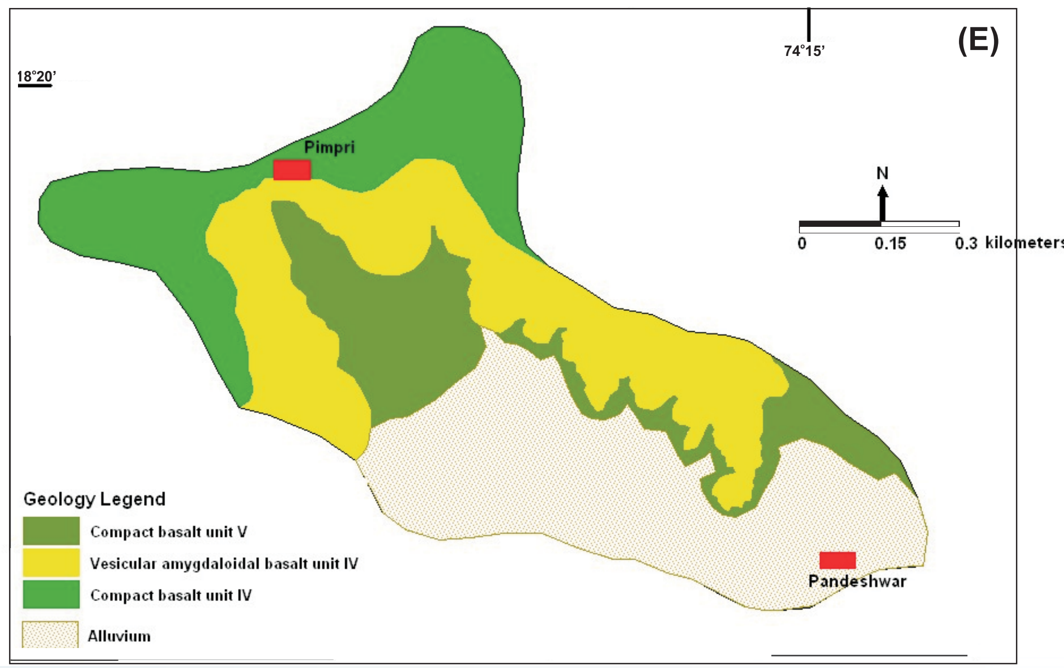


Figure 2.2(D) : Geological maps for Pondhe watershed

Figure 2.2(E) : Geological maps for Pimpri Pandeshwar watershed



Name	Geological Features	Hydrogeological Features	Watershed, where exposed
Compact basalt Unit I (CB I)	Generally without vesicles, or amygdales. Local sub-vertical fractures or columnar joints	Storage is limited due to the limited thickness of the fractured portion. Some transmissivity can be attributed to the sub-vertical joints.	*Waghapur watershed, Malshiras watershed.*
Vesicular amygdaloidal basalt Unit I (VAB I)	Characterised by spheroidal amygdales and some vesicles; the upper portion is characterised by pyroclastic material, while the middle and lower portions generally show a well-devloped network of sub-horizontal sheet joints.	Highly porous and permeable. High transmissivity due to a reasonable thickness.	*Waghapur watershed, Tekwadi watershed, Malshiras watershed.*
Compact basalt Unit II (CB II)	Generally without vesicles, or amygdales. Local vertical or columnar jointing.	Storage is limited due to the small thickness of this portion. Some transmissivity is attributed due to the sub-vertical joints.	Waghapur watershed, Tekwadi watershed, Malshiras watershed.
Vesicular amygdaloidal basalt Unit II (VAB II)	Formed at the center of the watershed. Spheroidal amygdales and vesicles; progressively more rubbly upwards with a network of sub-horizontal sheet joints.	Highly porous and permeable. High transmissivity.	Waghapur watershed, Tekwadi watershed, Malshiras watershed.
Compact basalt Unit III (CB III)	Dominated by typical columnar jointing (with colonnade and entablature structures); highly fractured at places, especially along regional fracture zones.	Storage is limited due to the small thickness of this portion. Some transmissivity is attributed due to the sub-vertical joints.	Waghapur watershed, Tekwadi watershed, Malshiras watershed.
Vesicular amygdaloidal basalt Unit III (VAB III)	Dominated by amygdales and vesicles; sheet jointed to a great extent.	Highly porous and permeable. High transimissityy, more on account of the widespread sheet jointing, although thickness is limited.	Waghapur watershed, Tekwadi watershed, Malshiras watershed.
Compact basalt Unit IV (CB IV)	Thick unit, with little fracturing (restricted to the upper couple of metres only). Discrete fractures that barely attribute permeability.	Storage is limited due to the impermeable nature of the rock. Some permeability (and local development of Transmissivity) apparent where fracture zones transect this unit.	Waghapur watershed, Tekwadi watershed, Malshiras watershed.
Vesicular amygdaloidal basalt Unit IV (VAB IV)	Relatively thin and with a limited development of sheet joints	Some degree of permeability, but storage is limited as compared to the VAB units in the upper parts of the watersheds	Malshiras watershed.
Compact basalt Unit V (CB V)	Covers the lower parts of the Malshiras watershed. Vertical to sub-vertical fractures dominate	Storage is limited due to the small thickness of this portion. Some transmissivity is attributed due to the sub-vertical joints.	Malshiras watershed.

Table 2.3: Classification of rocks from the project area (refer fig. 2.3)

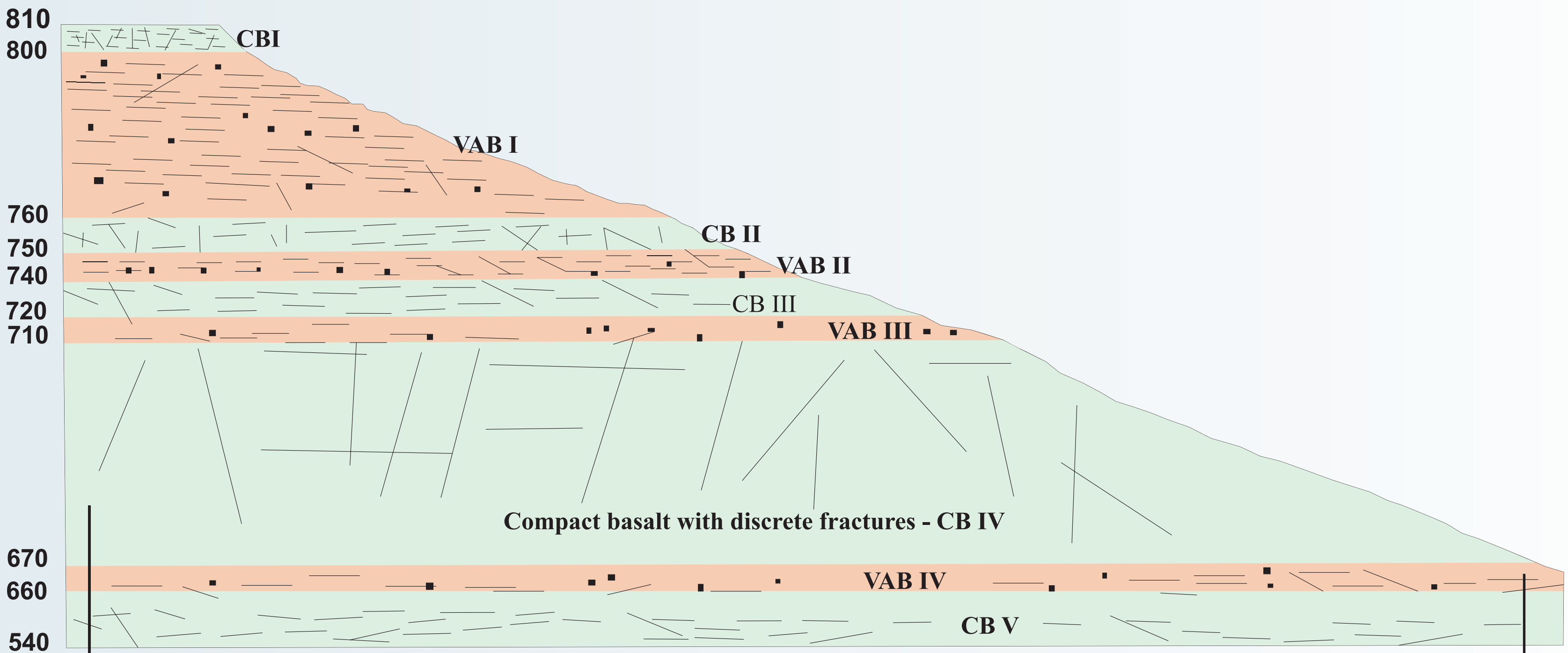


Figure 2.3: Generalized cross section of the geological units in the project area
(figure not to scale, especially laterally)

Compact basalt with subvertical joints

Vesicular amygdaloidal basalt with subhorizontal (sheet) joints

2.3: Hydrogeology

Hydrogeology is the study of groundwater and its linkages with surface water. It is an integral part of the planning of any watershed development and management programme. In this branch of science, a detailed study of the geology is conducted and the aquifers are demarcated for an area. Groundwater occurs in aquifers. Aquifers are made up of rocks or rock material, with sufficient porosity and hydraulic conductivity for water to be extracted from wells, bore wells, tube wells and other means of tapping groundwater. Developing an understanding of aquifers forms the first step in generating knowledge about groundwater and using such knowledge and information to manage groundwater in a sustainable manner. Aquifer delineation was rendered possible due to the detailed geological mapping of the watersheds, based on an established geological model by *(Kulkarni et al (2000)*. The details of the aquifer system in each watershed is given below.

Amble and Tekawadi watershed

Amble and Tekawadi watershed consists of seven alternate units of compact and vesicular-amygdaloidal basalts. It consists of three aquifer systems. Aquifer system I is the shallow aquifer for Pisarve village and Tekwadi village and is the deeper aquifer for Waghapur and Ramwadi. Aquifer system II is the shallow aquifer for Amble and Khandgewasti and aquifer system III is the shallow aquifer for Waghapur and Ramwadi village. The thickness of the shallow aquifer is around 10 to 15 m. The amygdaloidal basalt unit has a number of horizontal fractures and is highly weathered. The upper portion of compact basalt is also weathered and a number of vertical fractures are developed. The details like aquifer characteristics and aquifer properties are discussed later in this report. These two watersheds are the part of overexploited area and there are hundreds of dug wells and bore wells in this watershed. The overexploitation has caused a severe impact on the water levels in the dug wells. Around 30% dug wells run dry by the end of April, and with most dug wells penetrating to the base of the aquifers, this implies a complete dewatering of the aquifer at the end of a typical summer. *Figure 2.4* and *figure 2.5* indicate the generalized cross section of the geological units in the two watersheds.

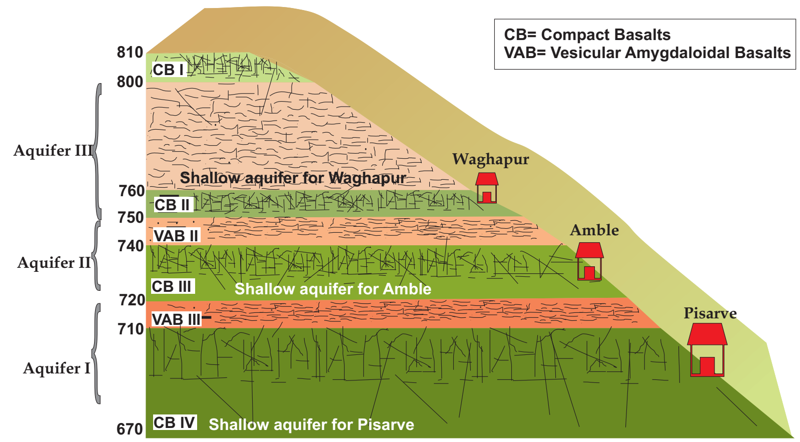


Figure 2.4: Generalised cross section of the geological units in Amble watershed (Figure not to scale, especially laterally)

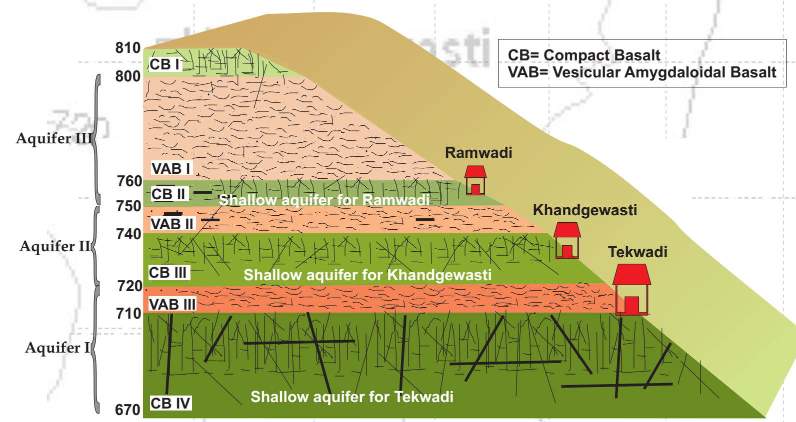


Figure 2.5: Generalised cross section of the geological units in Tekawadi watershed (Figure not to scale, especially laterally)

Naigaon watershed

Naigaon watershed consists of nine different units of basalt. It includes all the basalt units present in the study area. This watershed also consists of three aquifer systems. *Figure 2.6* indicates the generalized cross section of geological units in Naigaon watershed.

Aquifer I is the shallow aquifer for Naigaon and Romanwadi, which is also a deeper aquifer for the Malshiras watershed. The thickness of this aquifer is around 10m. Aquifer II is the shallow aquifer for Malshiras and represents the deeper aquifer for Bhuleshwar and the surrounding region. The thickness of this aquifer is around 10 to 15m. Aquifer III is the shallow aquifer for Bhuleshwar with a thickness of around 25 to 30m.

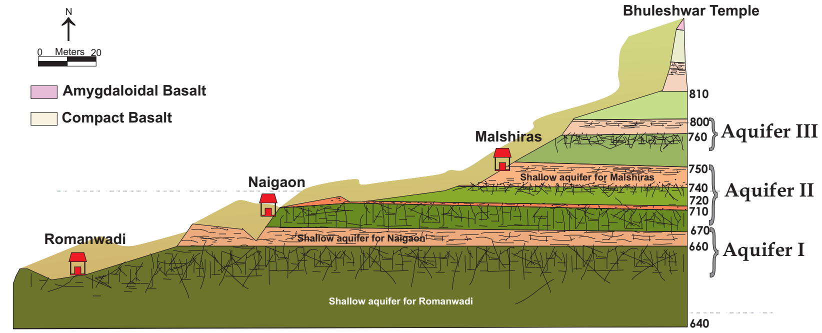


Figure 2.6: Generalised cross section of the geological units in Naigaon watershed (Figure not to scale, especially laterally)

Pimpri Pandeshwar watershed

Pimpri Pandeshwar watershed is different from the other watersheds of the study area as it has two different lithologies, one is the Deccan basalt and the other is the alluvial deposit, mentioned above. This lithological contrast is one of the major causes of groundwater salinity in Pimpri Pandeshwar. There are three aquifer systems in Pimpri Pandeshwar, two systems are in within the Deccan basalt and one system is within the alluvium. Aquifer system I in Deccan basalt is the shallow aquifer for Pandeshwar and deeper aquifer for Pimpri while aquifer system II is the shallow aquifer for Pimpri. The average aquifer thickness is around 10-15m. The aquifer system in alluvium has a thickness of around 8 to 10m but is quite extensive. Although mapped here as part of the watershed, the alluvial deposit is quite regional, especially to the south of the project area, across the river Karha. *Figure 2.7* indicates the generalized cross section of geological units in Pimpri Pandeshwar watershed.

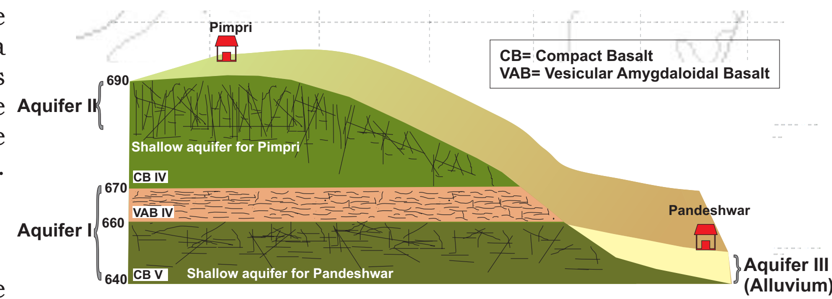


Figure 2.7: Generalised cross section of the geological units in Pimpri Pandeshwar (Figure not to scale, especially laterally)

Pondhe watershed

Pondhe watershed has two aquifer systems, one is the shallow aquifer and the other is the deeper aquifer, which is exposed as a shallow aquifer in the downstream reaches of the Pondhe watershed. Most of the wells in Pondhe tap water from the shallow aquifer(s). These aquifers are realistically some 12 to 15 m thick, on an average across the watershed. *Figure 2.8* indicates the generalized cross section of geological units in Pondhe watershed.

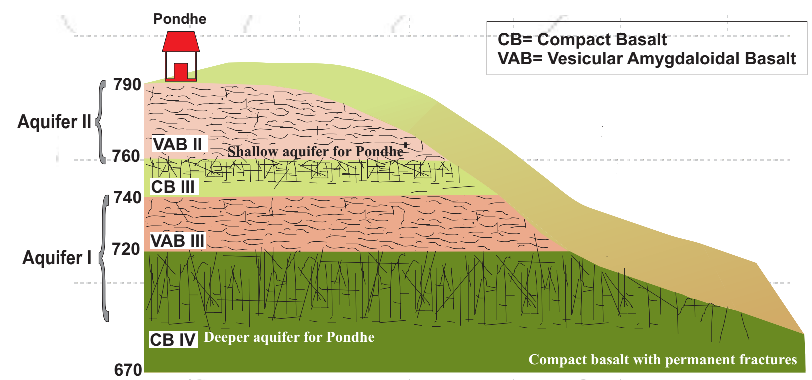


Figure 2.8: Generalised cross section of the geological units in Pondhe watershed (Figure not to scale, especially laterally)

Chapter 3: SITUATIONAL BASE

The area of eastern Purandar lies in the rain shadow region of Western Ghats. It is a typical drought prone low rainfall area with average rainfall of 500 mm. or less. The area is underlain by Deccan basalts, a hard rock regime. Traditionally, farmers in eastern Purandar relied on groundwater due to meager availability of surface water. Farmers have been digging a number of dug wells and later drilling bore wells which has resulted in falling ground water levels. During low rainfall years, farmers in Purandar do not have any alternate source of water besides groundwater and therefore overexploitation of groundwater is taking place for the last two decades. There is a complete mismatch between the availability, demand and supply of groundwater. Mr. Vilasrao Salunkhe was the first to develop a model that addresses supply as well as the demand side aspects of land and water management for this area. This "Pani Panchayat" model has been tested for more than two decades and has proved beneficial to villagers, especially from water scarce regions.


Landscape of Purandar

ACWADAM has been working in 10 villages of Purandar taluka of Pune district. This area is covered under 5 watersheds, four draining in the Karha river and one directly into the Mula river. The total area covered under this study was of the order of 15000 hectares, i.e. 150 km^2. A comprehensive hydrogeological study was undertaken to obtain a basic understanding of groundwater resources in the area and create a "knowledge base" for implementing agencies, mainly GGP and its partners, to take up any kind of water resources programme in the region as well as to advocate the typologies of groundwater problems that require specific approaches for mitigation.

The apex agency regulating groundwater resources in the State of Maharahstra - the Groundwater Survey and Development Agency (GSDA) - has included all these villages as one large overexploited block. The main conclusion that emerged from the ACWADAM study was that policy decisions such as regulation of "overexploited" blocks remain completely inefficient as they fail to capture the variability in conditions and the diversity of situations, especially surrounding groundwater resources from hard-rock terrains. ACWADAM's three year study revealed that, at the micro level, there are complex issues surrounding groundwater and it is prudent to understand, describe and manage groundwater resources at a more 'appropriate' scale than what is commonly practiced in India.

On more specific lines, although the area was divided into 5 watersheds, the variability in hydrogeological conditions and the situations resulting from such conditions made it possible to divide the project area into three different types and the study itself could therefore be separated as three typologies - based on the geographical spread of physical and resultant socio-economic manifestations (*Figure 3.1*). The map below shows the classification of villages into three typologies.

3.1: Typology 1: Overexploitation

Typology 1 included the study of three major watersheds - Amble, Tekwadi and. Naigaon. Groundwater overabstraction, during the last 10-15 years, compounded by a series of meteorological droughts, had created acute water scarcity in villages within these three watersheds. Rampant well digging and drilling of boreholes had led to a progressive fall in water levels in many villages in these three watersheds. The villages and habitations affected by a combination of droughts and groundwater overexploitation included Amble, Waghapur, Rajewadi, Pisarve, Tekwadi, Naigaon, Malshiras and Romanwadi. In the absence of long-term data on water levels in both shallow and deep aquifers, it would be difficult to discuss the precise history of over-development of groundwater resources. However, over large parts of the hard-rock landscape, including the Deccan basalts of Maharashtra, there are studies that have charted the process of groundwater overexploitation *(Macdonald et al, 1995; KAWAD, 2000; COMMAN, 2006)*. All of these studies have clearly spelt out indicators that are often useful in identifying the degree of overexploitation of aquifers. Moreover, on the socio-ecological front, four typical stages of groundwater use and their impacts have been discussed by *Shah (2009)* for the South Asia context. These very stages can be applied to many parts of the Indian scenario.

Groundwater resources have undergone a large transition in these villages. The numbers of wells and bore wells, along with the number of pumps have increased exponentially. There are 4960 irrigation wells in Purandar taluka. *(Agriculture Department Survey 2000-2001)*; however, such secondary data are only indicative of the nature of the problem on a regional scale. Surveys conducted by GGP for the ten villages (forming part of this study) in 2004-2005 showed that there were 2429 wells (dug wells and bore wells), making it to be about 49% of the total number of the irrigation wells in the entire taluka. This fact further highlights how important it becomes to conduct surveys of dug wells and pumps, whose numbers have significantly gone up – two clear indicators of the overdraft and decline stages described by *Shah (2009)*. Similarly, groundwater fluctuations, in wells from all these villages are significant. They were found to be significant in villages like Malshiras even during ACWADAM's 'reconnaissance study' of Pani Panchayats under the COMMAN project *(Sharma et al, 2003)*.

The summer water levels (pre-monsoon) in most wells in these 10 villages drops to the bases of dug wells; in many villages like Tekwadi, wells dry up in January and are often filled up by pumping adjacent bore wells. This fact clearly indicates that pre-monsoon water levels in wells are now at the very base of the shallow aquifer (*Figure 3.2*), an indicator studied in detail for a typical basalt aquifer by *Macdonald et al (1995)*. One of the constraints of the

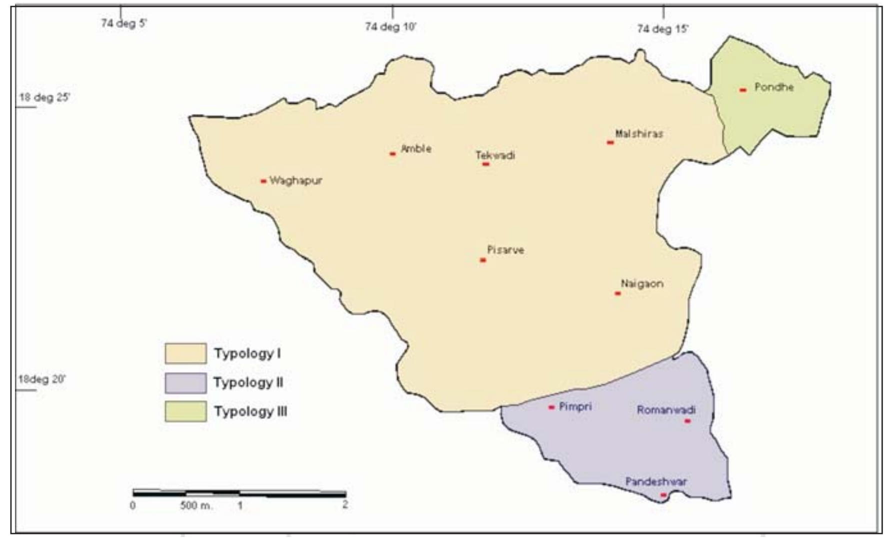


Figure 3.1: Villages in three typologies in the study area

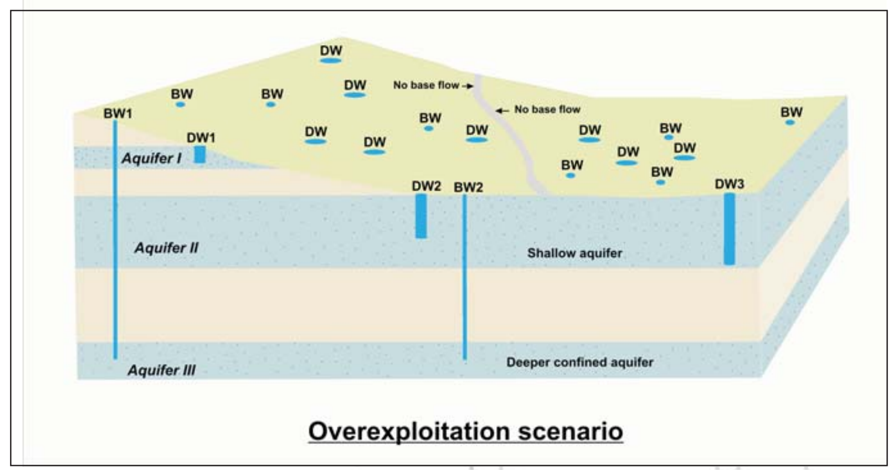


Figure 3.2: Conceptual model of aquifers under typology I

current study was the inability to drill observation bore holes due to the regulation of drilling rigs by the State. However, the topography of the region and the near-horizontal geometry of the basalt lavas implies that the basalt that makes up a shallow aquifer in the lower reaches of a watershed is actually a deeper confined aquifer in the upper reaches of the same watershed. This imbibes a very complex nature of overexploitation as shallow and deep aquifers (at different locations) often share the same recharge (and consequently the aquifer storage) under different sets of conditions.

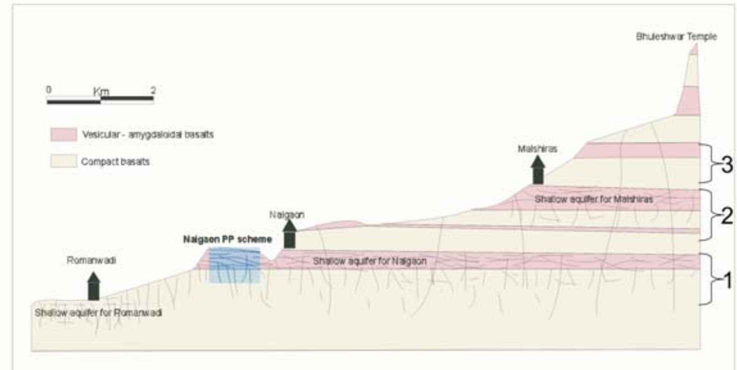
Finally, base flow contribution to streams in all the five watersheds is negligible and most higher-order streams in these watersheds maintain flows only for a couple of weeks after the monsoon season, an important indicator of overexploitation in similar areas from across the hard-rock regions of India *(Macdonald et al, 1995; KAWAD, 2000)*. The post-monsoon water levels in these villages cannot really tell the story of groundwater over-exploitation as most wells often fill up to their brims owing to a limited specific yield and also due to recharge inputs from the many percolation tanks in these watersheds.

The COMMAN Project *(COMMAN, 2005)* researched community responses to problems of groundwater overabstraction in many parts of India. Modeling under complex geological and social conditions, especially of aquifers under transition, showed that in India, the history of groundwater overabstration goes back to the early 1970s with the real crisis hitting resources and livelihoods in the 1990s. A gist of this narrative was captured in the form of a simplified model explaining groundwater overexploitation.This overexploitation of groundwater has been going on for the last 20-25 years with groundwater levels hitting the aquifer bottom especially in the last decade. *Figure 3.4* depicts the gradual process of overexploitation during last 30-35 years.

At present the State Government has imposed a ban on drilling in this area and has included it as a "dark zone", i.e. zone of groundwater overexploitation. Today, most of the villages in the eastern Purandar taluka are in the G and H situation*(Figure 3.4)*. In this case, as there is little storage in aquifer, the aquifer recharge depends entirely on rainfall during the preceding wet season, outlining the contours on whether a drought sets in right away or in early summer. Potential abstraction has already reduced significantly to a minimal amount and the size of the agrarian economy is quite limited, with clear trends of diversification out of agriculture, mainly in the form of migration.

3.2: Typology 2: Groundwater salinity

The alluvial deposits sets apart the stretch encompassing parts of Pimpri and the whole of Pandeshwar village, from the surrounding areas dominated by the Deccan basalt. A large part of this typology is included in the area around Pandeshwar village, including a portion of the Karha river. This area has problems of groundwater quality, essentially because of a higher



Aquifer 3 is the shallow aquifer for Malshiras-Bhuleshwar
Aquifer 2 is the shallow aquifer for Naigaon and Malshiras and deeper aquifer for Malshiras-Bhuleshwar
Aquifer 1 is the shallow aquifer for Naigaon-Romanwadi and deeper aquifer for Malshiras and parts of Naigaon

Figure 3.3: Conceptual diagram showing cross section showing geological units in Naigaon-Malshiras watershed (Diagram not to scale especially laterally)

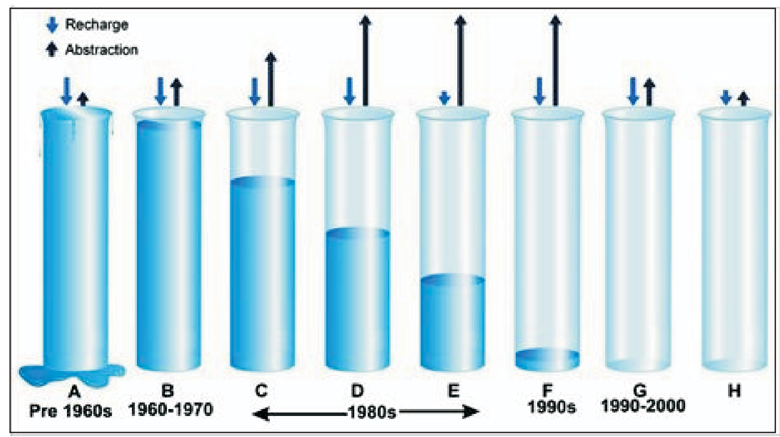


Figure 3.4: Groundwater overexploitation (Kulkarni, 2005)

concentration of dissolved solids, the problem of over-exploitation in villages mentioned in typology 1 notwithstanding.

The problem of groundwater salinity is due to the difference in groundwater properties of two lithological media – the basalts and the alluvium. The juxtaposition of two lithological types – basalt and alluvium – implies two contrasting regimes for the accumulation and movement of groundwater. More specifically, the recharge processes taking place under this regime are quite complex. Groundwater quantities moving through the basalts are relatively small but due to fracture-induced permeabilities, the velocities of groundwater movement are relatively greater. On the other hand, the alluvial deposit is a "sink" with large storage capacities and relatively low hydraulic conductivities. This implies much slower movement of groundwater through the medium, increasing the contact time of the groundwater with the alluvium. Groundwater within the alluvial deposit has a higher concentration of salts as it has a longer residence time in the aquifer material. A few wells like PP2 in Pandeshwar have TDS above 5000 ppm which is high by any standards. Most of the wells in Pandeshwar area have TDS above 1000 ppm. Similarly, these wells have higher concentration of sodium, chlorides and sulphates. Due to this salinity in groundwater the land irrigated through these wells is degraded.

3.3: Typology 3: Community based groundwater management system

The case of Pondhe represents a "typical" situation. The geology in Pondhe village is similar to that in Typology 1. Its situational reference has an extremely wide-ranging context – even from a national perspective. The scale of ratifying the degree of groundwater overexploitation is stipulated as a "block" or "taluka" or regional "watersheds". In Maharashtra, for instance, the unit for gauging overexploitation is a watershed. There are some 1504 odd watersheds in Maharashtra, and with a total area of 308000 km^2, one is considering a unit with an average size of 205 km^2. The question, therefore, is how many villages would typically fall within such a unit; more significantly, how many aquifers would be part of such a 'large' unit, considering that hard-rock aquifers, such as the Deccan basalt aquifers have a very local setting *(Adyalkar and Mani, 1971; Deolankar, 1980; Kulkarni et al, 2000)*. The size of the unit for deciding the degree of overexploitation is simply too large, especially if there are niches of 'under developed groundwater resources' in such a setting.

Pondhe village represents a niche of underdevelopment in a larger setting of overexploited aquifers. Pondhe village lies in the northeastern corner of Purandar taluka, adjoining the adjacent taluka of Baramati. Pondhe was mapped by the state groundwater agency (GSDA) as a village within an overexploited block. In reality, it is far from overexploited. On the one hand, it is part of the Mula-Mutha river basin, rather than the Karha river basin

Drilling going on in Pondhe for drinking water supply scheme

(typologies 1 and 2 are part of the Karha river basin). ACWADAM's study in Pondhe revealed a water level regime and base flow behaviour that clearly indicated that aquifers in Pondhe were <u>not overexploited</u>, although groundwater use seemed to be on an upswing, based purely on individual investments. This study proved to be critical in an initiative to derecognize Pondhe as a village with groundwater overexploitation and to kick-start an initiative on community based groundwater management, based on the principles of Pani-Panchayat. The typology of Pondhe, therefore includes piloting the practice of equitable distribution of water resources that GGP has been advocating for many years now, at the scale of an aquifer system which has a reasonably good coherence with the overlying village and watershed boundaries. The study in Pondhe village was further fine-tuned to compliment the initiative on the ground. This initiative involved setting up of community well-user groups based on a hydrogeological study and is complemented by a study on the social and economic variables in Pondhe village. The detailed hydrogeological investigation led to the structuring of well-user groups and the plan of how water will be used from each of the identified wells. ACWADAM's study also complemented the systematic deepening and construction of "community" irrigation wells taken up separately by GGP under a grant from Arghyam Trust. The management of this limited storage (in an unexploited conditions) is represented under typology 3.

Well water level after the monsoon

Chapter 4: CHARACTERISTICS OF GROUNDWATER

The data collected during the project has yielded interesting results. Salient results that have a bearing on the groundwater management strategy for the region are presented below.

4.1: Groundwater levels

Groundwater level measurement forms the basic building block to understanding groundwater resources *(Brassington, 2007)*. Wells are used to measure the groundwater levels as they provide the best option to look at the distribution of the "head" in an aquifer. In Purandar there are hundreds of dug wells and bore wells which form the main source of water supply for farmers in the region. It was not easy to measure the water levels in the study area as there are hardly any wells in the static state (without pumping). Most of the wells are pumped regularly to fulfill the growing demand of water for drinking, livestock and irrigation. As most of the farmers in eastern Purandar have a dug well and additionally a bore well, they often use water from both these sources, periods of regulation of electric supply and pumping schedulesbeing haphazard. Sometimes, during the Rabi season, when the water from the dug wells starts receding, farmers pump water from their bore wells into their dug wells. Therefore, it is quite challenging to obtain the actual water levels representative of aquifers, in the area. However, ACWADAM together with the GGP staff (from the project villages) were able to obtain accurate water level data for the selected 221 dug wells for monitoring. This was possible through a systematic process of monitoring wells. Wherever such practices were obvious, a noting of the same was made on the well-inventory form. Water levels were recorded early in the morning so as to ensure sufficient time for recovery, even for wells pumped the previous day. *Table 4.1* shows the number of wells monitored in each watershed from the project area.

At the beginning of this study, the frequency of monitoring was monthly. The monitoring of wells began in July 2006 for Pondhe and Tekawdi watersheds. In Amble and Pimpri Pandeshwar, the monitoring began in November 2006 and in Naigaon-Malshiras watershed the monitoring began in July 2007 as the selection of wells took longer than anticipated. After many deliberations with GGP staff, farmers and ACWADAM's student interns, who surveyed the watersheds in detail, at the beginning of the project, it was decided to leave out existing bore wells from monitoring. This was primarily because:

1. Most water levels in bore holes represented the phreatic surface due to the absence of separation between aquifers – through a proper casing assembly; bore holes tap both shallow and deep

Well monitoring in the project area

Watershed	Number of wells monitored
Amble	74
Tekawdi	55
Naigaon-Malshiras	51
Pimpri-Pandeshwar	25
Pondhe	16

Table 4.1: Details of number of wells monitored in each watershed

aquifers, making it difficult to identify the potentiometric surface of deeper aquifers (which usually is at some depth below the phreatic surface, i.e. water level representing heads in the shallow, unconfined aquifer.

2. Measurement of such heads is rendered difficult as the headwork assembly is quite complicated and it becomes difficult to introduce 'tippers' or 'water level recorders' into the casing pipe of such bore wells.

Water level information was plotted out in the form of well hydrographs for all the 221 wells and as watershed-wise / area wise water table contour maps (for each set of data). Some of these hydrographs and water table contour maps are presented below.

4.1.1: Amble watershed

Amble watershed is one of the 'groundwater overexploited' watersheds in Purandar taluka. As per the survey conducted by GGP in 2004-2005, there are more than 655 dug wells in this watershed. Out of these, 74 dug wells were selected for monitoring. The average depth of the dug well is around 10 m., while the diameter is 6-7m. All these wells have enough water till early February and then the water levels start receding. Out of these 74 wells, 7 wells run dry by the end of March while 25 wells dry up by the end of May. This means that some 9% of the total wells dry up in March while 33% run until the end of summer, i.e. May. *Figure 4.1* indicates the well hydrographs for Amble watershed.

It is generally observed that the water levels in the wells begin to rise immediately after the onset of rains and continue to rise until the last spell of rain; water levels begin to drop once the farmers start irrigating their lands for the Rabi crop, usually immediately after cessation of rains. This particular signature of the hydrograph implies an overexploited aquifer because any additional rain – beyond the last spell – will induce a further rise in the water level, as the aquifer still remains less than fully saturated leaving space for more additional recharge. Water levels reach the base of the wells in early April. It was observed that the around 40% wells had dried up by July 2008 due to the late rainfall (rainfall occurred in this watershed only in August 2008).

Figure 4.2 indicates the groundwater contour map for Amble watershed for two contrasting seasons, i.e. post-monsoon (October 2007) and pre-monsoon (May 2008).

In a water table contour map, recharge areas are characterized by diverging groundwater flow lines, whereas discharge areas are indicated by converging flow lines *(Fetter, 1980*). In figure 4.2, it was observed that the hydraulic gradient (slope of the water table) follows the general slope of land or the topography. In October 2007 (post monsoon), a couple of 'groundwater

Abandoned well in Amble

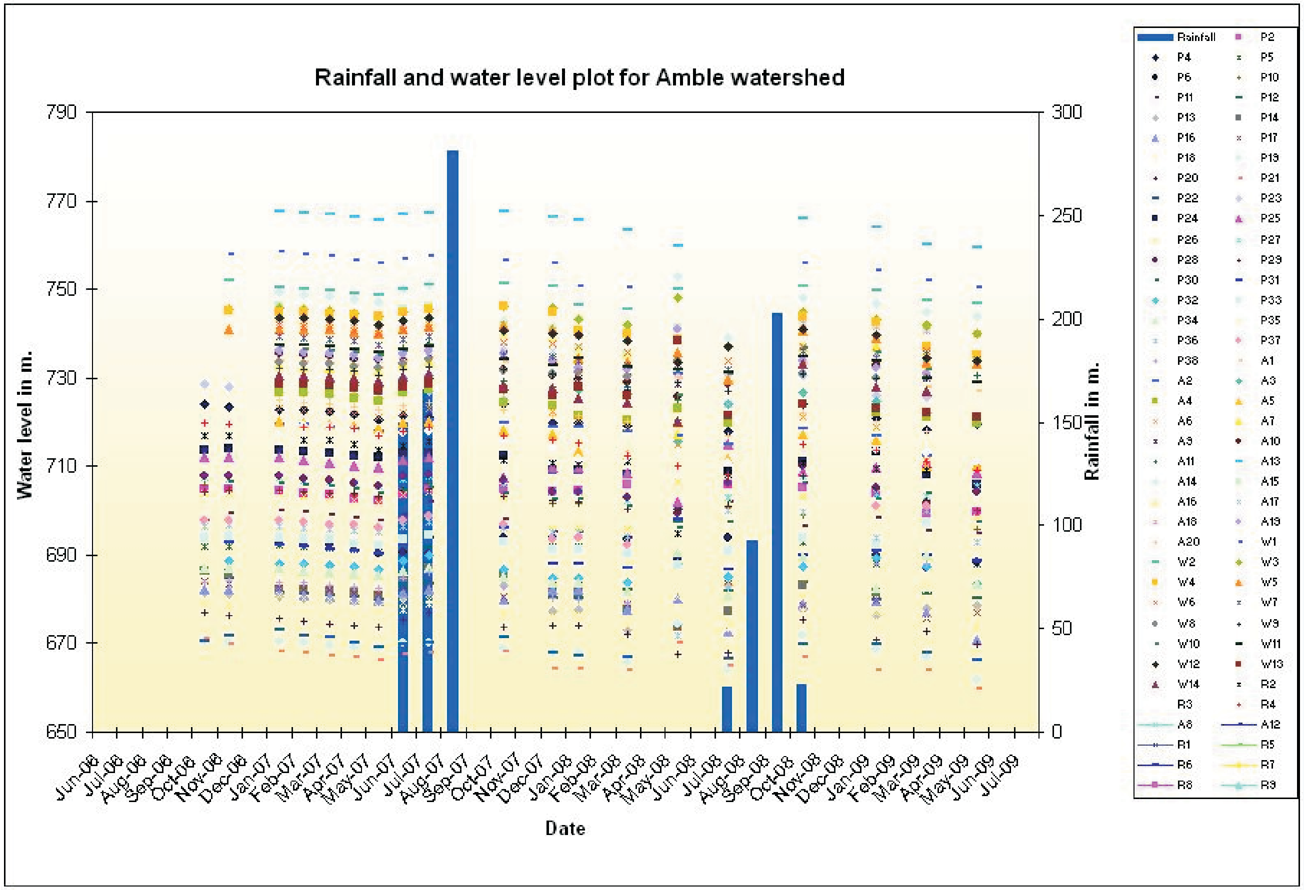


Figure 4.1: Amble watershed: rainfall and water level hydrographfor the last three years

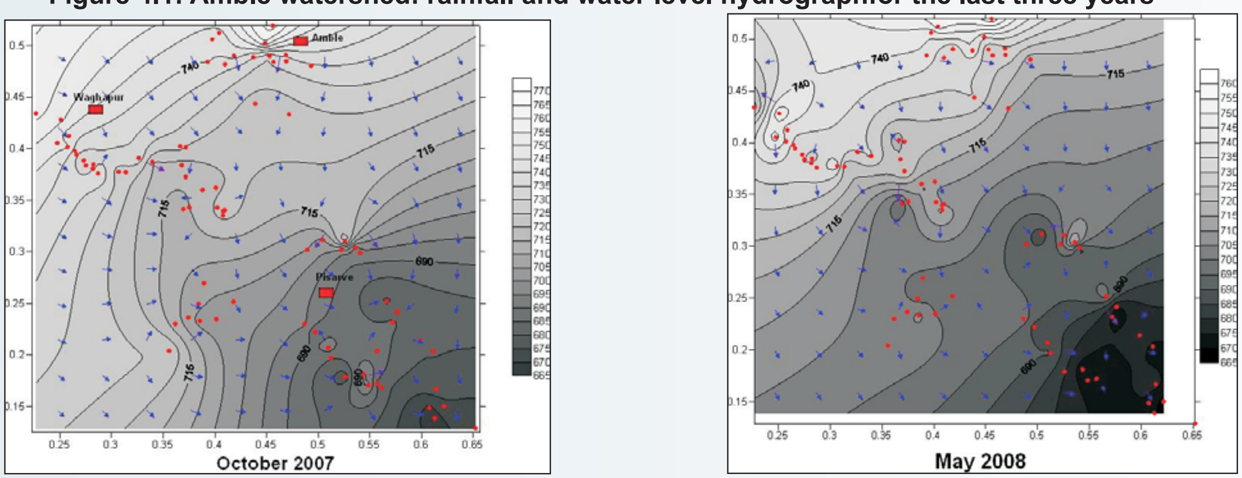


Figure 4.2: Groundwater contour map for Amble watershed for two seasons

mounds' are formed around Pisarve village. These mounds show diverging groundwater flow lines *(figure 1.2)* and act as a groundwater recharge areas. A mound is formed around wells P4, P33, P34, P36 and P37 (Pisarve), while a groundwater depression is formed around wells P12 and P35 (Pisarve). In May 2008, mounds are formed around wells W2, W3, W13 (Waghapur), R8 (Rajewadi), P6, P12 and P26 (Pisarve) while groundwater depression is formed around wells W10 (Waghapur), A14 (Amble), R2 (Rajewadi), P10 and P14 (Pisarve). Most mounds are in proximity to recharge structures constructed on streams – especially in Pisarve and Waghapur. However, recharge structures work best in natural recharge areas *(Kulkarni et al, 2005; Gale et al, 2006*). The same logic is not true for groundwater discharge zones (depressions in the water table contour maps), as these would tend to be modified greatly due to pumping. In October 2007, there are hardly any mounds / depressions formed in upstream villages like Waghapur and Amble while some changes occur during May 2008, due to decline in water levels in many wells, leading to localized groundwater flow systems.

4.1.2: Tekawadi watershed

Tekawadi watershed is also a part of the 'groundwater overexploited' area. In fact Tekawadi has the highest well-density among all the villages in the study area. As per the GGP survey conducted in 2004-2005, there are 229 dug wells and 74 bore wells in Tekawadi village. The average depth of the well is 9m, while the diameter is 6m. Most wells in Tekawadi have water till the month of March. The wells get dried up by the end of April or early May. In 2008, 3% of the monitored wells dried up in early March while 31% wells dried up in early May. In 2009, around 69% monitored dug wells had dried up by early May. *Figure 4.3* indicates the well hydrograph of Tekawadi watershed.

A well in Tekawadi watershed

The groundwater contour map for October 2007 indicates formation of groundwater depression around wells AT14, AT15, AT24 and PT4. Similarly the groundwater contour map for May 2008 indicates formation of depression around AT15, AT16 and PT4 and formation of mound around well no PT7 and PT8. The depression around well no. AT14 AT 15 and AT16 which is quite dominant in October 07 became less dominant (evens out) in May 2009. These wells along with PT4 may be located in the groundwater discharge area. A mound that is observed in well no PT7 and PT8 could be due to some recharge received by the tank located in the downstream area. *Figure 4.4* indicates the ground water contour map for Tekawadi village in two seasons.

4.1.3: Naigaon-Malshiras watershed

The conditions in the Naigaon-Malshiras watershed are in close agreement with conditions in the Amble and Tekawdi watersheds. Moreover, some information and studies were available for these three villages from an earlier study by ACWADAM in this watershed *(Sharma et al, 2003; COMMAN, 2005).* The monitoring in Naigaon-Malshiras watershed began a year later than in

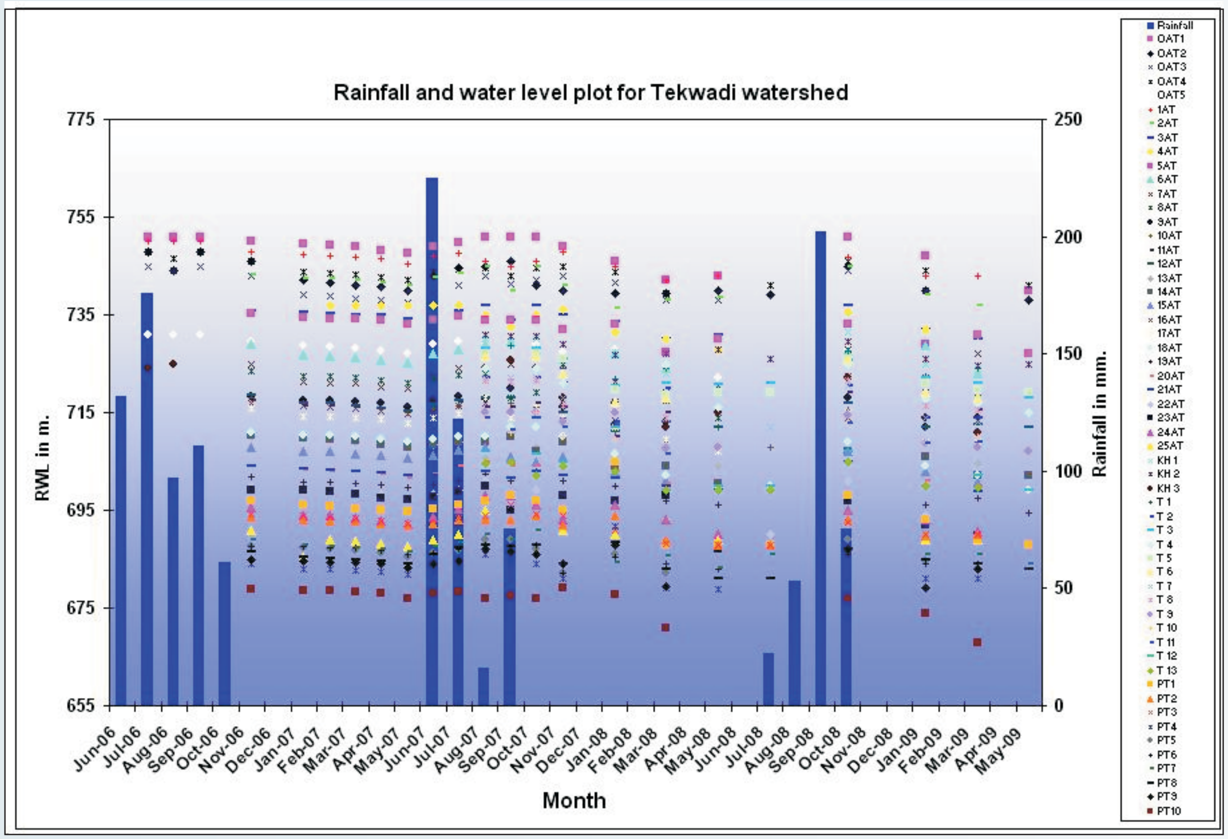


Figure 4.3: Tekawadi watershed: rainfall and water level hydrograph for the last three years

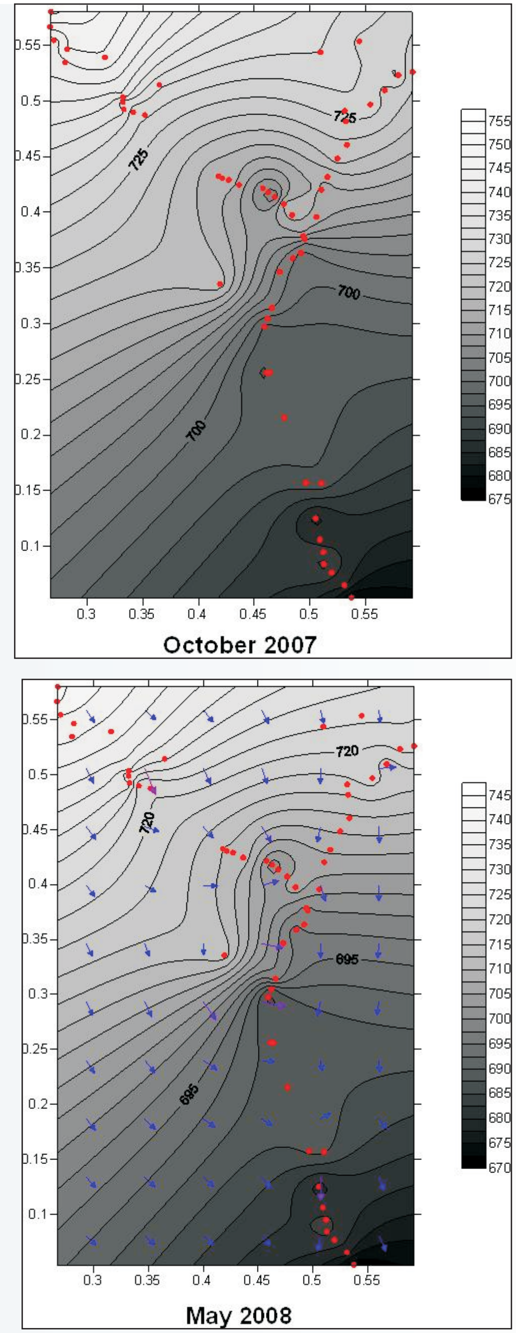


Figure 4.4: Groundwater contour map for Tekawadi watershed for two seasons

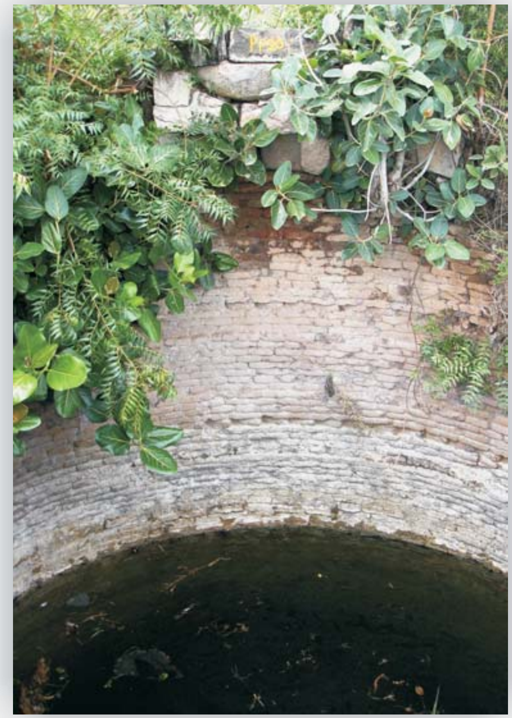
the other watersheds and was meant to capture a broad picture of the water level behaviour in this watershed. Hence, data is available for two years, for this particular watershed. Similarly, the selection of wells was dominantly in the lower portion of this watershed; water table contours were not too representative in the upper portions of the watershed due to a sparse network of monitoring wells. Hence, hydrographs could be plotted but water table contours were difficult to obtain with the existing data. As the Naigaon watershed covers most of the area in a "North-South" direction, a separate groundwater contour map is not given in this report. The regional map for groundwater contours (following section) is thought to capture the groundwater behaviour in this watershed to a larget extent.

ACWADAM had already conducted a detailed study in this area and some preliminary information was readily available regarding the water levels and groundwater behaviour from earlier periods. This watershed is also a part of the "groundwater overexploited" zone. As per the GGP survey conducted in 2004-2005, there are 513 dug wells and 79 bore wells in Naigaon-Malshiras (not including Romanwadi). All the dug wells are shallow dug wells having depth of 8 to 10m. In May 2008, 10% monitored dug wells dried up while in May 2009, 16% monitored dug wells dried up. Increase in drying up of wells can mainly be attributed to low rainfall in 2008. *Figure 4.5* indicates well hydrograph for wells in Naigaon-Malshiras watershed. The hydrographs follow a pattern that is similar to wells from Amble and Tekawdi watersheds.

4.1.4: Pimpri Pandeshwar

Pimpri Pandeshwar area, as mentioned earlier, is technically not a watershed. The mainstream in this area brings water from the upper watersheds – Amble and Tekawadi watersheds – but also has its own local catchment; hence, it has been considered here as a separate unit. The other reason to consider it separately is due to its unique problem – that of groundwater salinity. This watershed is located close to the Nazare dam on Karha river, and therefore farmers closer to the dam site have some additional benefit of surface water. As per the GGP survey conducted in 2004-2005, there are 376 dug wells and 45 bore wells in this area. ACWADAM-GGP monitored 25 dug wells in this area. Almost all these monitored dug wells have water throughout the year. In May 2007, none of the dug wells ran dry. In May 2008, only one well dried up while in May 2009, a couple of wells dried up. *Figure 4.6* indicates the water level and rainfall for the Pimpri Pandeshwar area. Many wells in Pimpri-Pandeshwar area are part of a complex aquifer regime.

The groundwater contour map for October 2007 reveals that there is a groundwater mound created near wells PP3, PP20, PP21 and PP25. Similarly, there is a groundwater depression created near wells PP11, PP12 and PP16. In May 2008, this groundwater mound slowly dissipates but there is no major change in the groundwater behaviour across the two seasons. *Figure 4.7* indicates the groundwater contour map for Pimpri Pandeshwar watershed for



A well in Pandeshwar

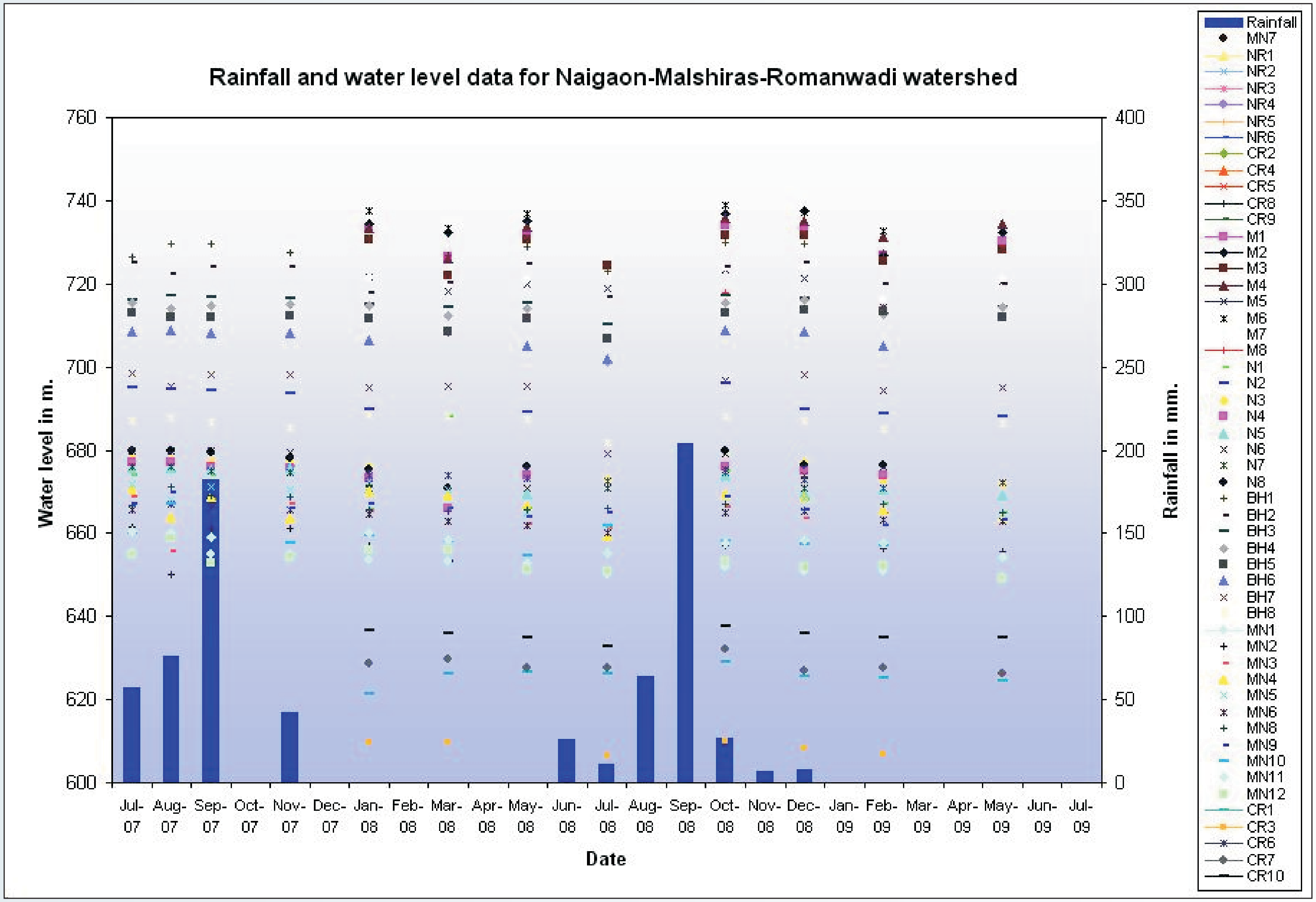


Figure 4.5: Naigaon-Malshiras-Romanwadi watershed: rainfall and water level hydrograph for the last three years

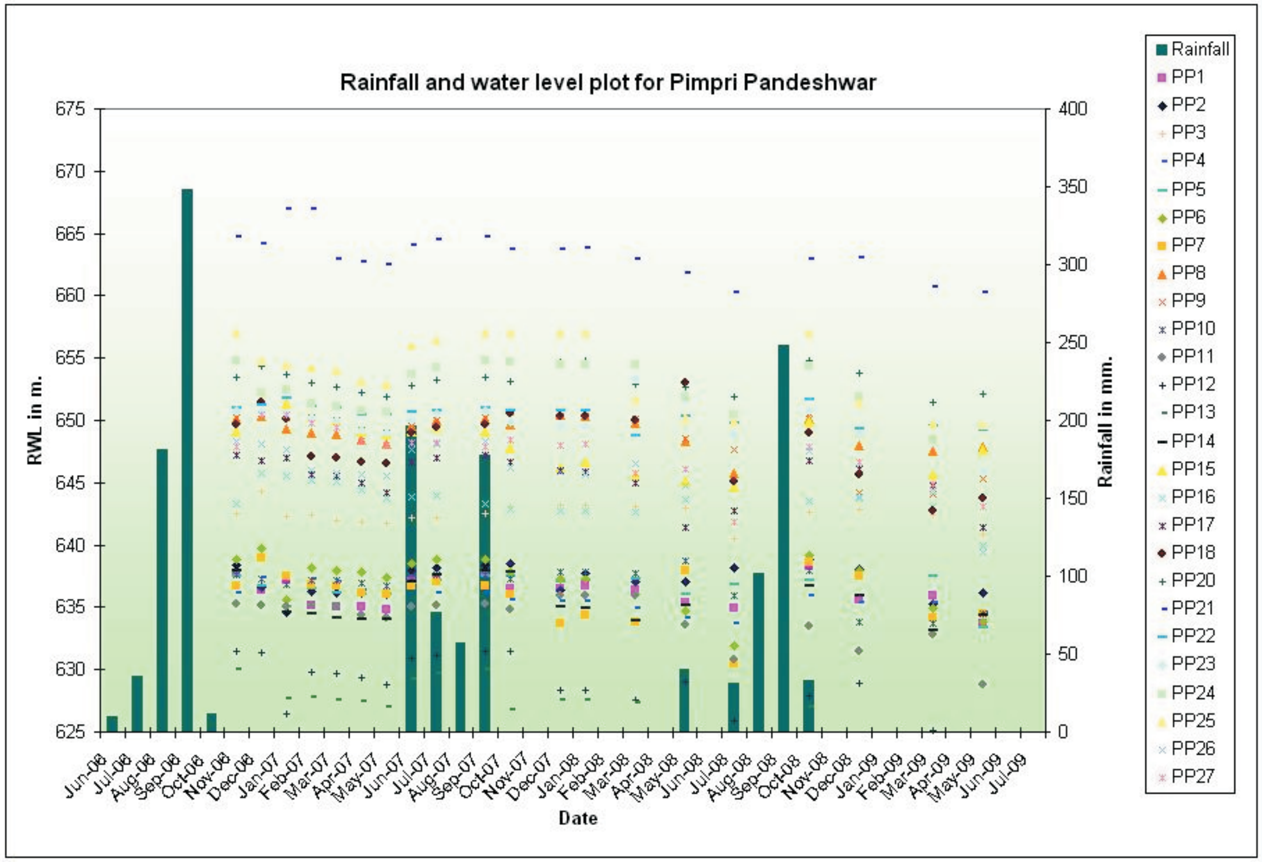


Figure 4.6: Pimpri Pandeshwar watershed: rainfall and water level hydrograph for the last three years

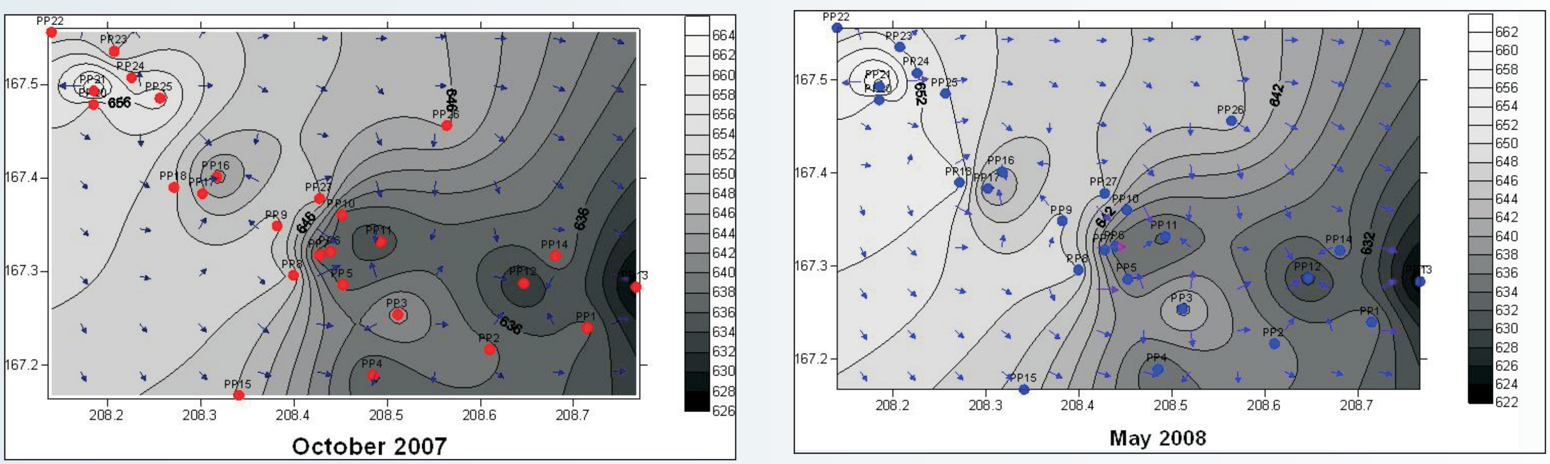


Figure 4.7: Groundwater contour map for Pimpri Pandeshwar watershed for two seasons

two seasons.

The groundwater contour map suggests that wells PP3, PP20, PP21 and PP25 fall in the groundwater recharge area while wells PP11, PP12 and PP16 fall in the groundwater discharge area. This hypothesis can also be confirmed by the water level data as the wells in recharge area show lot of fluctuation, while the wells in the discharge area show lesser fluctuation. Most wells in the discharge zones are located in the alluvial aquifer; it is not surprising to find this as the alluvium is likely to act as a 'sink', given its high storage capacity (as compared to the surrounding and underlying basalts).

4.1.5: Pondhe watershed

This study indicates that Pondhe watershed is not overexploited. As per the survey conducted by GGP, there are around 62 dug wells and 4 bore wells in the watershed, of which 16 dug wells were monitored under this project. It is observed that even after the consistently low rainfall during the last two years, none of the wells dried up. The water levels have gone down significantly but there was enough water in the wells, even at the end of the summer in May 2009. *Figure 4.8* indicates the rainfall and water levels in the dug wells in Pondhe for the last three years.

It is observed that the groundwater follows the topography. The groundwater contour map indicates that, in both the seasons, there is a mound created at well no. PO8 and PO11 while a groundwater depression is created at well no. PO13. There is no significant change in the behaviour of groundwater for the two seasons. Looking at the map, one can suggest that well no. PO8 and PO11 are located in the groundwater recharge area while well no. PO13 is located in the groundwater discharge area. *Figure 4.9* is the groundwater contour map for Pondhe watershed for two seasons.

Irrigation well in Pondhe

4.2: Regional variations in the groundwater contours

ACWADAM-GGP team has data for 221 dug wells for the period of 2 years. All this data, except for that in the Pondhe watershed, was plotted on one map to understand the regional behaviour of groundwater in the study area. Pondhe is not included in this map as it is part of Mula basin while the rest are part of Karha basin. Aquifer systems in these two zones are also not coherent. The regional map (*Figure 4.10* – data for May 2008), however, gives a perspective on the regional behaviour of groundwater in the area. It also divulges the close association between broad recharge-discharge geometries in the water level contour configuration and the underlying geology. Most recharge and discharge zones, are close to lithological boundaries.

Many of the recharge zones are located within compact basalts (clear recharge mounds are apparent in the compact basalt) while the vesicular-amygdaloidal basalts include convergence of flow lines, as discharge zones. It is not

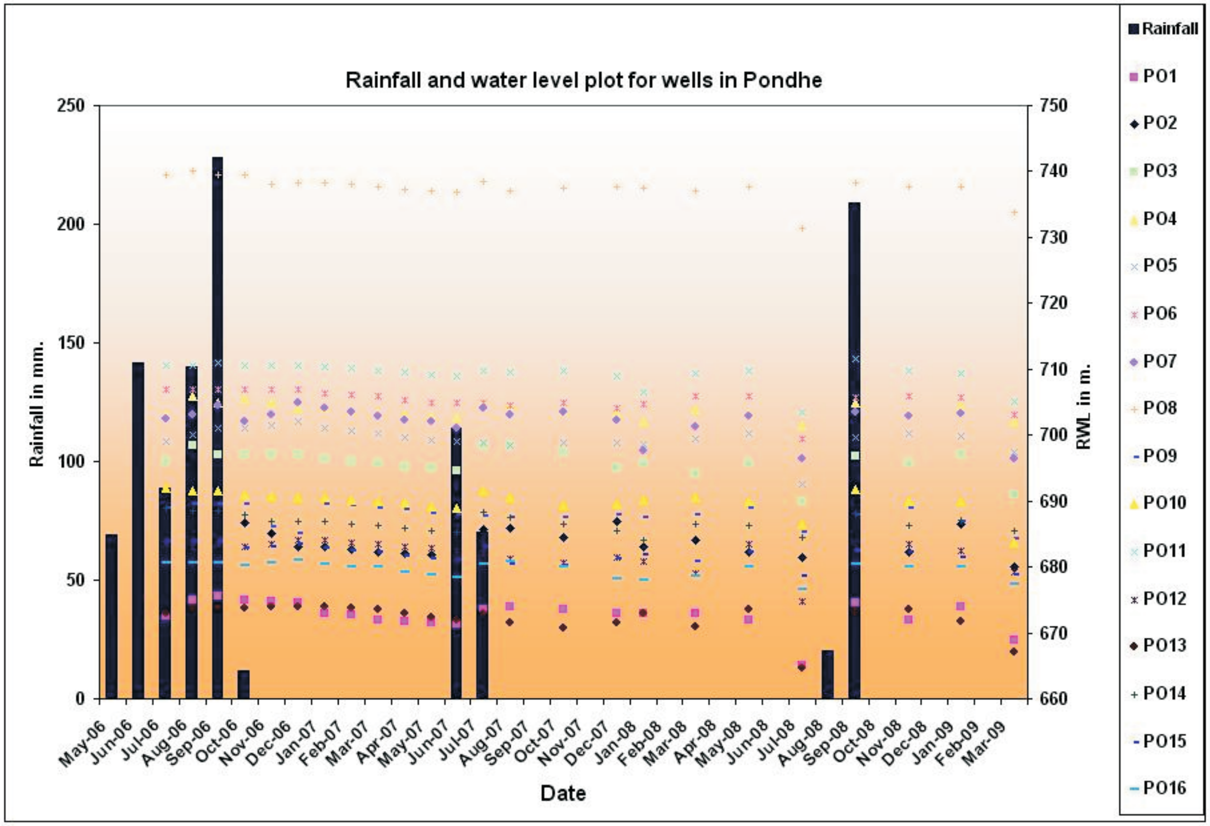
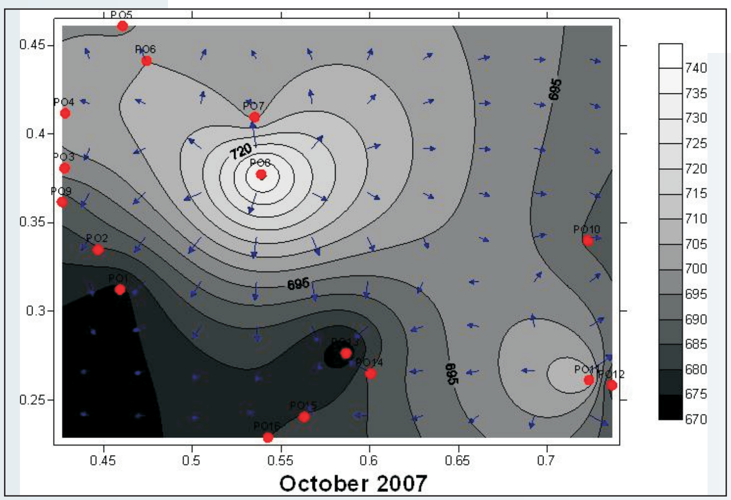


Figure 4.8: Pondhe watershed: rainfall and water level hydrograph for the last three years



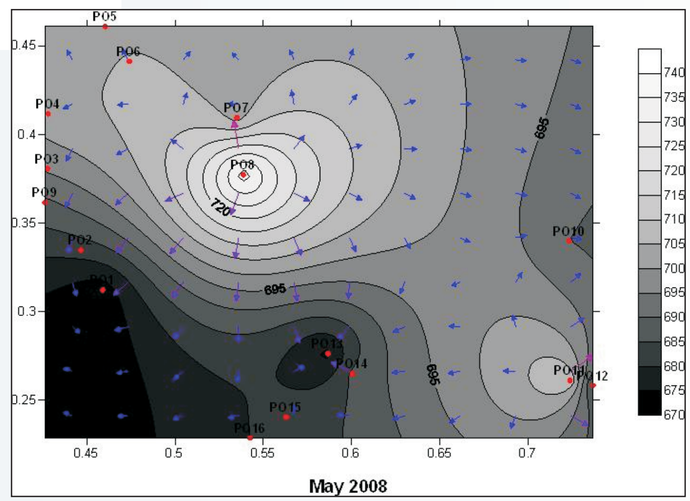


Figure 4.9: Groundwater contour map for Pondhe watershed for two seasons

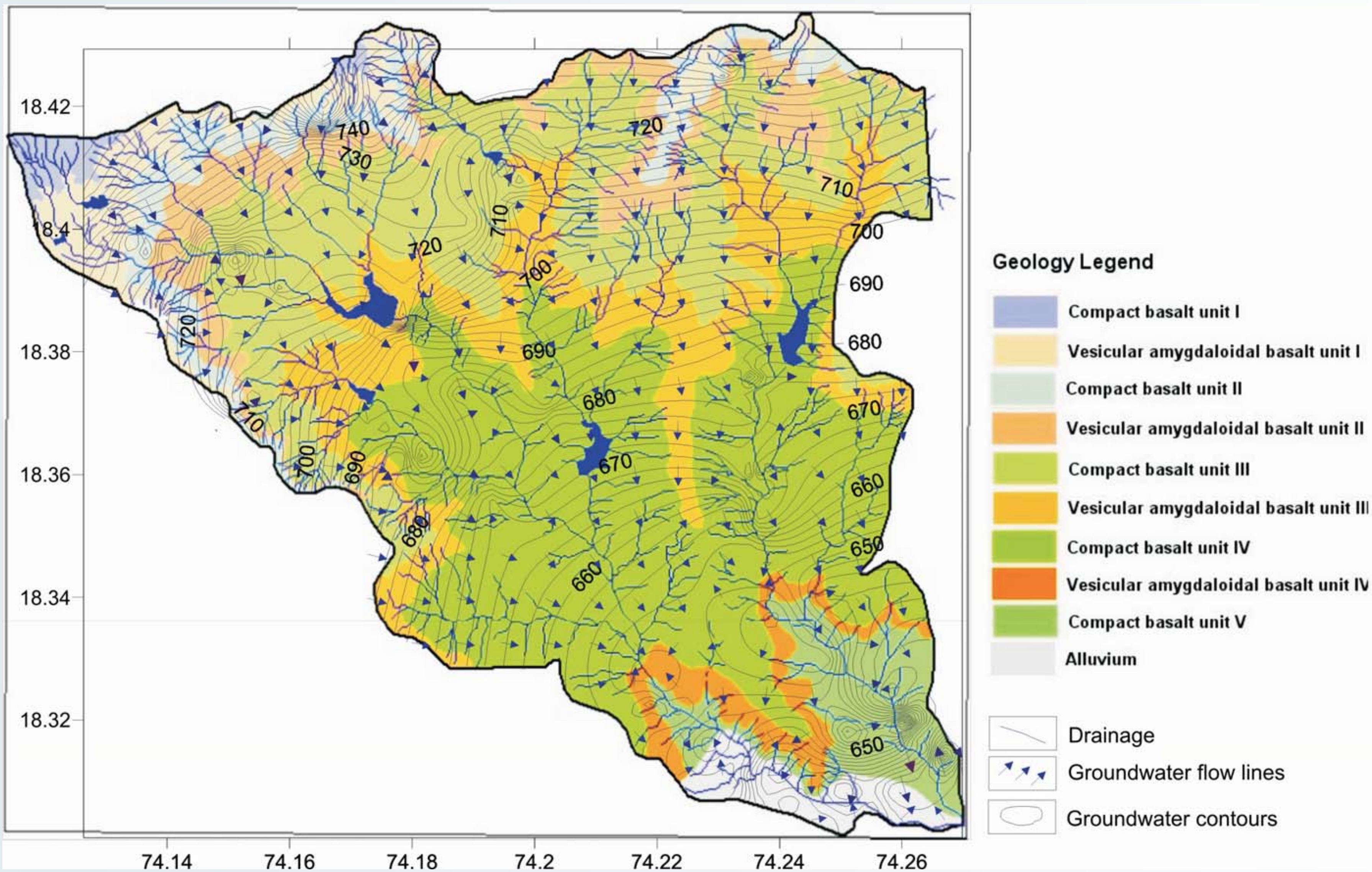


Figure 4.10: Regional geology and groundwater contours in the study area

surprising to observe groundwater discharge zones at the lower contacts of vesicular-amygdaloidal basalts because the overlying rock has both transmissivity and storage coefficients to serve as good aquifers. The compact basalts possess some tranmissivity but little storage space, hence, recharge zones are clearly indicated where these compact basalts are dominantly vertically fractured. Similarly, there are distinct groundwater discharge zones at the boundary of basalt and alluvium, evident in Pandeshwar.

4.3: Discharge measurement

A "V" notch was installed in Pondhe in November 2006 to measure the inflow from the stream. A 'V' notch is a flow measurement structure for measuring small discharges in streams and rivers. The measurement of flow on a V-notch includes passing all the water flow through a notch or contraction in a plate or a weir and measuring the height (head) created by the flowing water over the notch. The discharge is estimated using the Thompson's equation *(Ingersoll – Rand, 1970)*. The discharge for the Pondhe stream was measured on a fortnightly basis. *Figure 4.11* is the stream flow hydrograph created on the basis of the V-notch data, with corresponding data for rainfall.

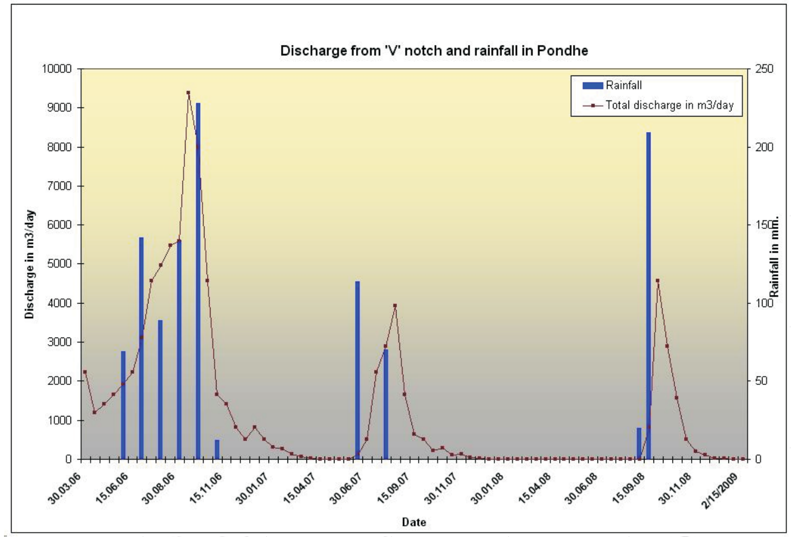


Figure 4.11: Discharge from 'V' notch along with rainfall in Pondhe

In Pondhe, the discharge was measured for three seasons, 2006-2007, 2007-2008 and 2008-2009. In the first season, the stream was nearly perennial and had some water until April 2007. Total volume of water generated between June 2006 and April 2007 was about 4,67,100 m^3 over 1000 hectares, which is equivalent to 467 mm over the watershed. In 2007-2008, the stream dried up in December itself and the total volume of water generated between July and December 2007 was about 170114.25 m^3 over 1000 hectares, which is equivalent to 170 mm over the watershed. In 2008-2009, there was a delayed monsoon and the rainfall occurred in the month of September. The total volume of water generated between September 2008 and February 2009 is about 216900 m3 over 1000 hectares, which is equivalent to 216.9 mm. over the watershed.

For 90° notch the (Thompson's) equation is **$Q = 0.8388H^{5/2}$**
where Q= Discharge in lpm and H= Head in cm.
Ingersoll-Rand (1970) in: Driscoll (1986)

4.4: Base flow

The contribution of groundwater to the ground surface through springs and seepages, which then flow as surface flow is called base flow. Base flow contributes significantly to the surface runoff in a stream or river. Streams, in many parts of India, continue to flow during the dry season due to base flow contributions. Separation of base flow from pure surface runoff for the monsoonal section of the hydrograph was done using the arbitrary base flow separation line. *(Wisler and Brater, 1959; Rodda, 1969 in Kruseman, 1988)* An estimation of base flow is done for Pondhe using the discharge data received from the "V' notch. These base flow estimates indicate that in a good rainfall year the base flow component of the total discharge is around 60 mm whereas in a low rainfall year the base flow component is significantly low (around 10-15 mm) *Table 4.2* indicates the rainfall and base flow contribution in Pondhe.

Year (considered from June to following May)	**Rainfall in mm**	**Base flow in mm** (rounded of to within 2mm)
2006-07	679.8	60
2007-08	183.8	10
2008-09	229	12

Table 4.2: Base flow estimates for three years in Pondhe watershed along with rainfall

4.5: Weather data

Any hydrological study requires the understanding of natural processes like rainfall, evaporation and infiltration. The variability in geomorphological and geological characteristics of a region call for a complete understanding of "micro-level" conditions that control the occurrence and movement of water, especially groundwater. It is then prudent to take this understanding to a "macro" level and then to the "mega" scale, say to the river basin level. In large parts of India, water resources depend largely on patterns of rainfall, dominated by monsoon precipitation. Spatial and temporal rainfall variability has a significant bearing on groundwater resources; however seldom is such variability considered in the micro-planning and management of groundwater. The monitoring of weather parameters under this study was undertaken with the basic purpose of studying rainfall variability and attempting to understand basic patterns of evaporation and associated parameters. While doing so, literature on monitoring weather was refered to , so as to ensure a smooth process from installation to analysis. *(Gunston, 1998, Sutcliff, 2004)*

The study area, as mentioned earlier, consisted of 10 villages in Purandar taluka encompassing an area of around 140 km^2. Government of Maharashtra has set up a manual weather station at Saswad which is around 25 to 30 km. from the study area. There is a lot of variation in rainfall and evaporation within the study area and therefore using Saswad data for weather parameters was impractical. Besides this government data, some rainfall data was available from village Khalad, where a rain gauge was installed by GGP and this data was available from 1987 onwards. (*Figure 4.12*) Later on, some secondary data was also obtained from the irrigation department from village Nazare which is closer to Pandeshwar but distant from villages like Waghapur and Pondhe. Time and again, during earlier discussions with GGP, ACWADAM felt that variability in weather conditions, especially rainfall, was quite high across the region. The need to set up multiple rain-gauging stations to probe this variability was felt even before the project commenced.

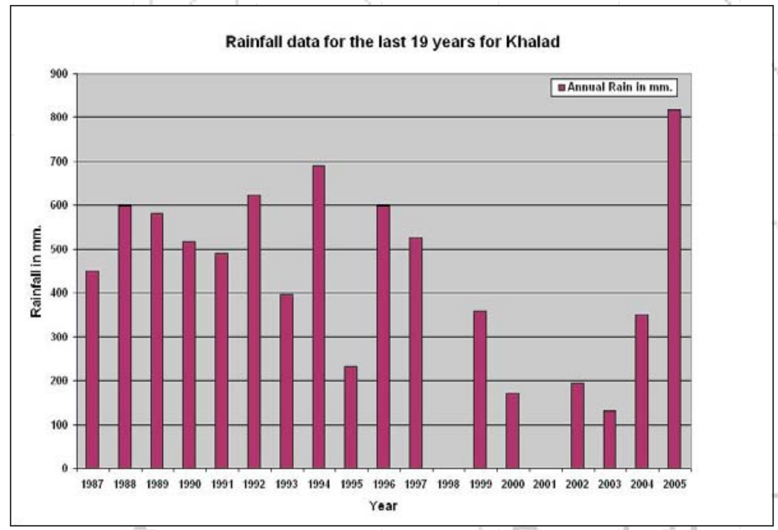


Figure 4.12: Rainfall data for Khalad for the last 19 years (Courtsey:GGP, Khalad)

To overcome this problem, ACWADAM set up an automatic weather station (AWS) at Naigaon which is a centrally located village and had all the other facilities like security and surveillance – GGP's Naigaon model farm was established here in the 1970s and there was a facility to house the station there. Hence, ACWADAM was able to study rainfall data from seven rain gauges, six of which were within the project area. The purpose of this exercise was to obtain a representative picture of rainfall and its spatial variability in the study area. The AWS at Naigaon included a pan-evaporimeter, and with another one at Khalad, the study also hoped to capture variability in

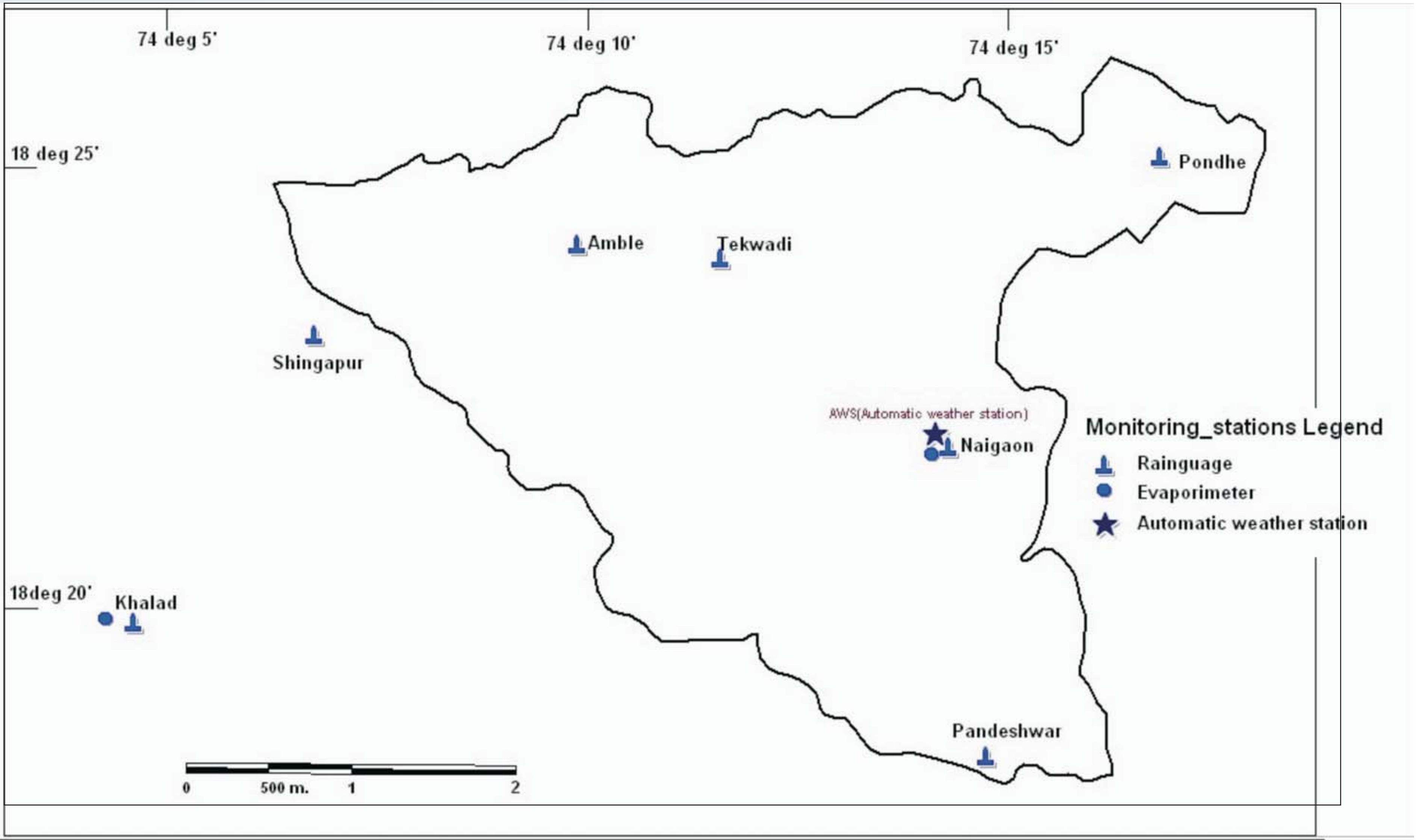


Figure 4.13: Location of raingauge and evaporimeter site

evaporation patterns across the region. *Figure 4.13* shows the location of rain gauges and evaporimeter sites.

4.5.1: Rainfall

ACWADAM with the help of GGP had installed six rain gauges in the study area. Rain gauges were installed at Amble, Tekwadi, Naigaon, Pandeshwar Shingapur, and Pondhe. Out of these , five rain gauges (Naigaon, Pandeshwar, Tekwadi, Khalad and Pondhe) were installed in 2006 and the remaining two (Amble and Shingapur) were installed in 2007. Data from the Shingapur rain gauge could not be collected in 2008 due to various reasons. Hence, three year records are available for Khalad, Tekwadi, Pandeshwar, Naigaon and Pondhe. (2006 to 2008) and two year data (2007-2008) is available for Amble watershed. *Figure 4.14* indicates the measured annual rainfall in five stations of Purandar from 2006 to 2008.

Rainfall has decreased from 2006 to 2008, at all stations, except Pondhe. In Khalad, Tekwadi, Naigaon and Pondhe, the rainfall in 2008 & 2009 was almost half of the rainfall in 2006. Year 2006 was a good rainfall year with the rainfall above 550 mm. As per the census data, the average annual rainfall for Purandar is 550mm. Pondhe has an average annual rainfall of 350 mm. It is also observed that the rainfall decreases from West to East. In 2007, Amble, Khalad and Pandeshwar received average annual rainfall. In the remaining villages the deficit was between 50 and 150 mm rainfall. In 2008, the rainfall decreased further, with none of the villages receiving the average annual rainfall. Pondhe received slightly more rain as compared to the previous year but the total rainfall was below the taluka average.

The rainfall pattern of the study area is also unique. It is observed that the rainfall occurs on 3 or 4 days with very high intensity spells (>50mm/day) and in the remaining monsoon months it is usually in the form of gentle drizzles. There are about 25 rainy days every year, when rainfall is more than 2.5 mm.*(Definition of rainy day as per the Indian Meteorological Department).* Pondhe recorded less than 15 rainy days during the last two years. *Table 4.3* indicates the number of rainy days in six locations of Purandar.

In Purandar, the rainfall mainly occurs in four months between June and September. There is a progressive increase in rainfall from June to September. There are occassional rains in October and November. During the last three years the rainfall has shown a great variation in the distribution pattern in the five watersheds. In 2006, Naigaon received maximum rainfall in October whereas Pondhe and Pandeshwar received maximum rainfall in the month of September. In 2007, the rainfall was evenly distributed in the four months with Tekwadi and Pandeshwar receiving maximum rainfall in June. Naigaon received maximum rainfall in the month of September, whereas Amble received maximum rainfall in August. Pondhe received rainfall for just two months, June and July. In 2008, there was very less rain in June and

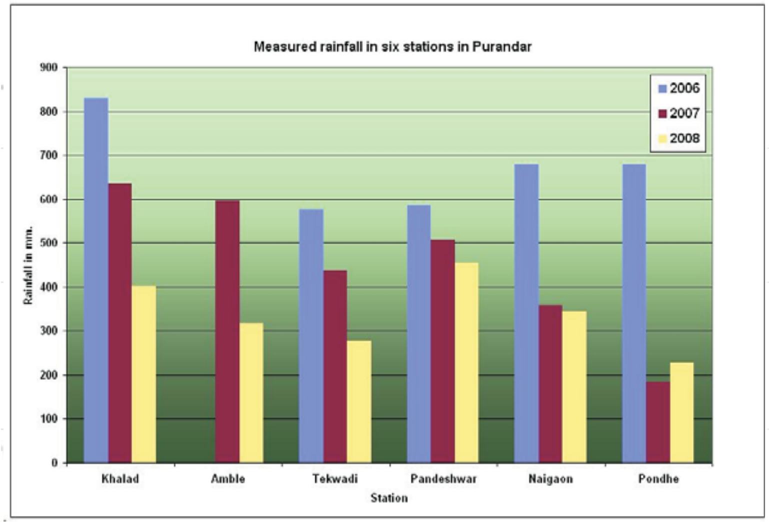


Figure 4.14: Measured rainfall at six stations in the project area (arranged roughly west to east)

Village	Number of rainy days		
	2006	2007	2008
Khalad	46	33	18
Amble		18	15
Tekwadi		19	15
Pandeshwar	16	21	23
Naigaon	34	16	28
Pondhe	34	6	8

Table 4.3: The number of rainy days at six locations of Purandar

July. Major rainfall occurred in the month of September with some rainfall in August and October.

Monthly rainfall data for the three years indicate that there is no particular trend observed in the rainfall. Long term rainfall data would be required to understand trends, if any. In 2007, Pondhe received rainfall in June and July while in 2008, it received rainfall in August and September. It is also observed that Naigaon receives late rainfall mainly in the months of August and September. *Figure 4.15* indicates the monthly distribution of rainfall in different watersheds during the last three years.

There is no pattern observed in the rainfall and therefore some pie charts are prepared to understand the distribution of rainfall in the five months. The rainfall is normalized for the five watersheds with each pie chart representing a year. In 2006, more than 70% rainfall occurred in the month of August, September and October. In 2007, the rainfall was evenly distributed throughout the monsoon with good rainfall in the month of June, i.e. during the sowing season. In 2008, more than 80% rainfall occurred in the month of August and September with less than 10% rainfall in June and July. *Figure 4.16* indicates the pie charts for 2006, 2007 and 2008 seasons showing rainfall distribution.

Along with the temporal variation trends mentioned above there is also spatial variation in the rainfall across the study area. The rainfall in the study area generally decreases from west to east. It is as high as 600 mm in Khalad to less than 300 mm in Pondhe. This decrease amounts to 50% over a distance of less than 15 km. *Figure 4.17* indicates the isohyte map for the study area, based on the average rainfall for the last three years.

4.5.2: Evaporation

ACWADAM installed two evaporimeters, one in Naigaon and one in Khalad. There is a significant variation in the evaporation rates at the two sites. The average annual evaporation in Naigaon is around 5.9 mm/day and the average rate of evaporation in Khalad is around 5 mm/day.

In Naigaon, during the summer the rate of evaporation is as high as 11.2 mm/day, while in winter, it is 3 - 4 mm/day. The rate of evaporation in Naigaon remains between 4 and 7 mm/day, during most times of the year. The high rate of evaporation in this area can be attributed to the hot and dry weather conditions which prevail throughout the year. *Figure 4.18* indicates the average rate of evaporation for Naigaon.

In Khalad, the maximum rate of evaporation is observed during the month of May. In May 2009 the rate of evaporation was as high as 12 mm/day. Generally, during summer the rate of evaporation is between 10 and 11mm/day while in winter the rate of evaporation is between 2 and 3

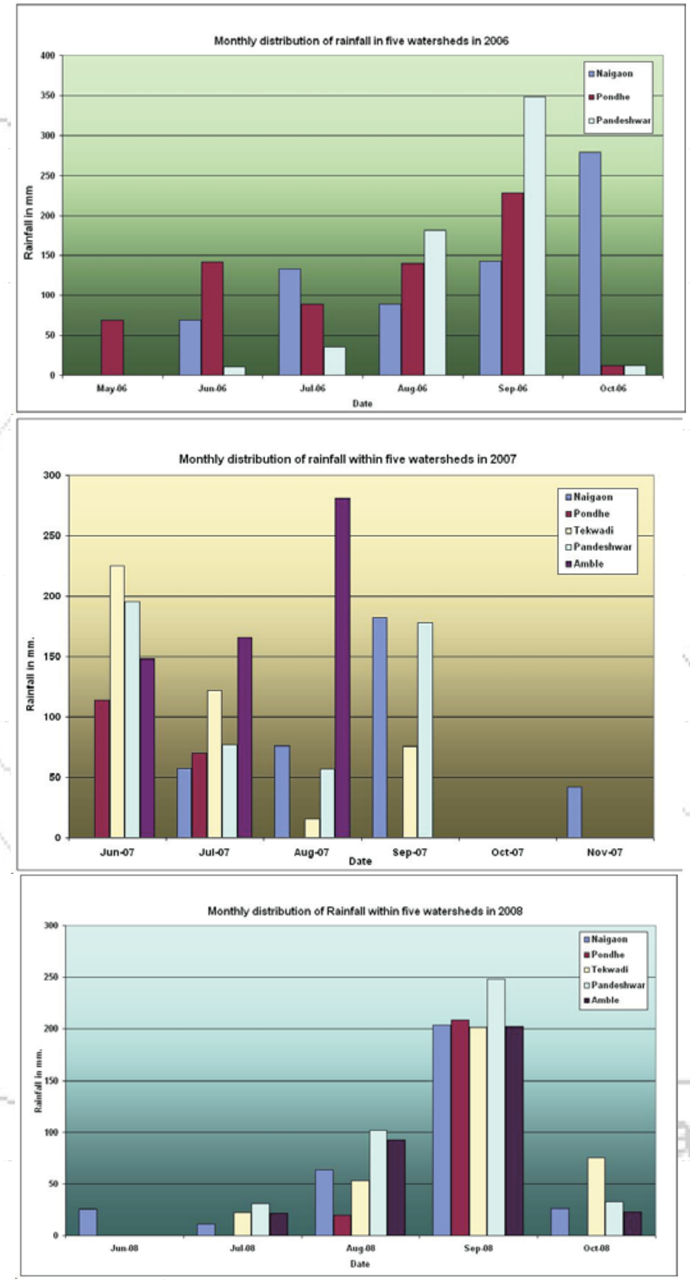


Figure 4.15: Monthly distribution of rainfall in five watersheds for the three years

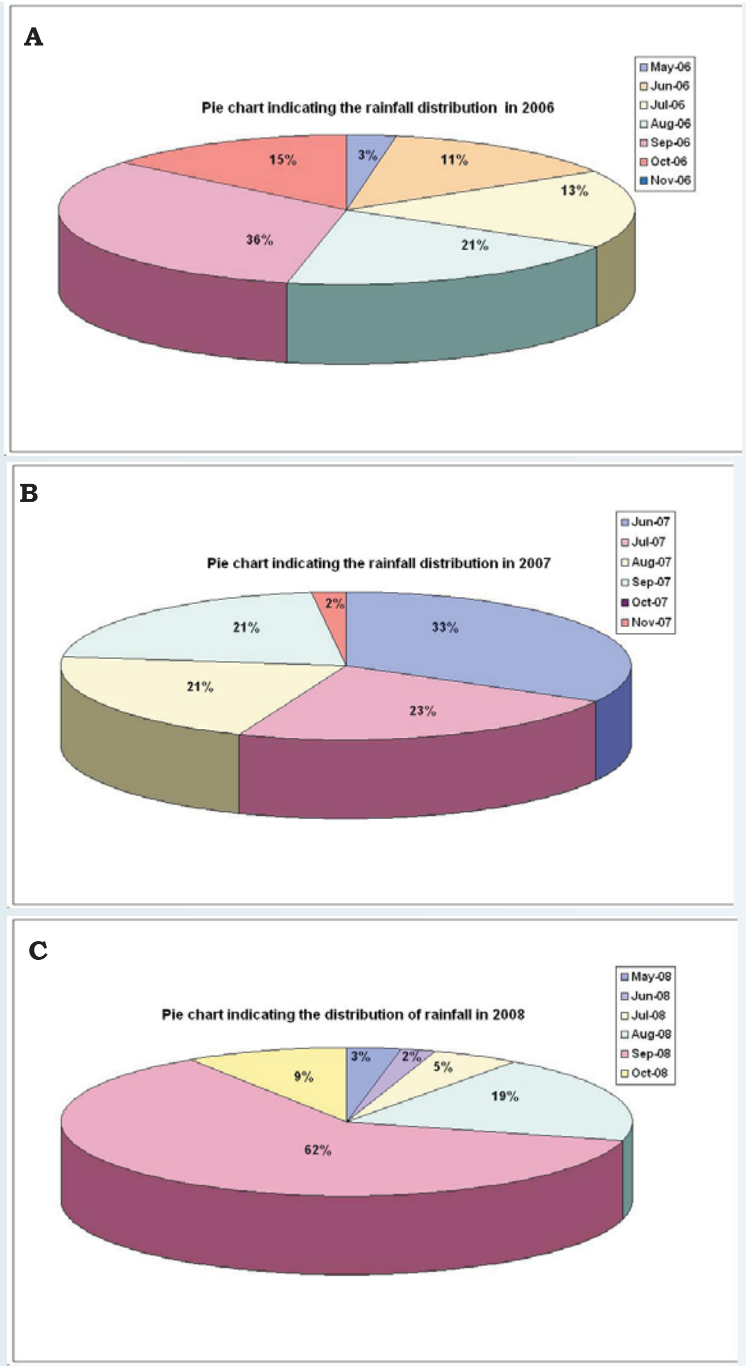


Figure 4.16: Pie chart for rainfall distribution in 2006(A), 2007(B) and

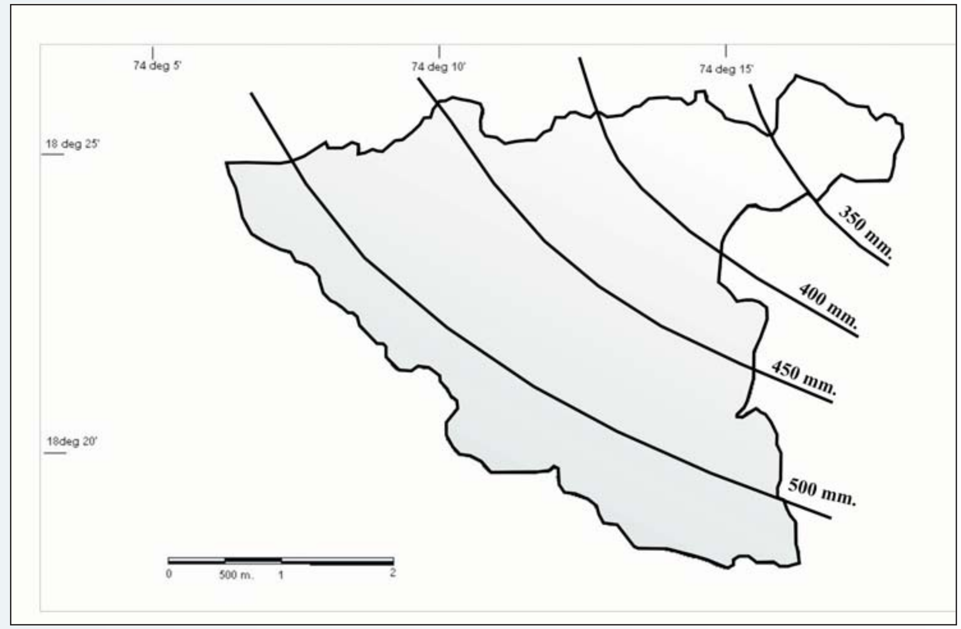


Figure 4.17: Isohyte map for the study area

mm/day. The average rate of evaporation is between 4 mm/day and 6 mm/day. *Figure 4.19* indicates the average rate of evaporation in Khalad.

The average evaporation rates (across different seasons) in Khalad are lesser than those for Naigaon. Khalad lies closer to the western ghat ranges and receives higher rainfall, probably has a highly variable wind regime, is less open and probably has a higher proportion of ambient moisture (due to greater vegetation and forest cover). Comparitive trends in evaporation for these two locations, are plotted as *Figure 4.20*. The distinct patterns are obvious despite certain overlaps. In both the stations there is progressive increase in the rate of evaporation from the month of February onwards and the rate of evaporation reaches its peak in the months of April - May. After the onset of monsoon almost until the following February, the rate of evaporation stays close to the annual average or drops below it. There is a slight increase in the evaporation rate in the month of October which is expected in this area due to the effect of sudden temperature spikes. In mid November, the rate of evaporation drops again as winter sets in.

The distinguishing feature in evaporation trends for these two locations is obvious. In Khalad, the trend mentioned in the above paragraph is clear, following a more linear path whereas the evaporation trend in Naigaon shows a more scattered pattern, but more so during the monsoon and winter periods, pointing to a greater intra-seasonal variability. The scattered pattern of evaporation in Naigaon could also be due to the changes in wind speed, wind direction and solar radiations during the day. These micro level changes in the weather condition may have some effect on the rate of evaporation in Naigaon.

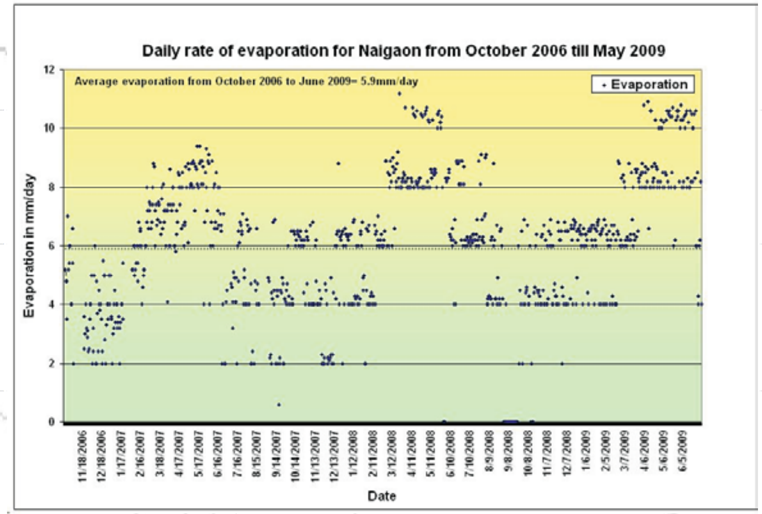


Figure 4.18: Average rate of evaporation in Naigaon

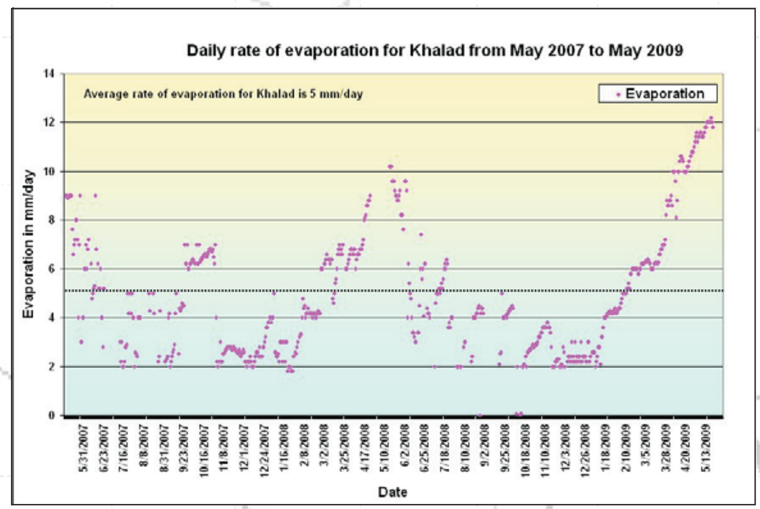


Figure 4.19: Average rate of evaporation in Khalad

4.6: Automatic Weather Station

The AWS at Naigaon measures six parameters on an hourly basis. These parameters are temperature, relative humidity, wind speed, wind direction, solar radiation and rainfall. At every hour, the instantaneous, average, maximum and minimum value for each parameter is obtained. A continuous data is obtained on a 24 by 7 basis throughout the year and so on. The weather station was installed in November 2006 and data are being obtained even today. As observed with most AWSs, there were a few data gaps due to some technical problems like problems with sensors or the data logger (and even with mice and bees!). The few data gaps were mainly in the temperature and humidity sensors which had to be changed in September 2007. Almost uninterrupted data is available from the AWS for the period 2007 until going to press on this report. Some of the salient findings from the AWS are presented below.

Temperature

The average annual temperature in Naigaon was 25°C. The average daily

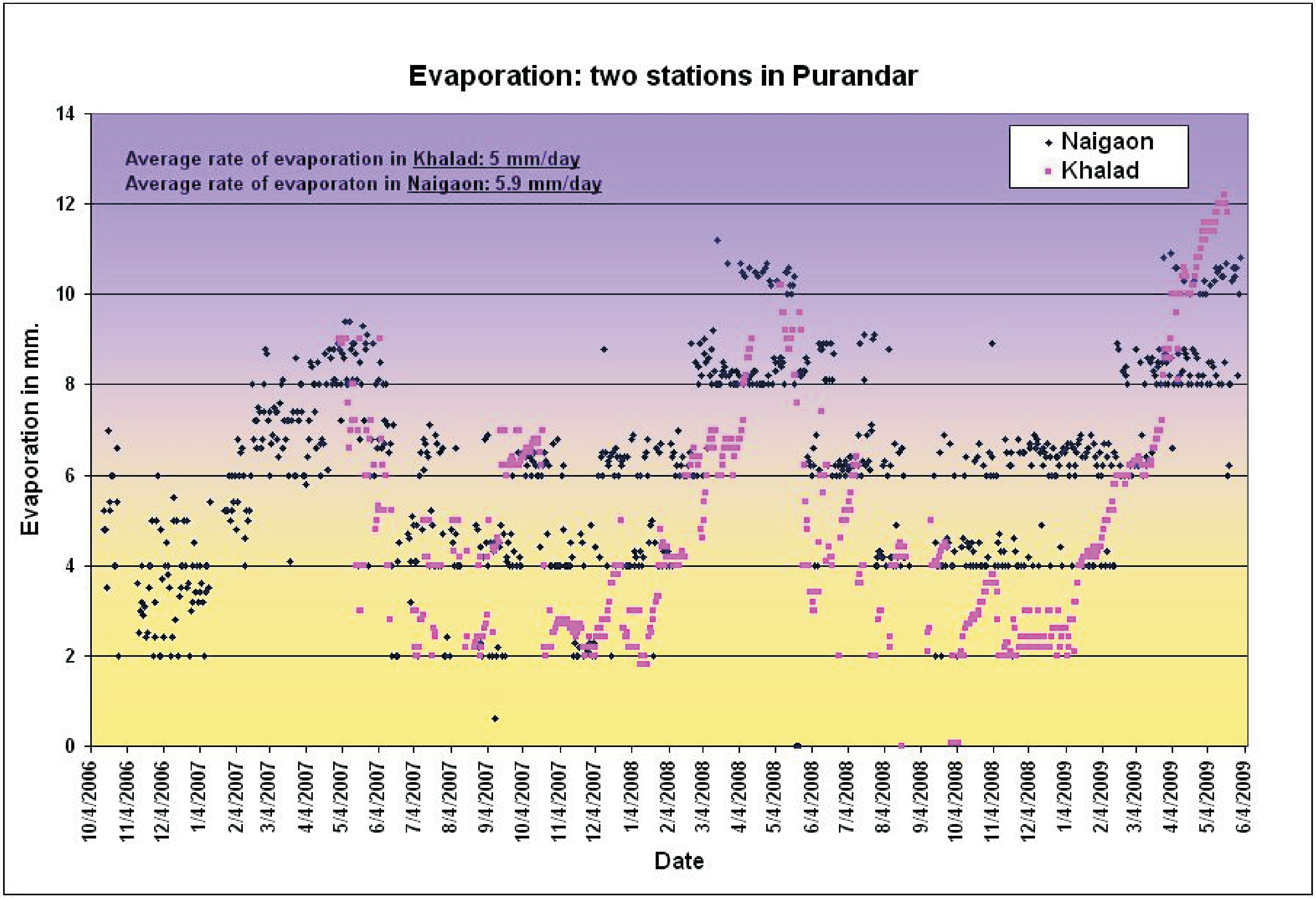


Figure 4.20: Comparative rates of evaporation at Naigaon and Khalad.

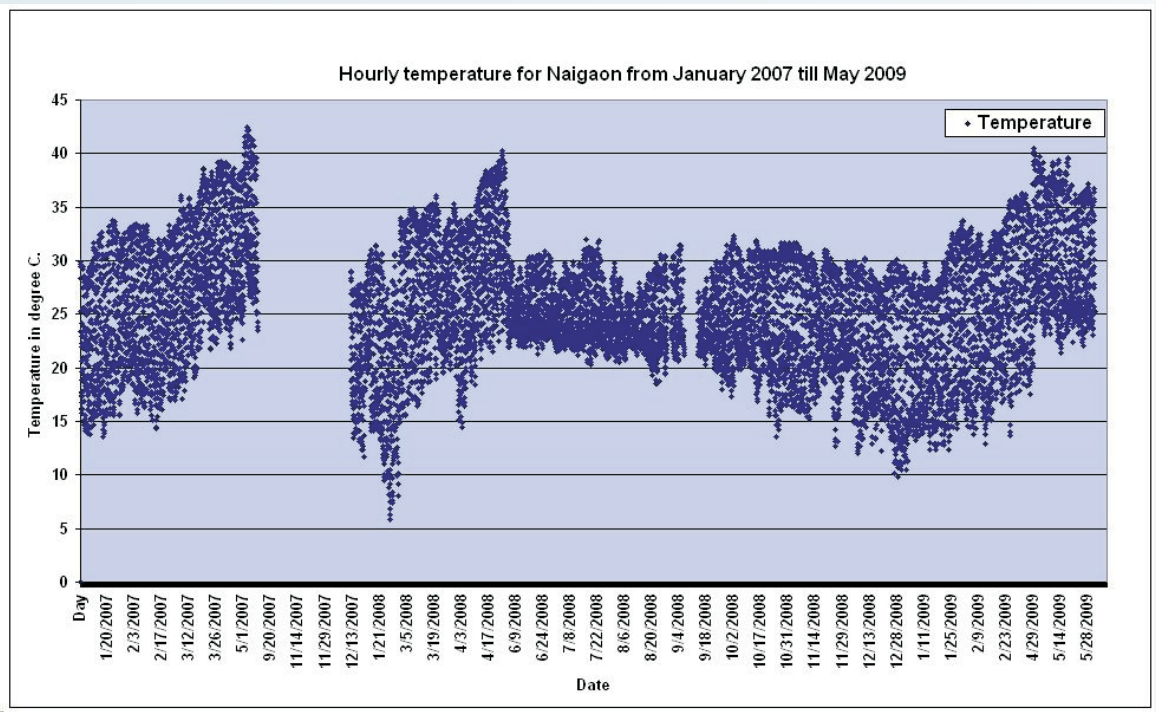


Figure 4.21: Hourly average temperature for Naigaon from January 2007 till May 2009 (Blank area indicating gap in data)

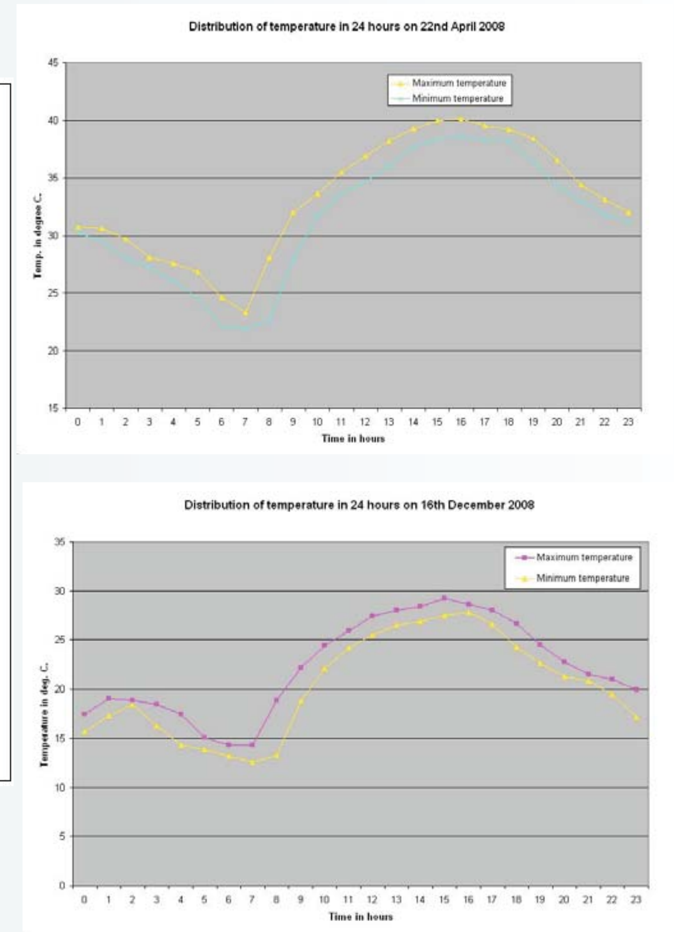


Figure 4.22 : Distribution of temperature in summer (A) and in winter (B)

temperature was 15° C, with a maximum temperature in summer reaching 40° C and minimum temperature dropping to 9°C in winter. Winters are usually pleasant with the maximum temperature between 25°C and 30° C and minimum temperature of about 10° C. The maximum temperature during most times of the year remains in between 30°C and 35° C, while minimum temperature remains around 15°C. *Figure 4.21* indicates the monthly temperature from January 2007 to May 2009.

The progressive rise in temperature begins in February and temperatures peak in April. Pre monsoon showers in May often bring down these peak temperatures. The analysis of the three year data indicates that the temperatures were slightly higher than normal in the summer of 2007 than in the following two years. The average summer temperature for April was 31.3° C as compared to 29° C in 2008 and 30° C in 2009. Winter temperatures were around 22°C during these three years.

The analysis of 24 hour data for summer and winter indicates that the diurnal temperature is minimum at the time of dawn (between 6 am and 7 am) and is maximum between 3 pm and 4 pm. *Figure 4.22* indicates the temperature distribution throughout the day on 22nd April 2008 (summer) and 16th December 2008 (winter).

Humidity

The study area falls in dry semi-arid climatic zone, and therefore, the relative humidity in this area is low almost throughout the year. It only increases during the monsoon, when the percentage of relative humidity is above 90. In the winter season, at the times of dusk and dawn also, the percentage of relative humidity is above 80% (dew effect). Otherwise throughout the year the relative humidity is less than 40%. This is one of the reasons of having higher evaporation rates in the area as the relative humidity is inversely proportional to the rate of evaporation, especially during periods of high temperatures. *Figure 4.23* indicates the plot for relative humidity for Naigaon between January 2007 and May 2009.

Wind velocity

Wind velocity is also one of the important factors determining the rate of evaporation and evapotranspiration in any area. It is directly proportional to the rate of evapotranspiration. Average wind speed in Naigaon is 1.33 m/s. The velocity is generally high between May and October and is low between November and April. The higher velocity of monsoonal winds during May-June and July is quite obvious. The average speed during the monsoon months is as high as 3 m/s. The average wind speed during winter season is around 1.2 m/s. Wind speed drops to the lowest during November / December although one would expect some interannual variability as to the exact time when wind speed is lowest during an annual cycle. *Figure 4.24*

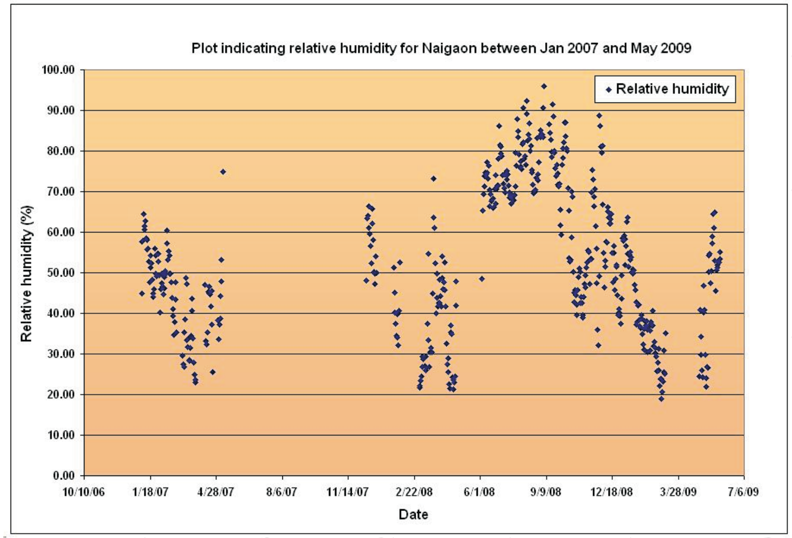


Figure 4.23: Plot indicating relative humidity for Naigaon between January 2007 and May 2009

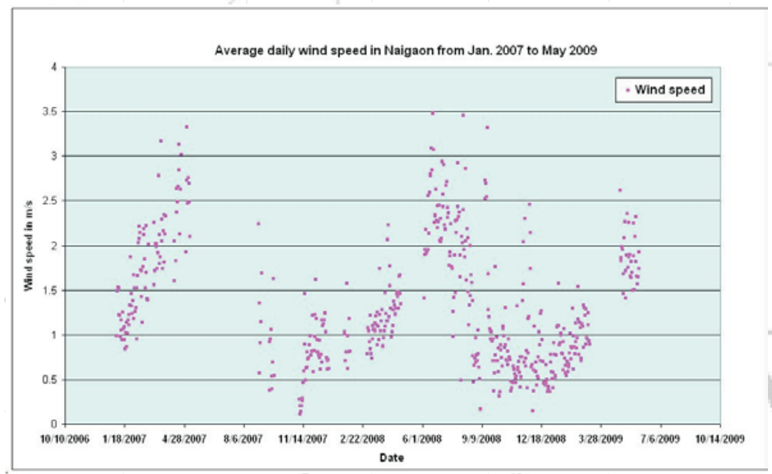


Figure 4.24: Average daily wind speed in Naigaon

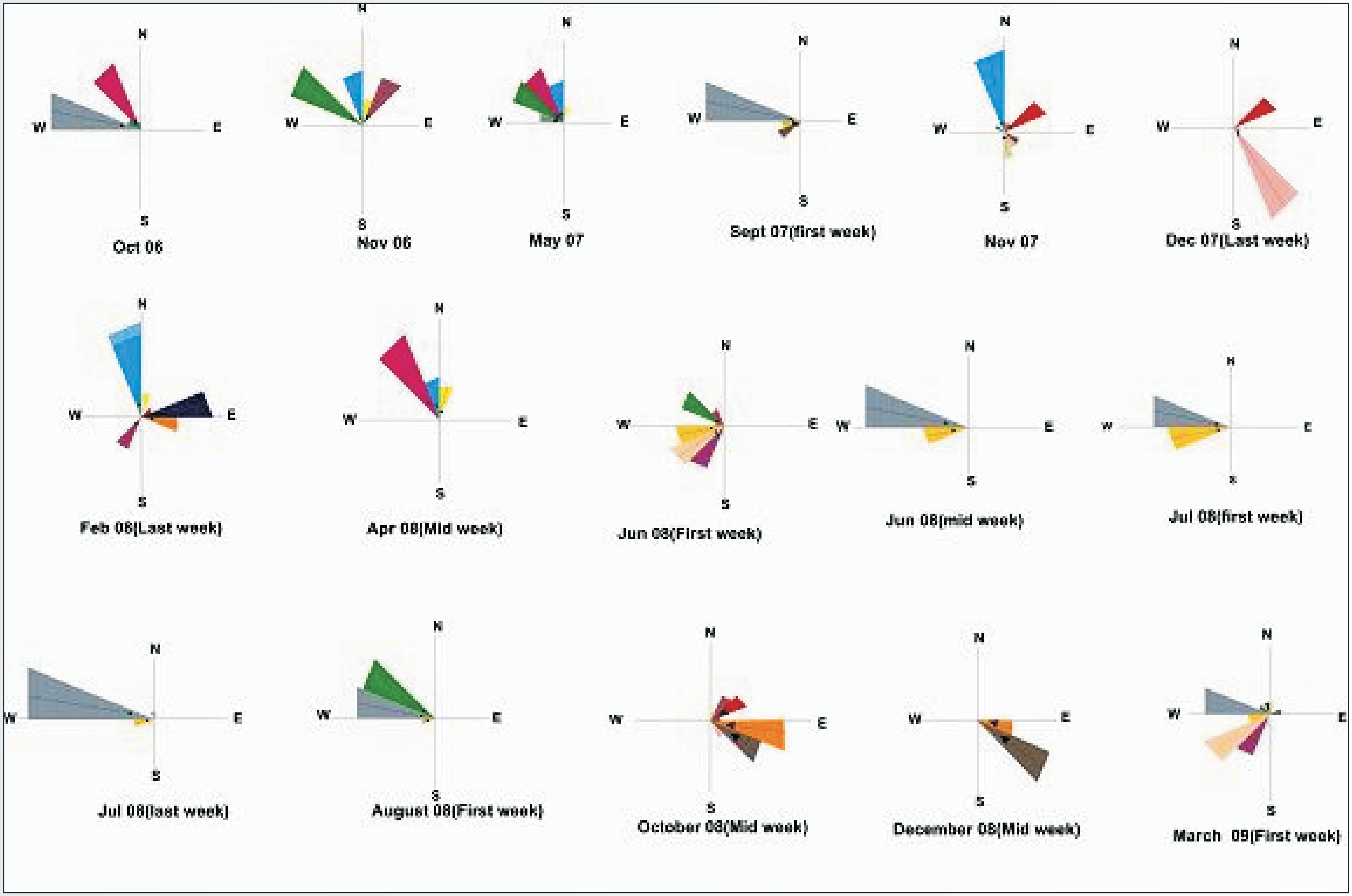


Figure 4.25: Wind direction rosettes for Naigaon

indicates the average daily wind speed in Naigaon from January 2007 to May 2009.

Wind direction

Wind direction sensor indicates the direction of wind. The direction is shown in the form of degrees which are based on the actual direction of wind with respect to the azimuth (north). Rosette diagrams (also referred to a rose diagrams) are used to plot this data. The data is plotted for 24 hours (each day). Usually, the direction of wind changes seasonally, and therefore, to obtain a general idea of wind direction, rosettes are plotted for the months of season change. The dominant trend of wind direction is from the N / NW towards the SE during most part of the year. In early winter, the wind blows from S, SE and even from the NE. *Figure 4.25* shows the direction of wind for different seasons.

Solar radiation

The average solar radiation during summer of 2006-2007 was around 290 watts/m^2 while in winter the average solar radiation was around 105 watts/m^2. It is observed that the intensity of solar radiation was higher in 2007 than in 2008 and 2009. The average intensity of solar radiation in summer of 2007-2008 was 115 watts/m^2, which was almost half the intensity recorded for 2006-2007. This observation is also coherent with temperature data - temperatures were higher in 2006-2007 by about 2°C to 4° C than in 2007-2008. In the summer of 2008- 2009 the average solar radiation was 144 watts/m^2 - also significantly low as compared to that in the summer of 2006-2007. The average solar radiation during the last three years was 133 watts/m^2. There was a major data loss between May 2007 and September 2007 and some minor data loss in Jan-Feb. 2008, May 2008, September 2008 and March-April 2009 due to some technical problems in the data logger. *Figure 4.26* indicates the average daily solar radiations for Naigaon from Jan. 2007 to May 2009.

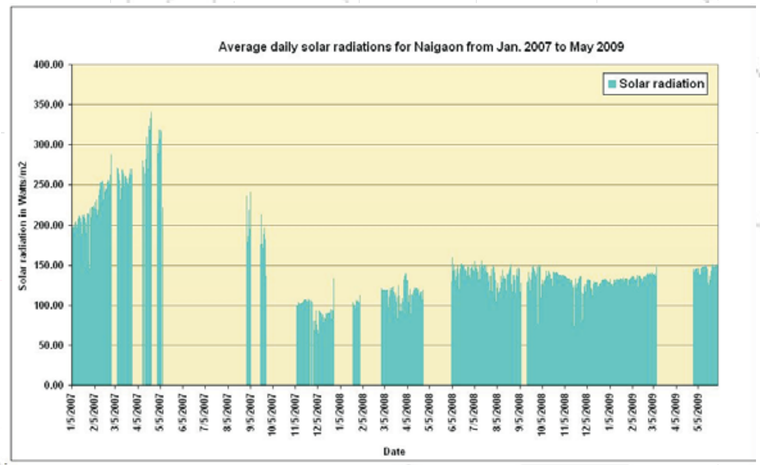


Figure 4.26: Average daily solar radiations for Naigaon from Jan 2007 to May 2009

4.5.4: Evapotranspiration

Evaporation and transpiration are two processes that occur simultaneously and it is often difficult to separate these two in terms of quantities, especially during the process of preparing water balances for an area. In evaporation, the water is converted into vapour and is lost to the atmosphere from the open surface water bodies like rivers, lakes and ponds. Transpiration consists of the vaporization of liquid water contained in plant tissues and the vapour removal to the atmosphere. In fields when crop is small, the water is lost predominantly by evaporation but when crop is ready for harvest and completely covers the soil surface then transpiration is the dominant process by which the water is lost to the atmosphere *(Allen et al, 1998)*. Weather parameters, crop characteristics, management and environment aspects are factors affecting evapotranspiration.

It is not easy to measure evapotranspiration. Specific devices and accurate measurements of various physical parameters or the soil water balance in lysimeters are required to determine evapotranspiration. All these methods are expensive and demand higher degree of accuracy. It is easier to calculate the potential evapotranspiration using empirical formulae. Since fairly accurate weather data, crop information and allied data about management and environment practices was available, the *FAO-Penman Monteith equation* (Allen et al, 1998) was used to calculate the reference evapotranspiration where the factors like temperature, humidity, wind speed, solar radiations crop type etc. are used to calculate the reference evapotranspiration. The following eqΔation was used to calculate the reference evapotranspiration.

$$Et_o = [(0.408 \quad (Rn-G)) + (\gamma\,(900/(T+273))u2\,(es-ea))]\,/\,[\Delta + \gamma(1+0.34u2)]$$

Where
ET_o = reference evapotranspiration (mm/day)
Rn= net radiation at the crop surface (MJ/ m^2/day)
G=Soil heat flux density (MJ/ m^2/day)
T= air temperature at 2 m height (°C)
U_2= wind speed at 2 m height (m/s)
Es= saturation vapour pressure (kPa)
E_a= actual vapour pressure (kPa)
E_s-ea=saturation vapour pressure deficit (kPa)
Δ =slope vapour pressure curve (kPa/°C)
γ = psychrometric constant (kPa/°C)

A continuous weather data without major gaps is required to calculate the ET_o, and therefore, the reference evapotranspiration is calculated for the period from February 2008 till February 2009. It is observed that the average rate of reference evapotranspiration using FAO-Penman Monteith equation is 4.1mm/day. The maximum rate of ETo is 8.84 mm/day in summer and less than 1 mm/day in monsoon. *Figure 4.27* indicates the rate of reference evapotranspiration calculated from Feb. 2008 to Feb. 2009 using FAO-Penman Monteith equation.

During most periods of the year, the rate of reference evapotranspiration (between Feb. 2008 and Feb 2009) is between 2 mm and 7 mm. There are not many highs or lows in the ET_o as compared to the actual evaporation. During monsoon season, the rate of ET_o is between 1.5 mm and 3 mm. *Figure 4.28* indicates the rainfall and ET_o for Naigaon between Feb. 2008 and Feb. 2009.

A comparison is made between the actual rate of evaporation and reference evapotranspiration in Naigaon. The evaporimeter pans provide a measurement of the integrated effect of radiation, wind, temperature and humidity on the evaporation from an open water surface. Although the pan

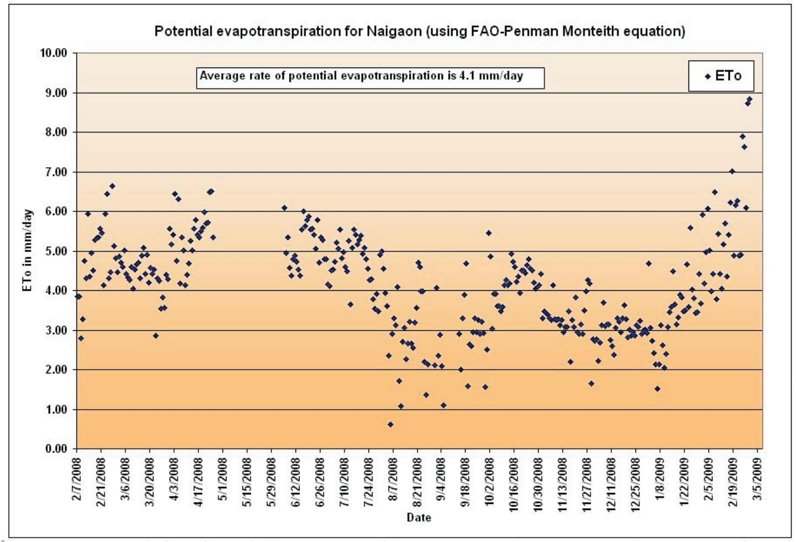


Figure 4.27: Calculated reference evapotranspiration for Naigaon from Feb. 2008 to Feb. 2009 using FAO- Penman

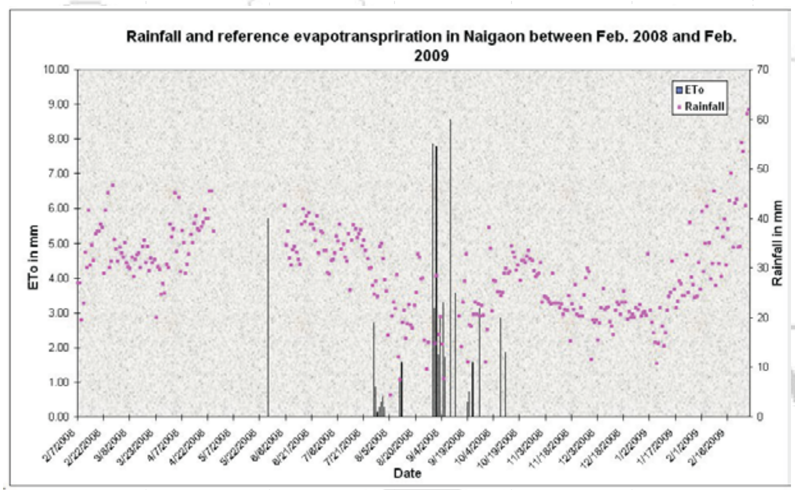


Figure 4.28: Rainfall and reference evapotranspiration in Naigaon between February 2008 and February 2009.

responds in a similar fashion to the same climatic factors affecting crop transpiration, several factors produce significant differences in loss of water from a water surface and from a cropped surface. Reflection of solar radiation from water in the shallow pan might be different from the assumed 23% for the grass reference surface. Storage of heat within the pan can be appreciable and may cause significant evaporation during the night while most crops transpire only during the daytime. There is also difference in turbulence, temperature and humidity of the air immediately above the respective surfaces. Heat transfer through the sides of the pan occurs and affects the energy balance. Therefore, the measured rate of evaporation is usually higher than the rate of evapotranspiration estimated from an empirical equation (part of the parameters are also measured directly in this case). Figure 1.18 indicates the graph for evaporation and evapotranspiration in Naigaon for the month of November 2008.

Usually, the rate of reference evapotranspiration is less than the rate of evaporation. However when the total loss of water from an area is considered, the loss through evapotranspiration is much higher than the evaporation as the vegetation cover is present over larger area as compared to the open, surface water bodies. As shown in *figure 4.29,* the average reference evapotranspiration for the month of November is 3.25 mm/day and the average rate of evaporation is 5.1 mm/day.

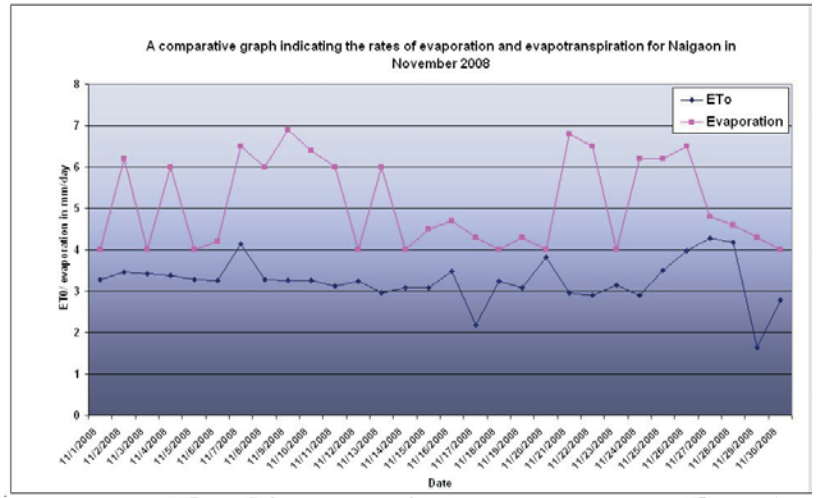
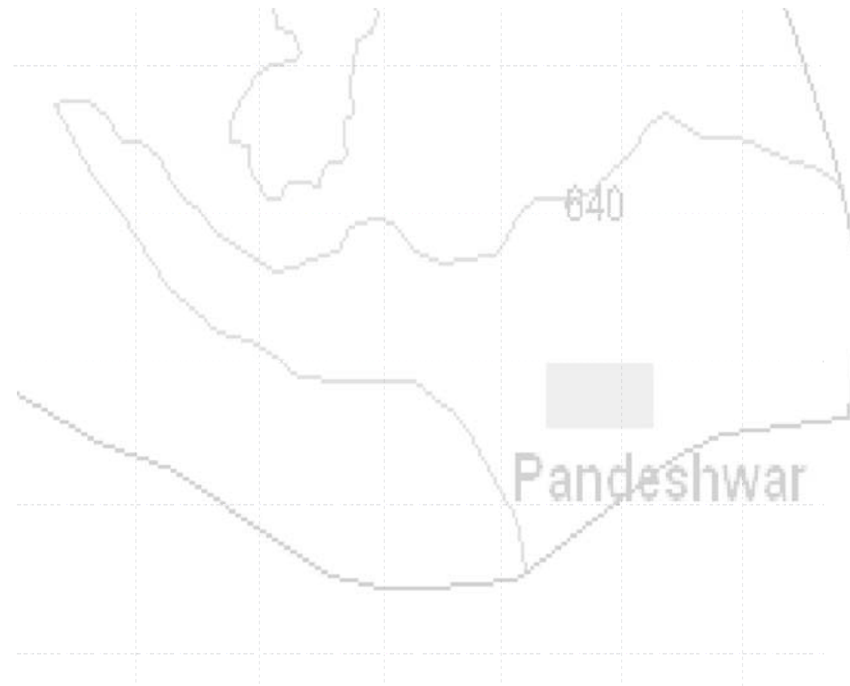


Figure 4.29: Graph for evaporation and reference evapotranspiration in Naigaon for the month of November 2008



4.7: Pumping test

The accumulation and movement of groundwater is a function of two basic 'hydrogeological' properties of rocks – the porosity and the hydraulic conductivity (also referred to commonly as permeability). In simple terms, the porosity and hydraulic conductivity are properties of rocks, properties that broadly indicate the storage and conductivity functions of a rock. On the other hand, when aquifers are identified and described, it becomes necessary to gauge the storage capacity and the transmission capability of an aquifer. The coefficient of storage (storativity) and transmissivity define the storage and transmission functions (capacities) of an aquifer. Pumping tests are the most straightforward and simple methodology for estimating the storativity and transmissivity of aquifers.

In order to obtain precise results, pumping tests have to be conducted in a particular manner, using specific equipment and making sure that certain conditions are adhered to. The important factors that require attention before and during a pumping test include geological and hydrological information, selecting the well to be tested along with its dimensions & design, the pump, the distances of piezometers / observation bore holes from the pumping well and various such factors (*Driscoll, 1986; Kruseman and De Ridder, 1990; Brassington, 2007*). Conducting a pumping test, therefore, poses certain practical challenges. Piezometers or observation bore holes are desirable but not always possible. In this light, it becomes difficult to conduct an 'ideal' pumping test. However, ACWADAM carries a long-standing experience of conducting pumping tests on dug wells in the Deccan basalt region and have produced reliable estimates of the storage and transmission capacities of basalt aquifers from different parts of the Deccan Volcanic Province *(Kulkarni et al, 2000*). This experience was brought to bear while designing and conducting pumping test data and in the analyses of this data for understanding the Purandar aquifers better.

Some 35 well-tests (pumping tests without observation bore holes) were conducted in the project area. Many of these tests were conducted by student interns associated with this project. These students were trained in the art of conducting pumping tests under adverse conditions. ACWADAM staff supervised many of these tests.

4.7.1: Methodology

Pumping tests are conducted to ascertain aquifer parameters like Transmissivity and Storativity; and the Specific Capacity or the 'yield' of a well. Transmissivity (T) indicates the rate at which water is transported through the aquifer and the value varies with the nature of the aquifer

Students conducting pump test in well in Amble

material, mainly with regard to the rock openings. Storativity (S) indicates the 'usable' water stored in the aquifer, as a fraction of the total volume of the aquifer (inclusive of both water and rock material). Specific capacity (C) of a well is the amount of water a well yields as a consequence of a 'unit' fall in its water level (unit drawdown) after pumping.

These parameters are largely a function of lithology and structures (joints, fractures etc.) that penetrate the rock body. In the Purandar area, the large number of wells and their proximity to one another, also affect these parameters. Quite often, a number of closely spaced wells pump water simultaneously, interfering with each other in terms of the fluxes on the aquifer. Pumping tests in the Purandar area were conducted on wells that were chosen at random, but keping in mind the ‘interference’ factor.

Certain equipment is essential to conduct a pumping test: a bucket or container of known volume, tape measures, stop clock and a pump. A specific point is chosen on the ground to make measurements (measuring point). The static water level (SWL) is measured prior to pumping the water out of the well. As the well is pumped, the drop in the water level (after a specified time interval) is noted down, which is the drawdown (in metres). Generally the wells were pumped for duration of about three hours but the pumping time understandably shortened during the drier months. Once the pumping stops the well is said to recover due to inflow of water (to the well) from the surrounding aquifer. During this period of recovery, the water level tends to rise up and this is measured in the form of 'residual drawdown' (i.e. the difference between static water level and the measured water level in the well). The rate of water discharge from the well is also measured using the bucket and the stop clock.


Well with a diesel pump in Naigaon

In almost all cases the tests had a three hour period of pumping. Though a longer duration of pumping is recommended, the constraints imposed by factors like the limited supply of power in the region, could only favour a maximum duration of three hours, although the odd test was longer. Sometimes, pumping was possible only for about an hour; this problem occurred especially in the summer months. Either the wells had precious little water which the farmer was understandably unwilling to part with at the given moment or the unreliable power supply would leave one stranded. However, on such wells, the recuperation or recovery was measured over a longer period, enabling a good enough record of data.

4.7.2: Aquifer characteristics

The data obtained from conducting the pumping tests are used to calculate the aquifer parameters and the specific capacity of the individual wells. Various methods of analysing pumping test data are available and the most detailed description of these methods is provided in *Kruseman and De Ridder (1990)*. The purpose of conducting pumping tests in this case was not to arrive at very precise estimates of T and S, but to make a good comparison of these values across the project area. The *Cooper-Jacob method (1964)* was used to estimate T and S; *Slichter's method (1906)* was used to determine the specific capacity (C) of the wells. The values of Storativity from the Cooper-Jacob method were much higher than expected for a basaltic aquifer; this has already been observed earlier *(Kulkarni, 1987)*; thus, British Geological Survey Pumping Test software (BGSPT), the efficacy of which has been tried and tested for basalt aquifers *(Macdonalt et al, 1995; Kulkarni et al, 2000)* was used to analyze the data and thereby estimate aquifer parameters.

In order to use the software, drawdown for pumping period and recovery were presented in continuum along side the respective time of measurement in unit of days. The data is fed to the software along with the values of Q (rate of discharge) and radius of the well. The software predicts the value of transmissivity and storativity for the given drawdown values and also generates a model to study the behaviour of the aquifer during drawdown and recovery. Some salient results from the analysis of pumping test data are presented below. Each section (watershed) has a short description of the specific capacity estimates, followed by ranges of T and S. Each also has one set of data and a plot of observed and modeled values of drawdown with respect to time.

Well water level before pumping

A: Tekwadi watershed:

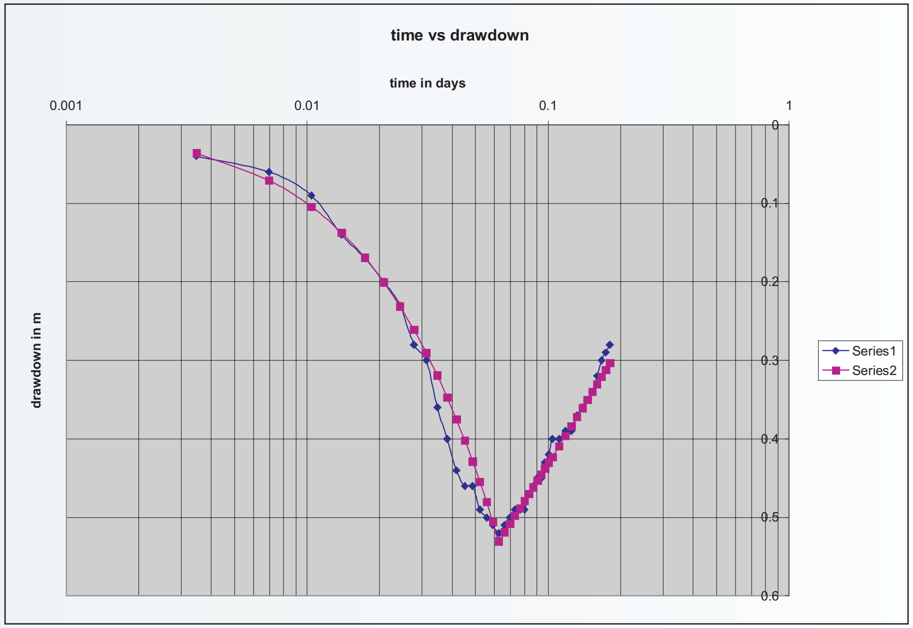
Most of the wells in the watershed yield a specific capacity ranging from 50 to 100 lpm/m of drawdown. Other wells recorded values ranging from 250-400 lpm/m of drawdown. One well yielded a distinctively high specific capacity of 2546 lpm/m of drawdown. The highest value of T observed was 105.6 m2/day for Ramesh Ganpat's well; the average value is in the range of 90 – 110 m2/day. The lowest value of storativity is 0.0001 and reaches a maximum of 0.01 (1AT). A model data for well no T4 in the Tekwadi watershed is presented in *figure 4.30.*

B: Amble watershed:

Specific capacity of Bhiku Pandole's well was 480 lpm/m of drawdown. This proved to be the highest value for all the wells monitored in the watershed. Santosh Vichkule's well had a very low specific capacity value of 27.25 lpm/m of drawdown; otherwise all the wells yielded specific capacities in the range 150-200 lpm/m of drawdown. There was a flip in the transmissivity value when analysed using the BGSPT, the Cooper and Jacob formulae yielded much lower values than predicted by the BGSPT software. However the predicted estimates were not consistent for all the wells. The average T for Amble is in the range of 152-140 m2/day. The S ranges from 0.0001 to 0.017. A model data for Amble watershed (well AT-2) is presented in *figure 4.31*.

Time in days	Observed drawdown (s) in m	Modeled drawdown (s) in m
0	0	0
0.003472222	0.04	0.035987
0.006944444	0.06	0.070676
0.010416667	0.09	0.10436
0.013888889	0.14	0.13718
0.017361111	0.17	0.16919
0.020833333	0.2	0.20047
0.024305556	0.23	0.23106
0.027777778	0.28	0.261
0.03125	0.3	0.29032
0.034722222	0.36	0.31906
0.038194444	0.4	0.34723
0.041666667	0.44	0.37485
0.045138889	0.46	0.40196
0.048611111	0.46	0.42858
0.052083333	0.49	0.4547
0.055555556	0.5	0.48036
0.059027778	0.51	0.50558
0.0625	0.52	0.53035
0.065972222	0.51	0.51871
0.069444444	0.5	0.50796
0.072916667	0.49	0.49782
0.076388889	0.49	0.48816
0.079861111	0.49	0.47892
0.083333333	0.47	0.47005
0.086805556	0.46	0.46151
0.090277778	0.45	0.45327
0.09375	0.45	0.44532
0.097222222	0.43	0.43762
0.100694444	0.42	0.43017
0.104166667	0.4	0.42293
0.111111111	0.4	0.4091
0.118055556	0.39	0.39602
0.125	0.39	0.38363
0.131944444	0.37	0.37186
0.138888889	0.36	0.36067
0.145833333	0.35	0.35
0.152777778	0.34	0.33982
0.159722222	0.32	0.33009
0.166666667	0.3	0.32079
0.173611111	0.29	0.31188
0.180555556	0.28	0.30334

T= 104.66 m²/day
S= 0.079
Q= 485.28 m³/day
Radius= 3.8 m

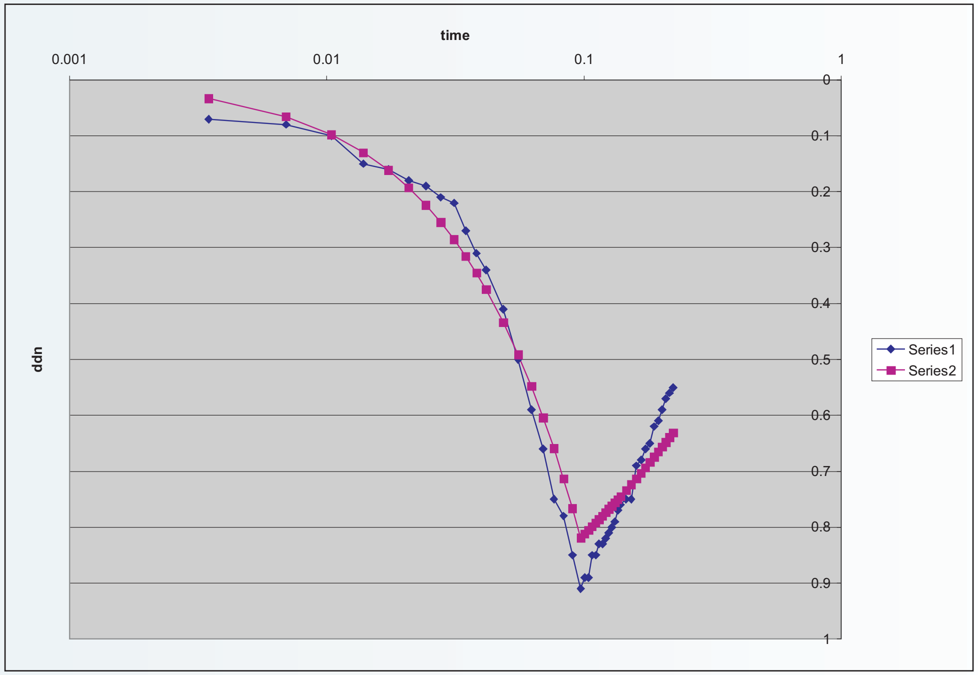


Series 1: Observed values
Series 2: Modeled values

Figure 4.30: A model chart showing drawdown and recovery of well T-4(Tekwadi well)

Time in days	Observed drawdown (s) in m	Modeled drawdown (s) in m
0.0034722	0.07	0.033126
0.0069444	0.08	0.065792
0.010417	0.1	0.098078
0.013889	0.15	0.13002
0.017361	0.16	0.16164
0.020833	0.18	0.19295
0.024306	0.19	0.22397
0.027778	0.21	0.2547
0.03125	0.22	0.28516
0.034722	0.27	0.31536
0.038194	0.31	0.34529
0.041667	0.34	0.37497
0.048611	0.41	0.43361
0.055556	0.5	0.49129
0.0625	0.59	0.54807
0.069444	0.66	0.60397
0.076389	0.75	0.65902
0.083333	0.78	0.71325
0.090278	0.85	0.76667
0.097222	0.91	0.81933
0.10069	0.89	0.81222
0.10417	0.89	0.80541
0.10764	0.85	0.7988
0.11111	0.85	0.79235
0.11458	0.83	0.78604
0.11806	0.83	0.77987
0.12153	0.82	0.77381
0.125	0.81	0.76786
0.12847	0.8	0.76201
0.13194	0.79	0.75627
0.13542	0.77	0.75061
0.13889	0.76	0.74504
0.14583	0.75	0.73415
0.15278	0.75	0.72357
0.15972	0.69	0.71328
0.16667	0.68	0.70324
0.17361	0.66	0.69346
0.18056	0.65	0.68392
0.1875	0.62	0.6746
0.19444	0.61	0.66549
0.20139	0.59	0.65658
0.20833	0.57	0.64787
0.21528	0.56	0.63934

T= 80.467 m2/day
S= 0.0011
Q= 655.2 m3/day
Radius= 4.65 m



Series 1: Observed values
Series 2: Modeled values

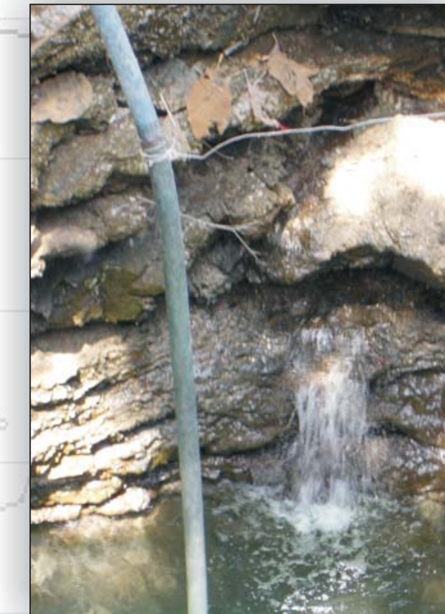
Figure 4.31: A model chart showing drawdown and recovery of well AT-2(Amble well)

C: Pimpri-Pandeshwar Area:

The average elevation of the watershed is about 650 m above mean sea level i.e. it is lower than both Amble and Tekwadi. The aquifer system is a combination of basalt and the alluvial deposit. Wells on which pumping tests were conducted were expected to yield anomalous values as compared to the other wells. The higher T values were expected but the anomalously low S values were not. One possible explanation to this could be the pore pressure element for the alluvial deposit, yielding low values – possibly in the range of confined aquifers. The data of well PP-5 is presented in *figure 4.32.*

4.8.3: Summary

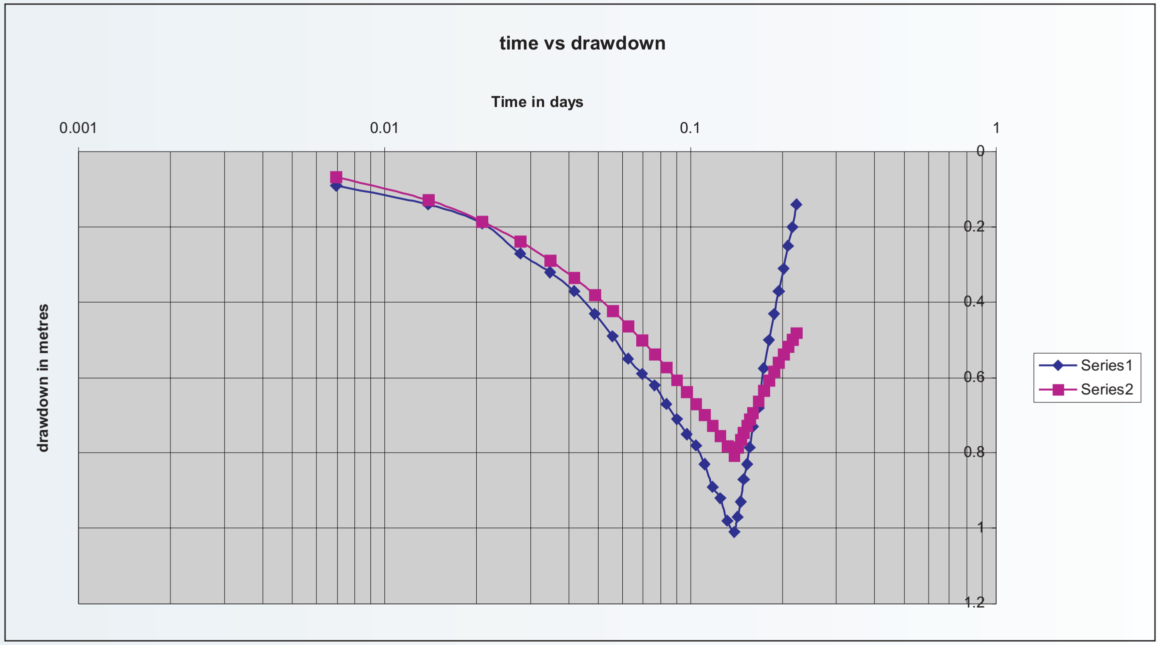
Basalt is the primary lithology in the area of Purandar. The transmissivity in the aquifers of eastern Purandar varies greatly. The lowest value encountered was 34 m^2/day in the Tekwadi watershed, the higher limit being 371.02 m^2/day at Pimpri. The values of transmissivity show a decreasing trend with decreasing elevation i.e. from Amble to Tekwadi. Storativity of aquifers in Purandar ranges between 0.0001 and 0.05. Observations have revealed that transmissivity decreases with reduction in the percentage of fractures and openings in the rocks. The reduction in transmissivity may also occur as the topography flattens, as gravity is no longer the controlling factor. However, the well PP-5 encountered in Pimpri-Pandeshwar recorded extremely high transmissivity suggesting the basalts in the area could be highly jointed or fractured. The extremely low storativity recorded by the same well compliments this assumption. Transmissivity and storativity values for the selected analysed wells in presented in *table 4.4*.



Water comming in to the well through horizontal fractures of a vesicular amygdaloidal basalt

Time in days	Observed drawdown (s) in m	Modeled drawdown (s) in m
0	0	0
0.00694444	0.09	0.067419
0.01388889	0.14	0.12859
0.02083333	0.19	0.18531
0.02777778	0.27	0.23836
0.03472222	0.32	0.28827
0.04166667	0.37	0.33538
0.04861111	0.43	0.38001
0.05555556	0.49	0.42237
0.0625	0.55	0.46268
0.06944444	0.59	0.5011
0.07638889	0.62	0.53778
0.08333333	0.67	0.57285
0.09027778	0.71	0.60641
0.09722222	0.75	0.63858
0.10416667	0.78	0.66945
0.11111111	0.83	0.69909
0.11805556	0.89	0.72759
0.125	0.92	0.75501
0.13194444	0.98	0.78142
0.13888889	1.01	0.80686
0.14236111	0.97	0.78558
0.14583333	0.93	0.765
0.14930556	0.87	0.7457
0.15277778	0.83	0.72744
0.15625	0.785	0.71009
0.15972222	0.73	0.69353
0.16666667	0.68	0.66253
0.17361111	0.575	0.63396
0.18055556	0.5	0.60748
0.1875	0.43	0.58284
0.19444444	0.37	0.55984
0.20138889	0.31	0.5383
0.20833333	0.25	0.51808
0.21527778	0.2	0.49906
0.22222222	0.14	0.48114

T= 371.02 m2/day
S= 0.00009
Q= 532.9 m3/day
Radius= 4 m

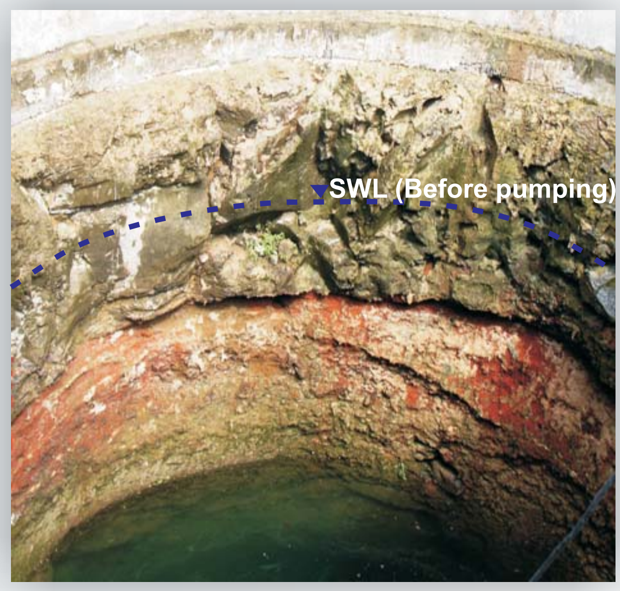


Series 1: Observed values
Series 2: Modeled values

Figure 4.32: A model chart showing drawdown and recovery of well PP 5 (Pandeshwar)

Well No.	Specific capacity (C) in lpm/m of drawdown *(Slichter, 1906)*	Transmissivity in m²/day *(Cooper-Jacob, 1965)*	Transmissivity in m²/day by BGSPT	Storativity (fraction) (BGSPT) *(Barker et al, 2000)*
1AT	96.83815	76.07	90.76	0.01
20A	50.68881	37.07	0.99	0.0001
T19A	53.6356	117.36	77	0.0001
T4	366.3919	104.66	104.66	0.0079
Tekwadi	71.18429	105.59	105.6	0.0001
AT2	199.18647	78	80.46	0.0011
AT4	200.9077	95.35	165.87	0.0001
AT5	160.6982	34.41	34	0.0069687
Amble	857.0572	32.86	279.52	0.017
PP 5	78.25895	75.13	371.02	0.00009
PO3		71.82		0.0049
PO5		85.39		0.0133
PO7		114.83		0.0091
PO8		179.80		0.00172
PO9		46.78		0.082
PO16		30.50		0.08

Table 4.4: Transmissivity and Storativity values of the analysed wells



Well water level after pumping

4.8: Hydrochemical Characteristics

The primary aim of collecting the water samples in the five watersheds was to understand the fundamental hydrochemical properties of groundwater and observe the changes in the hydrochemical properties occurring with seasons. The other aim was to ascertain if there were any obvious hydrochemical signatures to the groundwater under the three sets of conditions – overexploited aquifers, saline aquifers and the aquifer in Pondhe (not exploited). Three samples from each of the five watersheds were collected during four seasons beginning November 2007 and until April 2009. Some 72 samples were collected and analysed during this period. Additionally, in-situ water sampling was done for 30 different sources in the project area. *Figure 4.33* shows the map for water sampling points in the Purandar project area.

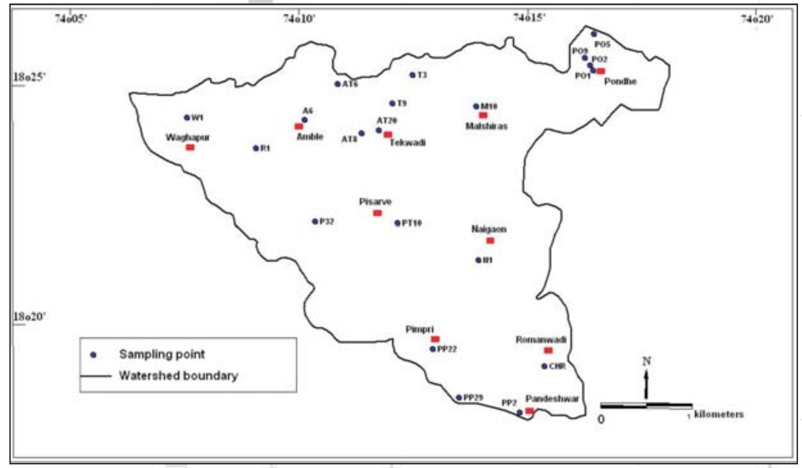


Figure 4.33: Map showing all sampling sources from the project area in Purandar

Grab samples were collected from 20 shallow dug wells, one check dam and one stream usually twice a year; once pre monsoon and once post monsoon. Twenty out of twenty two samples were groundwater samples and remaining two were surface water samples. The sampling dates were selected to coincide with the peak summer (April) and post monsoon (November-December) periods. Onsite measurements were done for pH, TDS, salinity and electrical conductivity. The samples were collected in one liter plastic bottles and analysis was completed within 1-2 days of collection. All the samples were analysed from Polytest, an ISO certified laboratory in Pune.

4.8.1: Water Type and physiochemical properties

Water in Purandar can be divided into three different groups; fresh, mineralized and saline water. Samples collected from Naigaon-Malshiras and Pondhe are fresh water samples while samples collected from Pandeshwar are saline. Water samples from Amble, Tekwadi, Romanwadi and Pisarve are highly mineralized samples. The fresh water samples generally appear to demonstrate a fresher signature of Ca-Mg with HCO_3 as the dominant anion while saline water samples appear to demonstrate signature of Na-Mg with Cl as the dominant anions. The mineralized water samples show Mg-Na-Cl-HCO_3-Cl-SO_4 type.

The average conductivity value in all the samples is relatively high (>1000 µs/cm). The lowest value of conductivity is 512 µs/cm (W1) and the highest value is 13460 µs/cm (PP2). A well in Pandeshwar (PP2) show consistently high value of conductivity (>9000 µs/cm). In samples like PP2, PP22, PP29 and AT20, the conductivity is found to be above 1000 µs/cm while in the remaining samples it is in between 500 µs/cm to 900 µs/cm. Generally, conductivity increases in the summer and decreases after the monsoon. But

Parameter	Units	Min	Max	Mean	Median	MAC *(India-Class A drinking water standard))*
pH		7.3	8.4	7.62	7.6	6.5-8.5
Chlorides	mg/l	17.99	1899.44	245.44	79.98	250
Sulphates	mg/l	6.93	1298.3	115.82	47.2	400
Fluoride	mg/l	<0.01	0.654	0.13	0.077	1.5
Arsenic	mg/l	0	0	0	0	0.05
Calcium	mg/l	11.2	220	92.45	72	
Sodium	mg/l	7.2	2030	184.41	68.865	200
Iron	mg/l	<0.013	0.675	0.08	0.0031	0.2
Manganese	mg/l	0	<0.051	0.05	0	0.5
Magnesium	mg/l	7.67	280.8	60.19	37.44	100
Potassium	mg/l	0.2	45.46	6.62	2.83	
Nitrates	mg/l	<0.081	35.36	16.15	17.76	20
Carbonates	mg/l	0	14.4	0.25	0	
Bicarbonates	mg/l	102.48	658.8	377.18	317.2	
Conductivity	µs/cm	512.4	13460	1892.12	995	

Table 4.5: Summary statistics of major and minor element concentration in the Deccan Basalts of Purandar
(The highlighted results exceed Maximum Admissible concentration (MAC))

in dug wells like PP2, PP29, M10, W1 and PO1 the conductivity decreases in summer indicating late freshening, possibly due to slow movement of groundwater within the alluvium. *Figure 4.34* indicates the conductivity values for the three seasons. The high conductivity in most samples could be due to low annual recharge as this area is a drought prone area with average annual rainfall of less than 500 mm. High value of conductivity (mean 995 µs/cm) could be attributed to more rock water interaction, causing mineralization.

The pH ranges between 7.2 to 8.5 which is within expected limits for Deccan basalts. Sample collected from Romanwadi check dam (CHR) shows pH value above 8 indicating slightly saline water. The high pH in water could be due to higher exposure to the open environment because the check dam is an open water body – depleted CO_2 content and evolved, with base flows contribution from the alluvial Pandeshwar aquifer – which has saline groundwater. The pH is generally low in the post monsoon season and increases during summer (except in CHR). *Figure 4.35* indicates pH values for the selected samples in pre and post monsoon season.

Samples from Pimpri Pandeshwar consistently remain dominated by Na-Cl. A couple of samples from Tekwadi (AT20) and Romanwadi (CHR) also show

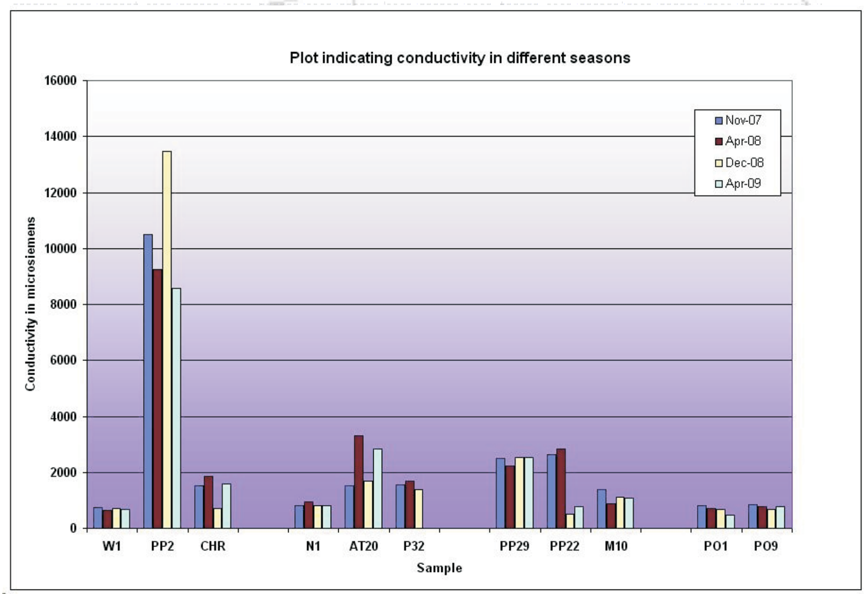


Figure 4.34: Conductivity values for selected samples in different seasons.

dominance of Na-Cl, indicating the presence of local alluvial aquifers associated with the basalt aquifers in these areas. Such 'local' exposures of alluvial material can be noticed in the vicinities from where these samples were collected. The remaining samples show the dominance of Ca-Mg-HCO_3 during post monsoon which tend to become Mg-Na-HCO_3 type in pre monsoon season, a typical hydrochemical signature for groundwater in Deccan basalts *(Gale et al, 2007; Kulkarni et al, 2005)*.

Comparison of Piper Plots (Piper, 1944) of all samples for the three seasons – post monsoon 2007, pre monsoon 2008 and post monsoon 2008 indicate relatively more clustering of water quality signatures in November 2007, i.e. post monsoon 2007.*(Figure 4.36*) On the other hand, there is greater scatter of samples on the Piper plot for both the pre monsoon 2008 and post monsoon 2008 plots, while the scatter for the pre monsoon 2008 period can be expected (increased concentration in summer months); the post monsoon scatter (2008) can possibly be attributed to the relatively low rainfall in the area, resulting in limited recharge to the aquifers, on the whole.

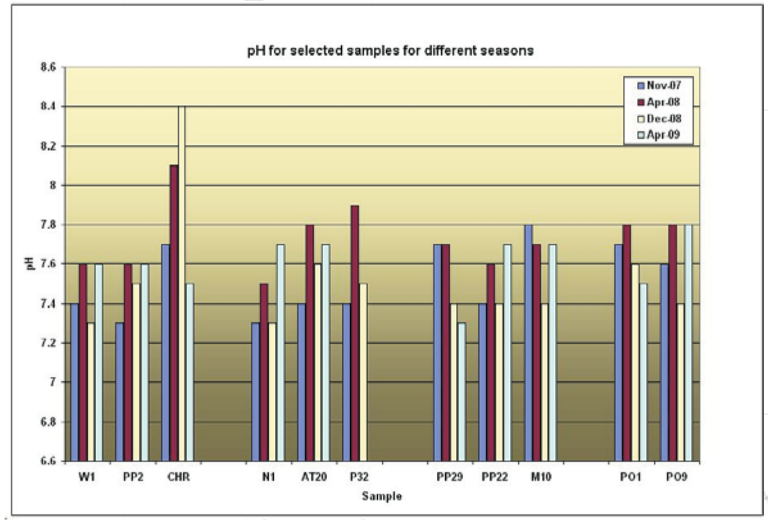


Figure 4.35: pH values for selected samples in different seasons

4.8.2: Major and minor elements

Purandar water samples demonstrate high concentration of major elements in most of the samples. For example, high median value of Cl (80.975 mg/l) suggest a long residence time of groundwater in Purandar and high water-rock interaction. The high median values for Cl and SO_4 are found especially in the samples of Pimpri Pandeshwar in all the four seasons where there is a lagged transfer of water from the surface to the aquifer. Moreover, the high storage capacity of the alluvial aquifer allows salinity to develop as the resident time of water in the aquifer may be significant and several annual rainfall-infiltration cycles are embedded within the groundwater storage in the aquifer. Groundwater in the alluvial aquifer of Pimpri-Pandeshwar is generally saline and possibly older than that in other places in the project area. Most of the other samples demonstrate high median value of HCO_3 (330.62 mg/l), supporting the suggestion that groundwater freshening occurs after every recharge input – related to an annual cycle of recharge and discharge. As the samples are collected from the shallow dug wells, it is expected that after every rainy season fresh recharge occurs and a large part of the storage in the shallow unconfined aquifer is replenished. In all the samples except Pimpri Pandeshwar, groundwater follows an annual freshening trend.

High median value of Mg (38.4 mg/l) and Na (65.7 mg/l) also supports the suggestion that there is a high water rock interaction in many parts of the region. This also suggests a significant weathering of the basalts, especially the vesicular-amygdaloidal basalts. No major concentration of trace elements is found in any of the wells. The concentration of Fluoride is within the safe limits and no Arsenic is found in any of the samples. Although the concentration of Fluoride is within the safe limits, it is observed that the

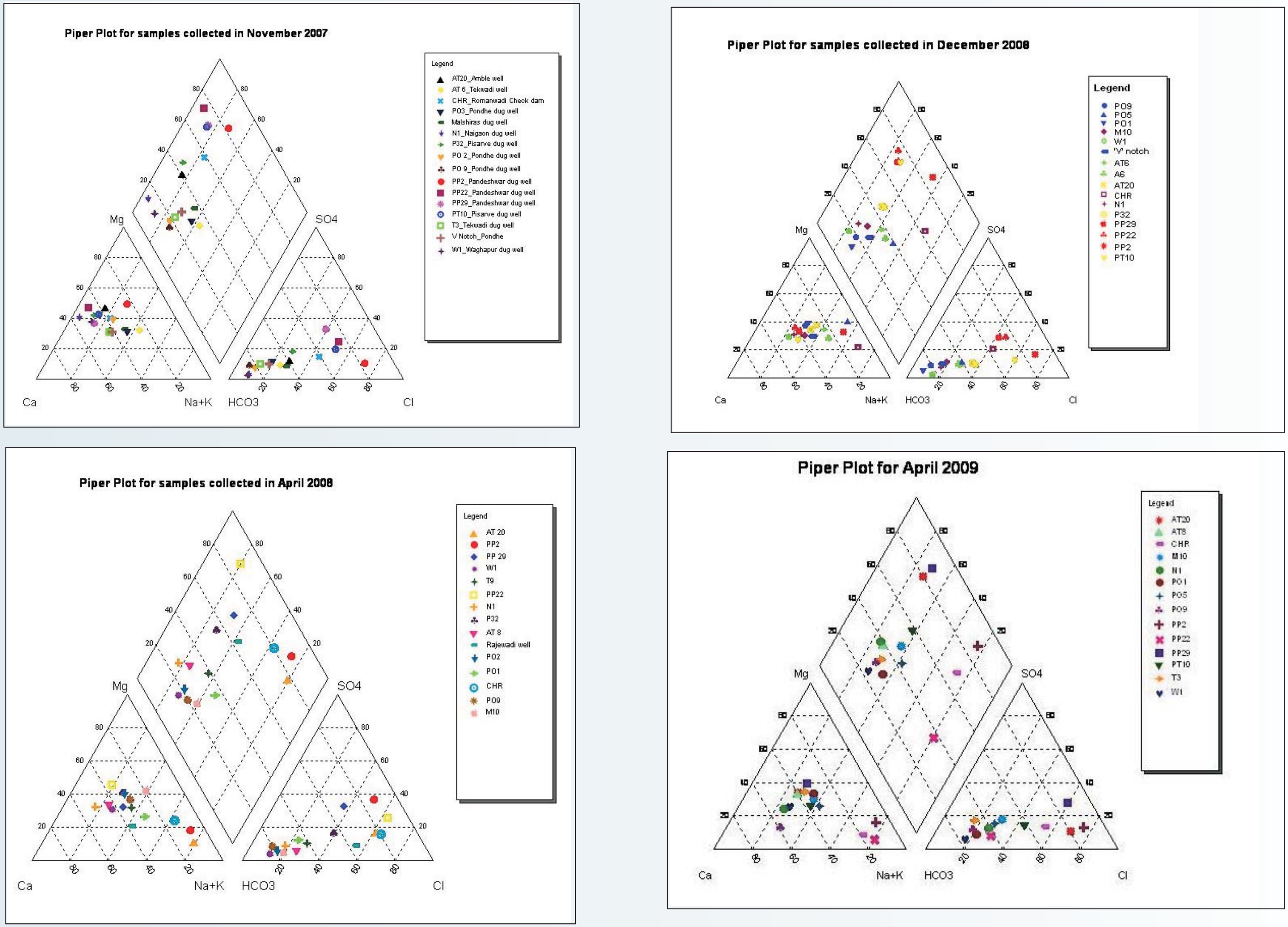


Figure 4.36: Relative changes in concentration of cations and anions in Purandar

Fluoride concentration increases in summer and decreases in post monsoon season indicating prevalence of reducing conditions in the dry season. *(Kulkarni et al, 2005)* The concentration of iron is also within the safe limit with the exception of one odd well (PT10) which indicates a slight rise in Fe during summer, also indicating reducing conditions.

Most groundwater in basalt will have higher concentration of Ca, Mg, Na, SO_4 and Cl which indicates depletion of aquifer storage in this area. The water levels in most of the wells fall quickly, which supports the theory of overexploitation of aquifers in dry semi arid regions. This is also due to the fact that most of the wells are found in groundwater overexploited area where one bad year of monsoon may also severely affect the recharge to the dug wells. This area is mainly arid with low rainfall and therefore the shallow aquifer nearly empties by early May. The rate of evaporation is also high in this area (average 4.5 mm/year to 5 mm/year) causing deposition of salts.

The Ludwig Langelier plot is used to study the pattern or correlation between major cations or anions. In this study Ca-Mg is plotted along with Na-K to understand their relation during the four seasons. It is observed that during post monsoon season, the samples do not show any pattern, (scattered) which indicates that the process of ion exchange is not complete. During summer there is a trend observed where samples from Pandeshwar, Romanwadi and Tekwadi fall in one group while remaining samples form another group. In this season, separation of samples on the basis of water types can be done. Ludwig Langelier plot indicates that water in Purandar take some time to achieve ionic equilibrium achieved only in summer. *Figure 4.37* is the Ludwig Langelier plot for four seasons in Purandar.

4.8.3: Geochemical controls

The dominant geochemical processes, which influence groundwater chemistry include:

- Mineral dissolution
- Redox reactions
- Ion exchange
- Mixing of older formation waters.

The potential influences of each of these processes are discussed, with particular focus on interpretation of temporal variations throughout the year. The initial interpretation suggests that mineral dissolution is probably the most important geochemical process influencing groundwater chemistry in Purandar.

A. Mineral dissolution/precipitation

The concentration of anions and cations is relatively high in most of the water samples in Purandar, especially in comparison to other areas underlain by Deccan basalt *(Gale et al, 2006; Kulkarni et al, 2005)*. The cations are

In situ water quality measurement using tracer

Pandeshwar

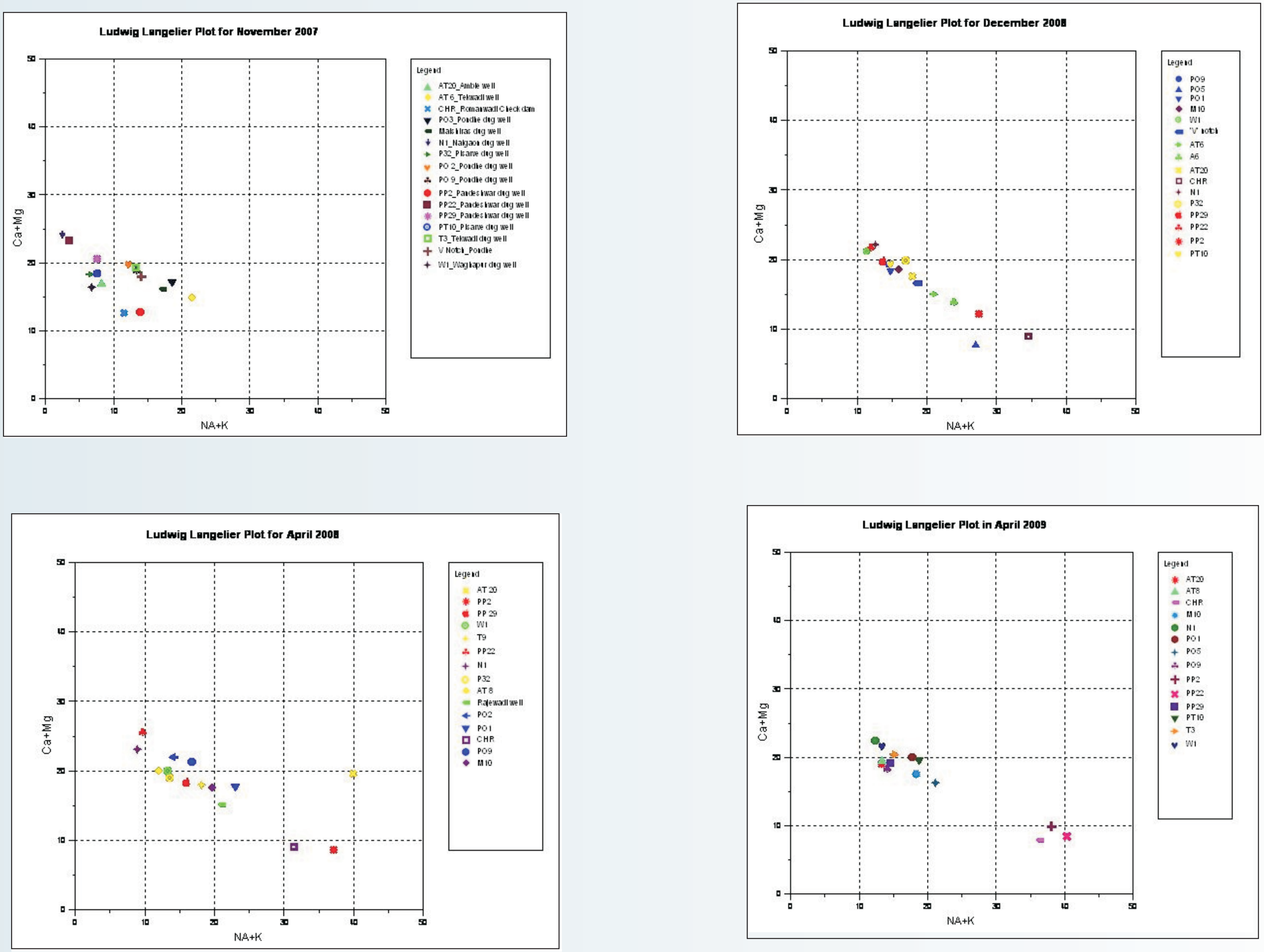


Figure 4.37: Ludwig Langelier plot indicating concentration of Ca-Mg with respect to Na-K for four season

Figure 4.38: Concentration of ions in different seasons

dominated either by Ca or Na. Concentration of Mg is relatively low in most of the wells. Well no. AT20, PP2, CHR, PO1, PO9 and M10 show relatively high concentration of Na as compared to well no. P32, PP29, PP22 and N1 which are dominated by Ca. In most of the wells the concentration of Na increases in summer and decreases in the post monsoon season due to freshening by rainwater indicated by the dominance of Ca.

Anions are dominated either by HCO_3 or by Cl. Well no. AT20, PP2, PP22 and CHR are dominated by Cl and the remaining samples are dominated by HCO_3. In most of the wells the bicarbonates increase in post monsoon season and decrease in summer at the expense of Cl and vise versa. In well no. PP2 and PP29 there is increase in concentration of SO_4 at an expense of Cl and HCO_3. Another reason for high sulphate concentration could be the presence of sulphate bearing minerals like gypsum – a rather unlikely occurrence in ths case. This would require more detailed probing, but clearly the groundwater in Pandeshwar is indicative of a more evolved stage – HCO_3 – SO_4 facies in the Chebotarev sequence, as described by *Freeze and Cherry (1979).*

B. Redox reaction

All the water samples were collected from open dug wells and one sample was collected from a check dam, both sets at least partially open to the atmosphere. The samples were collected using the grab sampling method and therefore most of the results illustrate oxygen rich water, as would be expected.

The concentration of Fe, As and Mn are indicative of reducing conditions. However in all the samples of Purandar the As and Mn concentration is well below the permissible limit while Fe is also within permissible limits with an exception of one odd well (PT10) during summer. However, the results indicate the prevalence of reducing conditions in summer.

C. Ion exchange

In Purandar water samples, instead of ion exchange there is an enrichment of ions. There is no particular trend observed in the behaviour on ions. For example well no PP2 and PP29 indicate decrease in Cl concentration along with decrease in HCO_3 and increase in SO_4 in pre monsoon season (April 08). During the next season there is an increase in Cl concentration in pre monsoon season (April 09) but decrease in HCO_3 and SO_4. Similarly, in case of cations there is no dominant ionic exchange taking place. In the same well the concentration of Na and Mg increases in summer, while it decreases in post monsoon season. Ca show decrease in concentration in April 08 but then there is a constant increase in the following year.

In situ water quality measurement done by students

D. Mixing with older formation water

Chloride is the best indicator of mixing with older formation water as excessive chloride in water suggests older water with lot of mixing *(Kulkarni et al 2005)*. It also suggests that the aquifer is not flushed properly and probably receives an annual recharge, which is only a small component of the total storage capacity of the alluvial aquifer in Pandeshwar. High concentration of Na and Cl in wells like AT20, PP2, PP22 and CHR indicates more mineralized groundwater, the last clearly indicating base flow contribution from the alluvial aquifer to the drainage in the area, which in turn discharges such water into the structure (CHR). In other wells, an increase in Na and Cl is seen only during the dry season. However, HCO_3 continues to dominate the anion concentration in the areas where basalt aquifers are present.

4.8.4: Regional Characteristics

The typology of groundwater occurrence studied through this project has brought out three distinct "types" of situations – referred to as typologies. These types are a result of significant variations in geology, aquifer characteristics, distribution of recharge and modes of discharge, with a clear footprint of the human element through the nature and quantity of water use. The three types identified earlier are:

1. Overexploited aquifers
2. Pondhe aquifer – not exploited
3. Aquifer system related to 'groundwater salinity'

The water quality – as deciphered from the hydrochemical analysis - also depends upon the type the sample belongs to. In the overexploited aquifers, samples indicate more mineralized water as compared to the Pondhe aquifers, the latter belonging to the 'not exploited' type. The nature of groundwater in the overexploited aquifers has a higher proportion of dissolved material, which current levels of recharge are not able to dilute to the extent of dilution in the Pondhe aquifer. Moreover, farmers often transfer water from deeper aquifers (bore wells) into their wells during the non-rainy season, implying that the water quality significantly changes to a more 'dissolved solids' type especially in the post-monsoon period.

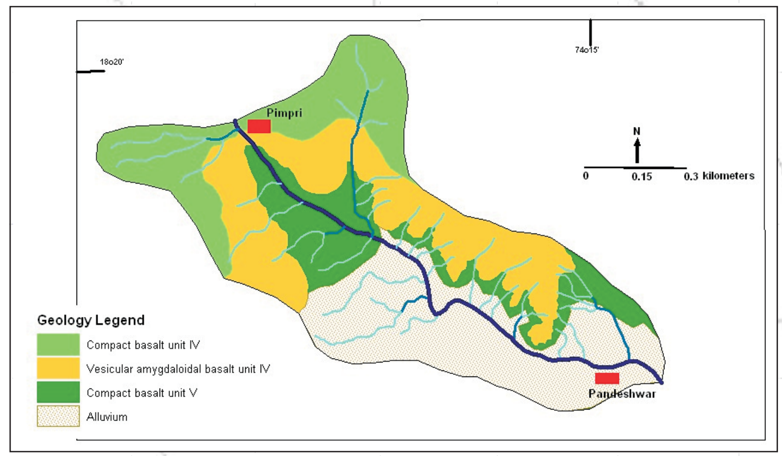


Figure 4.39: Geology map of Pimpri Pandeshwar

The problem of salinity in Pimpri and Pandeshwar is directly related to the inherent aquifer salinity due to the contrasting hydrogeological characteristics of the alluvial aquifer and the surrounding basalt rocks. *Figure 4.39* indicates the aquifer map of Pimpri Pandeshwar watershed. As the water passes from the basalts to the alluvium (which consists of coarse and fine grained hardened alluvium), the diffusivity (ratio of Transmissivity to Storage coefficient) reduces, increasing the resident time of groundwater in a medium rich in chlorides that could have leached through the upper soil layers. It is a well known fact that leaching of chloride in the upper soil layers is a common phenomenon in the dry climatic areas *(Nagabhushaniah H.S. 2001).* The annual cycle of recharge and discharge is fairly balanced in the Pondhe watershed, which has the least variability between pre and post monsoon water quality among the three types, despite low annual rainfall.

Figure 4.40 indicates the Piper diagram for water samples from the different types / situations. The polygons drawn around samples clearly bring out the concept of 'hydrogeological typology' in Purandar. Therefore, the hydrochemical analysis was useful in clearly bringing out the typological characteristics of the project area in Purandar taluka of Pune district in Maharashtra state.

4.9: In- situ quality analysis

In situ water analysis was undertaken to understand the water quality in the field. At times when samples are collected in the field and then sent to laboratory for analysis, the properties of water like pH, conductivity or TDS maybe altered due to exposure to the external environment and therefore in situ readings of the samples are useful, before sending them to the laboratory for detailed analysis. In Purandar, in situ water analysis was undertaken during four seasons. Four properties were recorded - pH, electric conductivity, total dissolved solids (TDS) and salinity - during the four seasons and the dissolved oxygen (DO) was measured for the last season.

It was observed that the results are in compliance with laboratory results. The pH ranges between 7.3 and 8.5. Only in two instances, i.e in December 08 and April 09, the pH of Romanwadi check dam was exceptionally high, 10.5 and 8.5 respectively. The in situ electrical conductivity ranges between 500 µs in wells of Pondhe to 20000 µs in Pandeshwar. The electric conductivity of 20000 µs was observed in PP2 in December 2008. Similar to electric conductivity the TDS ranges between 500 ppm to 14000 ppm with maximum amount of total dissolved salts found in Pandeshwar well (PP2) in December 2008. The data clearly strengthens the typology of groundwater conditions in the project area – the Pondhe aquifer has low TDS groundwater, followed by higher TDS in aquifers from the overexploited villages of Malshiras, Naigaon, Romanwadi, Amble, Tekawadi, Rajuri, Waghapur, Pisarve etc. and the maximum for the alluvial aquifer of Pandeshwar.

ACWADAM was able to obtain measurements of dissolved oxygen (DO) in April 2009. Dissolved oxygen meter measures the amount of gaseous oxygen (O_2) dissolved in an aqueous solution. Oxygen enters water by diffusion from the surrounding air, by aeration (rapid movement), and as a waste product of photosynthesis. *(www.Wikipedia.com)* Adequate dissolved oxygen is necessary for good water quality and is an indicator of the overall health of water.

Generally DO value of 5 mg/l is considered to be good for aquatic life and

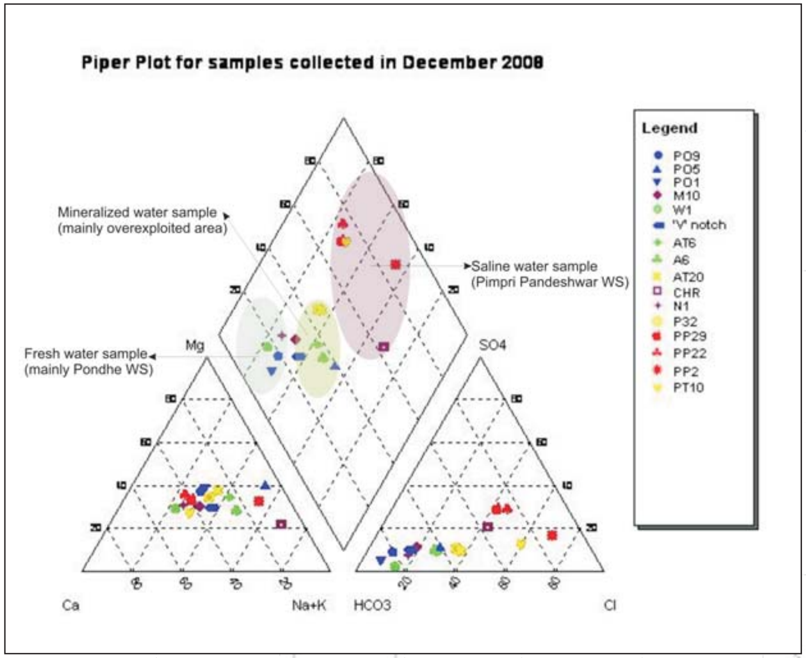


Figure 4.40: Typology of water quality using a Piper diagram

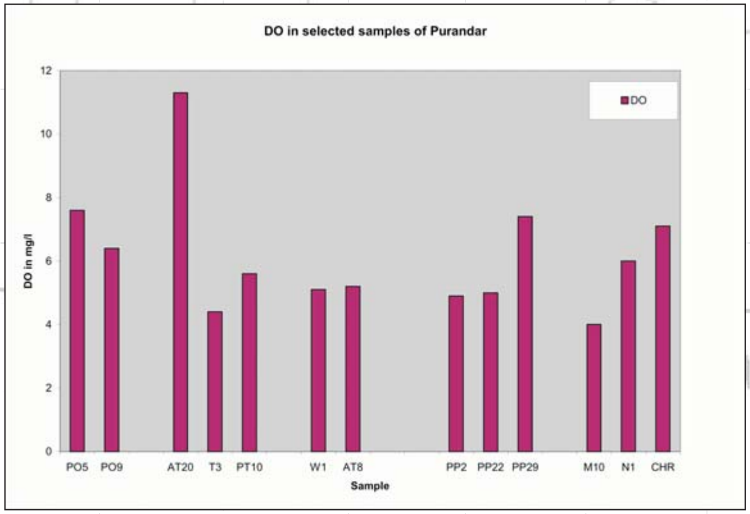


Figure 4.41: Concentration of dissolved oxygen in different samples of Purandar

water having 5mg/l of DO is considered to be water of good quality. In Purandar, the DO ranges between 4.3 mg/l to 7.6 mg/l with an exception of AT20 having DO above 11 mg/l. *(Figure 4.41)* Well no. AT20 is located in the village but shows algal development in the well. This could be one reason of high value of dissolved oxygen in water as algae decompose the organic matter present in the well and in the process release oxygen. In all the remaining samples, the DO is within desired limits.

4.10: Pollution indicators

Purandar taluka is dominantly agricultural, with very few industries in the actual study area. The likely sources of pollution is the use of fertilizers and pesticides in the farms. The elevated values of NO_3, SO_4 and K may be indicative of the impact of fertilizers on groundwater sources, although a more detailed hydrochemical analysis is required to confirm this notion. However, the water quality trends after the harvesting of rabi crop i.e in the pre monsoon season, show high concentration of NO_3, SO_4 and K which may imply the effect of fertilizer use on water quality during this period. Open access sanitation could be another reason for the elevated value of NO_3.

Besides this there are geological or natural factors affecting the quality of water like the low rainfall and geology which has also caused an increase in the concentration of Na and Cl in the water. *Figure 4.42* indicates the Wilcox diagram showing samples falling in sodium and salinity hazard. In December 2008, all the samples were in the low sodium (alkali) hazard but medium to very high salinity hazard. Samples in Pandeshwar and Tekwadi fell in very high salinity hazard zone. In April 2009, a couple of samples from Pandeshwar and Romanwadi showed medium sodium hazard while the remaining samples fell in low sodium hazard zone. In this season too, the samples indicated medium to very high salinity hazard.

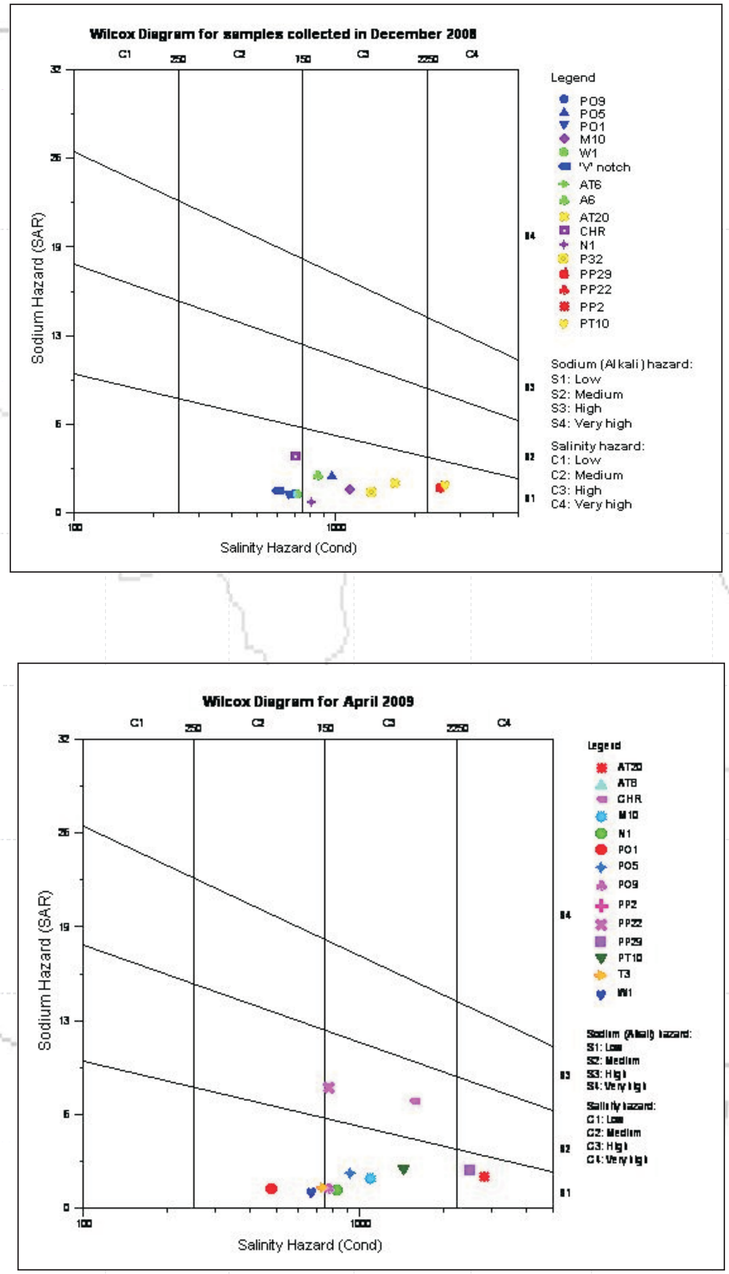


Figure 4.42: Wilcox diagram for two seasons

4.11: Automatic water level recorder

An automatic water level recorder is a self contained and completely submersible troll (sensor) used for collecting real time information for analysis of both short and long term water level trends. This recorder includes pressure and temperature sensors, internal data logging, memory and power. It is quite sturdy and can be used very effectively in the field. Initially the plan was to install the automatic water level recorder in an observation bore well which can give accurate information about the aquifer in a controlled environment. Unfortunately, due to ban on drilling by the GSDA (for the overexploited block in Purandar taluka), no bore wells could be drilled and therefore this recorder was installed in the GGP - Naigaon well (N1) in January 2008. The automatic water level recorder collects the data at a 15 minute interval. This data, stored in the sensor instantaneously at recording interval, was retrieved once every month by uploading it to a laptop computer. The main purpose of installing this recorder in the dug well was to understand the changes in water level in a typical well from the Purandar area with regard to the following factors:

1. The daily water level behaviour of the well in response to pumping.
2. The pumping cycle of the well – daily, monthly and seasonal trends.
3. The annual water level behaviour –the relationship of the well water level with regard to rainfall (recharge) and other fluxes (pumping and natural discharges, if any).

A continuous record of data from the well was expected to throw light upon the transmissivity and storage characteristics of the aquifer and a long term trend analysis of the well hydrograph since the recorder gives accurate data and there is little chance for human error. The depth of the Naigaon well is 12 m. *Figure 4.43* is the rainfall-water level hydrograph for the Naigaon well, normalized to a daily frequency. The well is pumped almost every day (except during the monsoon) and the graph indicates portions of the hydrograph corresponding to the drawdown and recovery – nearly a daily cycle.

From figure 4.43, it is observed that from 9th January, 2008 to 17th April, 2008 the net water level decline was 2.5 m. The data indicates that once the well is pumped, it takes more than one day to regain its original water level, i.e. achieve near complete recovery (90 to 100%). The water level hydrograph also shows an interesting shift in the pattern of fluctuation after early March, in both years – 2008 and 2009. Most fluctuations in or before March are well-balanced on a daily basis, i.e. the well recovers nearly to a level from which it was pumped and there is little progressive decline from January 2008 to early March 2008. After early March 2008, the well clearly showed a progressive decline in the water level (until end-April) by almost 3 m. The graph also indicates that rainfall (19 mm) on one day i.e. 26th April affected the decline in

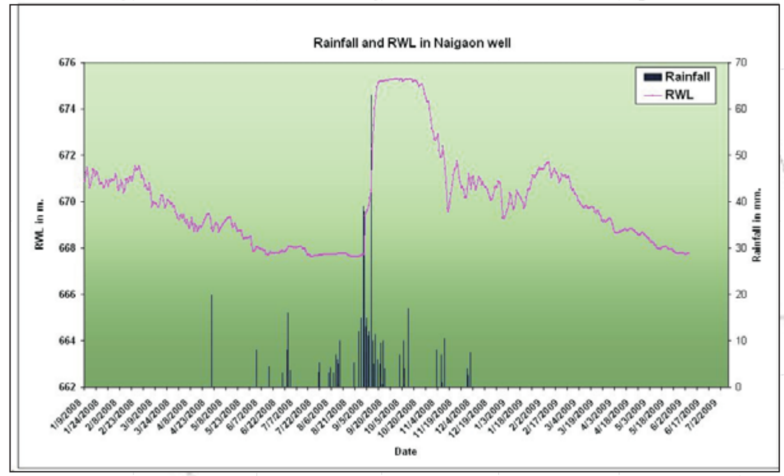


Figure 4.43: Water level in Naigaon well along with the rainfall on daily basis

the well water level in summer.

There was no significant change in the water level by the first 50 mm. of rain and the water level rose by 0.2 m only, after the first few spells of rain in June and July 2008. The water level remained consistent over a long period from June to late August, with sporadic rain spells and little pumping for the Kharif crop. The first significant rise in the water level took place after the first week of September as a response to 100 mm of rainfall in the last week of August 2008. A continuous rainfall period from late August to about mid-September ensured that the well filled up by 20th September(*Figure 4.44)*. Although the well filled up, the aquifer did not get fully saturated, evident from the fact that the adjacent stream did not have water after the rainfall. If there would have been any base flows, the stream would have flowed longer. This also means that the well had not filled up to its full saturated thickness. This well, before the stage of overexploitation, was a couple of meters above the current post monsoon level. Today, because of overexploitation, the aquifer does not get completely saturated with the amount of rainfall received every year and therefore the well has a capacity to fill up further by a couple of meters.

After 15th October, the well showed progressive decline in the water level and the water level droped by almost 5.5 m by 15th November, mainly because of pumping for the Rabi crop. During this period of sustained pumping, the well hardly recovers to its original water level. There was some rain in mid November which caused rise in the water level by about 2 m.

From November 2008 till January 2009, the hydrograph shows effects of pumping and recovery. From mid January to early February 2009, there was an increase in the water level by 1.5 m. which was mainly due to reduction in pumping – the Rabi crop is almost ready for harvest and does not require much water. From February 2009 onwards, there was a progressive decline in the water level, again with pumping for the summer crop, and by the end of May the water level reaches its base. One must keep note of the fact that the Pani-Panchayat well – N1 – is regulated, mainly on the basis of maintaining a water column in the well even in summer. Moreover, there are no wells in close proximity to N1, precluding effects of well interference. In many ways, it represents the conditions in the aquifer, foreclosing large-scale "transient" effects. It represents the conditions within a basalt aquifer that has been under stress, with the water level fluctuating across the entire thickness of the aquifer, during a typical annual cycle.

A pump test was conducted on this well to estimate aquifer characteristics using the BGSPT Pumping Test Program.*(Barker and Macdonald, 2000*) The transmissivity of the well is about 5 m^2/day and the specific yield is 0.001 or 0.1%. The specific yield was also estimated from the water AWLR data for the well. The hydrogeological mapping reveals that the Naigaon aquifer is approximately 2 km^2 in its surface area (A); during the post-monsoon phase, its total pumping is estimated to be at the rate of 500 m^3/day, for a total

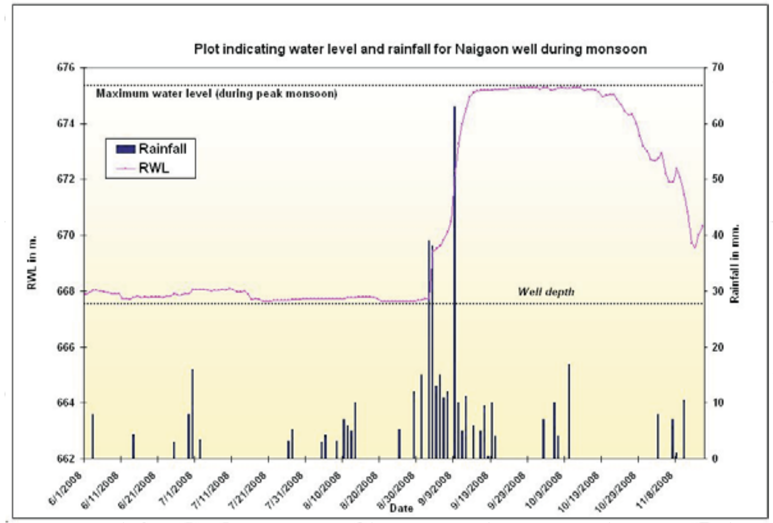


Figure 4.44: Plot for water level and rainfall for Naigaon well during monsoon (June 2008 to November 2008)

period of 50 days. Specific yield (S_y) can be estimated by dividing the abstraction (Q) by the decline in water level (∇wl) caused by this abstraction.

$$S_y = Q/(\nabla wl \times A)$$

Substituting above values in this equation yields a specific yield of 0.0017 for the Naigaon aquifer, a value of the same magnitude obtained from analysis of pumping test data. Through the Rabi season, until early March, the well showed recovery within a day but after March the well showed progressive decline in the water level indicating either or both of two things – significant depletion of aquifer storage and lowered transmissivity in the lower part of the aquifer. Overexploitation, therefore may not necessarily imply drying up of such wells in summer, but a drastic drop in the well-yield, whereby further pumping would imply either drying up or extremely slow well recoveries.

On the basis of automatic water level data, some analysis of drawdown and recovery was attempted for the Rabi season. The well was pumped almost every day for 4 to 5 hours in the afternoon, depending upon the availability of electricity. This analysis was attempted for 15th and 16th December 2008. The well was pumped everyday for a minimum of 3 hours. *Table 4.6* gives the details of pumping and recovery.

On 15th December the well was pumped for 2 hours 45 min. which caused a drawdown in the well by 0.631 m. The well took 19 hours to recover which means that the well recovered at the rate of 0.033 m/hour.

Date	Pumping time	Drawdown in m.	Recovery time	Total recovery in m.
15th Dec.	2 hrs 45 min	0.631	19 hrs	0.631
16th Dec.	4 hrs	0.851	20 hrs	0.851

Table 4.6: Details of pumping and recovery of well on 15th & 16th December 2008

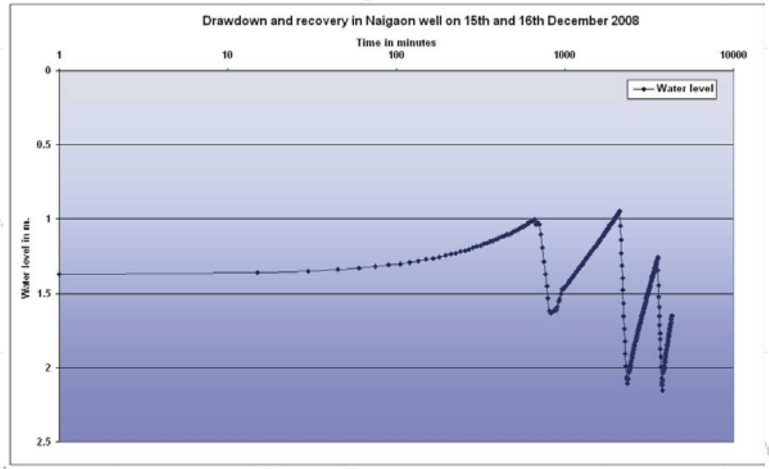


Figure 4.45: Drawdown and recovery in Naigaon well on 15th and 16th December 2008

4.12: Socioeconomic aspects

Groundwater has enabled the small farmer in India to gain easy access to irrigation; to understand groundwater, it is equally important to understand the people who use groundwater *(Shah, 2009)*. The dynamics of groundwater use in India extends beyond the physical characteristics of the resource. The socio-economic conditions in an area play a crucial role in shaping the patterns of groundwater use and how communities perceive groundwater resources. Therefore, an understanding of the basic socioeconomic conditions of a community is necessary to understand how groundwater resources shape the livelihood patterns within the community. GGP has been working in this area for the last 30 years. Through their work, mainly on the development of Pani Panchayats in the region, a substantial body of knowledge and understanding of the communities residing in this region is now available. Using some of this knowledge – documented and undocumented, ACWADAM collected some primary information by conducting surveys with the help of GGP. Socio-economic surveys were conducted in December 2007 and December 2008, with a clear focus on water related questions. Secondary data through the *District Census Handbook (2001)* and through GGP's earlier surveys complimented the primary surveys. Background information of the ten study villages is given below (*Census, 2001*). The technical component of the current study used watersheds as primary units of data collection, but the socio-economic component of the study considered the village as a unit, simply to obtain the right scale of information and capture 'inter-village' variability across the project area.

Agriculture is the main occupation of the people in Purandar

4.12.1: Socio- economics: Secondary data

ACWADAM has conducted two socioeconomic surveys in the area. The first survey was a detailed survey on water. Around 125 households were surveyed during this exercise. In this survey, questions regarding the economic status, social status, land and water assets, water requirement, quality of water, crops grown, changes in livelihood pattern, impact of watershed development work and the need of groundwater managements were discussed. The second survey was a rapid survey conducted to obtain a perspective of the local volunteers who are working in watershed development and management. A gist of the outcomes from the two surveys is presented below.

A: Population

Among the ten villages, Malshiras has the highest population (3245) followed by Tekawadi (3054) and Waghapur (2457). Pondhe (770) and Pisarve (959) are the least populated villages. The average population in the ten villages is 1949. The average family size in each village is considered to be five. The average density of population in the ten villages is 1.29 people per hectare, with Tekwadi having the maximum density of population (2.43 people per hectare) and Pisarve having the least density of population (0.55 people per hectare). Details about the population and number of families in each village are given in the *table 4.9*.

B: Distribution of land

The total area of 10 villages is 16062.47 hectares. Malshiras is the largest village (3491.15 ha) followed by Amble (1883.15 ha) and Naigaon (1535 ha). Per capita land holding is 0.9 hectares. Availability of total land area in the 10 villages is given in *table 4.10*.

In these villages, the total land under agriculture is 12312.37 ha. Land under forest is 856.74 hectare and the wasteland is 1412.73 ha. According to the census data for 2001, the total irrigated land in the 10 villages is 1395.47 ha, which is around 9% of the total land. Remaining 10916.9 ha of land is unirrigated, rain fed.

C: Sources of water

There are a number of non perennial streams in the area. All these streams, except the Pondhe stream, drain into Karha river. The Pondhe stream drains into Bhima river. Wells are the main sources of water for drinking and irrigation in these villages. As per the GGP survey conducted in 2004-2005, there were 1835 dug wells in the 10 villages. A few of these wells are community wells and the rest are individual wells. Many farmers have drilled bore wells in this area. The average depth of a bore well is 100 m. There are some 580 bore wells in the area. As the water level in the dug wells is going down, farmers are going for deeper bore wells. Apart from the successful dug wells and bore wells, there are number of failed or abandoned wells/ bore wells.

D: Sources of irrigation

Farmers use all the sources of water for irrigation like the dug wells, bore wells, farm ponds, tanks etc. There are 1576 agricultural connections in the ten villages as per the records of Maharashtra State Electricity Board. Many farmers have agricultural "electric" connections. Farmers have installed 5HP pumps or less on their water sources. Total installed HP on agriculture in the ten villages is around 6510 HP. *(GGP survey 2004-2005)* Unauthorized connections are apparent, but it is difficult to provide a number to the proportion of such connections to the total.

Sr. No.	Village	Population	Number of families
1	Amble	2198	452
2	Malshiras	3245	629
3	Naigaon	2008	393
4	Pandeshwar	1804	361
5	Pimpri	1599	331
6	Pisarve	959	655
7	Pondhe	770	125
8	Rajewadi	1393	283
9	Tekwadi	3054	287
10	Waghapur	2457	542

Table 4.7: Population data for ten study villages

Sr. No.	Village	Total land (Ha)	Total irrigated land (Ha)
1	Amble	1883.15	67.28
2	Malshiras	3491.15	51
3	Naigaon	1535	137
4	Pandeshwar	1493.22	134
5	Pimpri	1369.69	400
6	Pisarve	1738.35	178.87
7	Pondhe	1102.51	73
8	Rajewadi	1074.06	45.38
9	Tekwadi	1254.08	48
10	Waghapur	1121.26	260.94

Table 4.8: Total land area of ten villages along with the irrigated land

E: Occupational pattern

Agriculture is the main occupation of people residing in the area, with more than 60% families engaged in agriculture. Although difficult to state from the Census Data, GGP's surveys during different periods of their work point to diversification of livelihoods out of agriculture – probably driven by the push from recurrent droughts and the pull factor provided by opportunities in burgeoning urban and industrial centres in and around Pune city. People commute to nearby towns or to Pune for jobs, even on a daily basis. Hence, services form the second largest occupation in the area. *(GGP survey 2004-2005)* Many farmers in this area own livestock. Around 15 to 20 percent people are engaged in dairy as one of the many livelihood options. Dairy, in many cases is a supplementary source of livelihood to the main source, agriculture. Some marginal farmers or the land less work as agricultural labourers. Some 10 to 12 percent population works as 'labour' in this area. Very few people are into trade and business and a negligible population is engaged in traditional craftsmanship.

Animal husbandary has the second largest share of occupation after agriculture, in Purandar

4.12.2: Socio-economics: Primary Information

Primary data was collected using questionnaires and house-hold level interviews. A socioeconomic survey was conducted in the five watersheds during November-December, 2007. The main focus of the survey was 'water availability' in the area. Along with water, the survey attempted to capture the overall economic and social status of the family. Some 25 families were surveyed in each watershed. A brief report of the findings from the socio-economic survey is given below.

This survey was done using the random sampling method. It was decided that at least 20 to 25 families should be surveyed in each watershed to enable this project to capture indicators on the overall socio-economics of the project area. *Table 4.11* indicates the number of families surveyed in each village.

A five page questionnaire in Marathi was prepared, with specific questions about the family, their economic condition, sources of irrigation, availability of water and the impact of different watershed development programmes in the region. The overall response to these questions was good, i.e. people responded with specific answers to most questions, although some people could not answer a few of the questions.

The survey enabled certain broad generalizations about the watersheds and their current status. Amble-Waghapur-Rajewadi along with Tekwadi and Naigaon-Malshiras watersheds are part of the groundwater overexploited area. Tekwadi has a maximum number of wells / bore wells among the five watersheds. The survey, supported by GGP's survey of wells in the region indicates that there are at least 1500 wells and bore wells in the Naigaon-Malshiras watershed. The survey also brought out specific issues - Pimpri

Watershed	Village	Sample families
Amble	1. Amble	14
	2. Waghapur	4
	3. Rajewadi	5
Tekwadi	1. Tekwadi	25
Pimpri Pandeshwar	1. Pimpri	10
	2. Pandeshwar	12
Pondhe	1. Pondhe	29
Naigaon-Malshiras	1. Naigaon	5
	2. Malshiras	10
	3. Romanwadi	9
	TOTAL	**123**

Table 4.9: Details of number of families surveyed per village

Pandeshwar watershed has a problem of salinity and Pondhe is a village where water resources development has not 'reached' the people in any form (this study also prompted the setting up of a community based groundwater management system in Pondhe, on the principles of Pani Panchayat).

4.12.3: Salient findings from the primary socio-economic survey

The main findings from the sample survey of households in the project area are presented below under five broad heads – family matters, economic status-family ownership, water requirement, income sources and impact of watershed programmes. These are presented below.

A: Family matters:

The farmers in Purandhar area were divided in three groups, depending upon land ownership. The three groups are large farmers having land more than 3 acres, (*Figure 4.46*) medium farmers have land between 1 and 3 acres and small farmers having less than 1 acre of land. Surprisingly, it is seen that more than 70% farmers belong to the first group, having lands more than 3 acres. Some 19% farmers belong to the medium farmer category and 9% farmers belong to the small farmer category. There were only 2% landless families surveyed during the study. Due to the small size of the sample, these may not represent the actual distribution, but a trend of large farmers dominating the area is clearly obvious. All the villages like Amble, Waghapur, Malshiras, Pondhe and Romanwadi have large land holding families. On the other hand, villages like Naigaon and Tekwadi have medium and small land holding families. The average family size in this area is between 5 to 6 persons per family.

This area is a drought prone, low rainfall area and therefore most farmers own some source of water like a well or bore well. The larger land-holding may actually indicate the boom in the number of wells – farmers are not constrained by the size of land to sink and drill dug wells and bore wells as the water level in the aquifer drops. Due to the erratic nature of rainfall, irrigation is required during the monsoon season too and therefore around 66% farmers have partially irrigated land where they can provide water for at least one crop as and when required. There are 22% farmers having totally irrigated land and only 12% farmers have only non irrigated rain fed land. It is interesting to note the close match between irrigation land types and the land holding of farmers – a close match indeed. The major source of irrigation is wells and/or bore wells. In the five watersheds, among the 123 families surveyed, 98 families have at least one well which is about 80% of the total families. There are 15 families having one or more bore wells which is about 15% of the total families. No farmer mentioned a source of irrigation other than wells and bore wells.

Flood irrigation technique used in Purandar

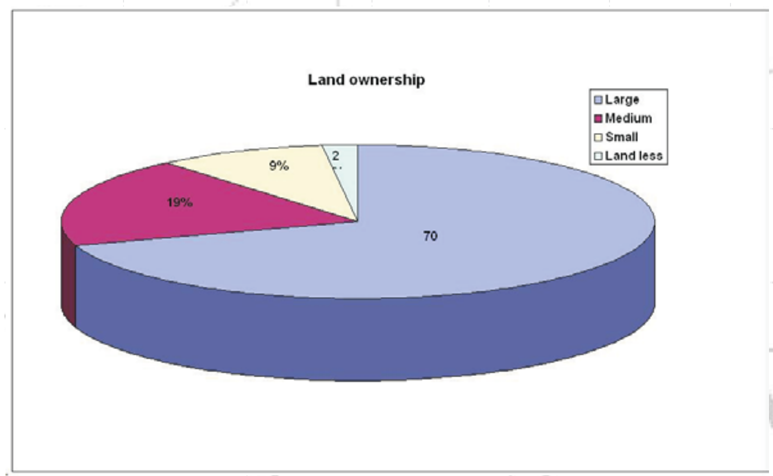


Figure 4.46: Land ownership pattern in the five watersheds (as per the ACWADAM's socioeconomic survey conducted in Nov-Dec 2007)

B: Economic status and family ownership:

The type of house gives some idea about the economic status of the family. In this area, around 46% families have ;pucca' (properly constructed) houses. There are 17% families having partially constructed of 'ardhpucca' (half constructed) houses and 24% families have 'kuccha' (crudely constructed) houses,*(Figure 4.47).* Almost half the surveyed families live in properly constructed houses but there is very little awareness about the need for proper sanitation. Only 28% families have latrines, and the remaining 70% families practice open access sanitation. Villages like Pondhe, Naigaon, Malshiras, Pimpri and Pandeshwar have less than 10% households having toilet blocks, which is low by any standards. Farmers in these villages have spent thousands of rupees on purchase of land and/or on construction/repair of houses, but have hardly spent anything on the construction of latrines.

Toilet and a biogas plant constructed by an individual farmer

Every household in this area has cattle (cow/buffalo) or livestock (goat/sheep) and/or poultry, mostly chicken. Almost 80% families have livestock. Among the livestock, 61 families have cow/buffalo or bull, 60 families have goat/sheep and 59 families have poultry. Being a drought prone area, animal rearing is looked upon as an additional income generating activity in this area.

In this survey it appears that there is some increase in family wealth during the last 10 years. Most families have ploughed back such income into various forms of activities. For instance, around 28% families have bought some livestock, 9% families have invested in well digging, 10% families have invested in bore well drilling and 25 % families have repaired their houses.Some 6% families have bought new land in the last 10 years. In villages like Naigaon and Rajewadi, no family was reported to have purchased anything, neither livestock, nor have invested on house or well digging, during the last 10 years. This could be because of the small sample size surveyed in the two villages. In all the other villages, people have invested in some or the other category which indicates rise in the economic status of the family. Among all the five categories, people have invested more on livestock possibly because of the WSD activities undertaken by GGP, whereby more grass or fodder is available for the animals, which in turn has reduced the pressure of purchasing fodder from other areas. This livestock is also used in the lean period, when the farmer can get some money by selling the animal. Village Amble and Pondhe top the chart of purchasing of livestock during the last 10 years.

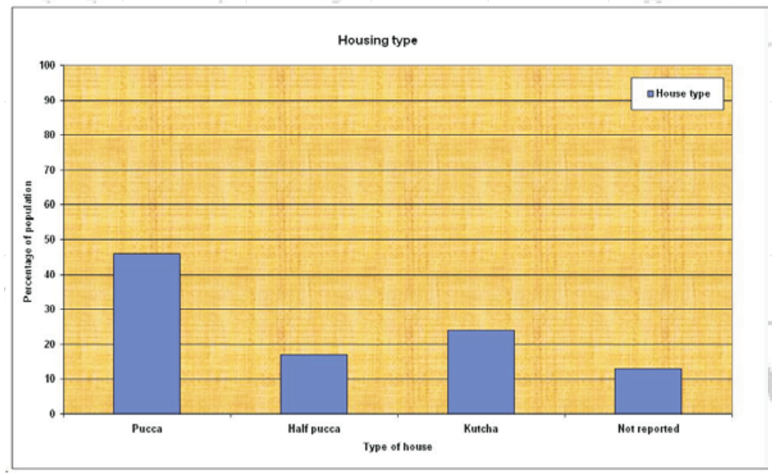


Figure 4.47: Plot for housing type in five watersheds (as per ACWADAM's socioeconomic survey conducted in Nov-Dec 2007)

C: Water requirement:

The water requirement in these 10 villages is different. On an average, the daily requirement is around 200 lit. per family, which includes water for drinking, cooking, washing, bathing and for livestock. In the villages like Pimpri, Pandeshwar and Romanwadi the demand of water is more than 250 lit/day/family, which is higher than in the other villages. This could be because of large number of milking animals owned by the farmers. Most villages require 170 to 200 lit of water per day/per family. In many of the villages like Amble, Pimpri, Pandeshwar, Waghapur, Rajewadi and Pondhe, there are government supported drinking water supply schemes. If required, they use water from their own well/bore well for supplementing drinking water provision and for maintaining livestock. A few families living in isolated areas get their water from wells. Villages like Tekwadi, Naigaon and Malshiras, do not have access to government water supply schemes and therefore people use well water for drinking and domestic purposes.

In this area, farmers need to irrigate their crops for a minimum of 5 months. Around 80% farmers use wells as a major source of irrigation. Some 20% farmers use both wells and bore wells to irrigate their crops. Some farmers in Amble irrigate their crops for 8 months while some farmers in Pondhe take irrigated crops throughout the year.

During summer months when water levels go down in wells and there is not enough water, people rely on Government water tankers which provide water to the village. In villages like Tekwadi and Pondhe people use water from wells as well as from lakes or streams, whenever available. But mostly from March to June government water tankers are the only source of water for the villagers, in the overexploited villages which dominate the project area.

The overall quality of water is good in all the watersheds except Pimpri-Pandeshwar, where there is a severe problem of salinity. People are so much used to drinking the saline water that 12 out of 22 families mentioned that the quality of water is good. Only 10 families agreed to the fact that the quality of water in the village is poor.

The hand pump is one of the major source of drinking water in many villages of Purandar

D: Income sources:

Around 90% families earn their livelihood through agriculture. Many of these farmers have complained that there is very little profit earned in a year. There is hardly any difference in the income and expenditure. Almost all the farmers spent a minimum Rs. 10,000/- in agriculture, but only 41% have earned more than Rs. 10,000/- in a year; 35% farmers have earned Rs. 10,000/- or less in a year through agriculture; Some 20% farmers did not give figures of their agricultural income and expenditure. On an average, the annual income earned from agriculture is about Rs.18,000/-. The average expenditure incurred upon agriculture is about Rs.10,500/- per year. All these farmers have some income through dairy or poultry which adds to their income, but it became difficult to quantify this income. Some families work as agricultural labour to earn their livelihood. A few of them have stalls or petty shops in the village. The percentage of population engaged in tertiary activities like service or business is quite negligible among the surveyed families.

E: Watershed development programme:

Many episodes of watershed development are apparent in the area. More than 80% people interviewed during the survey have agreed to the fact that the water levels have gone up after the implementation of watershed development programmes. A few farmers in Tekwadi, Pimpri, Pandeshwar and Malshiras disagreed with this. One of the reasons for disagreement on the issue of benefits from watershed measures is because of the imprint of overexploitation on the water resources regime in the region.

Around 40% people believe that there is no change in the cropping pattern but water availability has increased. 35% farmers said that there is a definite change in cropping pattern, before the watershed development programme, farmers used to grow traditional crops like jowar, and bajra. Now, farmers are growing a variety of vegetables, mainly onion during rabi season along with a mix of vegetables like fenugreek, spinach, coriander and a variety of beans on their farms. Some farmers, mainly in Amble and Waghapur are involved in floriculture as they have a good market for flowers in Pune. Farmers in Pimpri village are growing sugarcane (mainly because it is the only salinity-tolerant crop, fetching good returns) while farmers in Pondhe are growing sunflower and 'kardai'. The most significant change that has occurred in the area is the plantation of orchards. Farmers are growing fruit plants like fig, pomegranate and custard apple, which are ideal for the dryland environment. Farmers have earned good profits through these crops. The crop calendar(Table 4.12) is based on the current status of cropping in the area.

Sitaphal is one of the main horticulture plant grown in Purandar

Most farmers believe that due to the successful implementation of the watershed development programme, their own village as well as the adjoining village has benefited. Only farmers of Tekwadi village believe that their village has not been benefited in any way, due to the watershed development programme. Instead the adjoining village, Pisarve, has benefited more. In other villages, people are satisfied with the programme and its results.

Not surprisingly, more than 65% farmers believe that there is no co-ordination between the watershed development programme and the ground water abstraction; they believe that water levels in their wells are progressively declining despite the watershed development programme, as the effects of groundwater over-abstraction override the impact of the watershed programme. In this connection, the survey posed a query on the Groundwater Act (*Maharashtra Groundwater Act, 1993; Maharashtra Groundwater Act – Proposed – 2009*). People in the area have absolutely no idea about the Groundwater Act. Some of them believe that it is a kind of new watershed programme where groundwater will be distributed through some government scheme!

This survey clearly indicates that there is some positive change in the livelihoods of the community. Even the independent survey conducted by GGP confirms the fact that there has been some economic development in this area during the last 10-15 years. This is also evident from the fact that migration was a major problem in this area, say 30 years ago. The migration was mainly seasonal. This problem was even more acute 10 years back due to the acute scarcity of water on account of repeated droughts. Today many farmers are getting leased farms in the irrigated tracts. After the initiatives from Pani Panchayat (GGP), there is a significant change in migration patterns. Today, the percentage of migration per village is 1 to 3 families. Earlier the percentage was more than 15 *(GGP, pers. comm., 2009)*.

4.12.4: Socio economic survey conducted in December, 2008

The second socio-economic survey was a short survey conducted to capture the problems of water management in the area. GGP volunteers along with a few others who are working in the field of water management and have some knowledge of groundwater problems were surveyed- a selective sample. A short two page questionnaire was prepared for this survey. Questions regarding the existing problem of water, it's implications and possible solutions were discussed in this survey. The survey also tried to capture the changes that have occurred (if any) in the social status of the people during the last 10 years. The overall water problems including surface & groundwater, along with the possible practical solutions to these problems, were discussed in this survey. The findings from this survey are narrated below.

Being a drought prone area eastern Purandar is generally water scarce. In the last couple of decades, people in Purandar tried to counter this problem by exploiting groundwater. The unprecedented extraction of groundwater has added to their woes by creating a problem of over exploitation. Today, villages of eastern Purandar are included in the groundwater dark zone by the Groundwater Survey and Development Agency, Government of Maharashtra. Government has implemented a number of schemes in the past which are presently defunct or need serious attention. In Pondhe village alone, there are around 60 (small and large) structures constructed over an area of 900 hectares. Some of these structures are in a bad shape and need immediate repairs. Similarly in other watershed areas, the schemes implemented by the government and other organizations are not fully functional. Generally, the villagers believe that there is a lack of planning and understanding in solving this major issue.

The problem of water for eastern Purandar cannot be solved overnight. The geographical location and the climatic conditions of this area cannot be changed and therefore the water problem of this area can only be solved by proper water management. As the rainfall in limited, the demand of water can be fulfilled either by an appropriate use of existing water resources or bringing the water from outside, the later being expensive and a somewhat impractical solution. In this light, the study sought to understand how people perceived the problem and what they thought would be the best response mechanisms

Month	Jowar	Bajra	Onion	Fodder	Oil seeds	Horti-culture	Flori-culture	Pulses	Vegetables
Jun									
Jul		Rain fall	Rain fall + 4 to 5 times water-ing (if required)		Rain fall		Rain fall + 5 to 6 times water if required	Rain fall	
Aug									
Sept									
Oct									
Nov	4 to 5 times watering					Regular water as per the demand			4 to 5 times watering
Dec									
Jan									
Feb									
Mar				3 to 4 times watering					
Apr									
May									

Table 4.10.:Crop calendar for Purandar

to address the problem.

Following were the broad responses of the people regarding solving the water problem for Purandar:

1. Regulating water abstraction
2. Rejuvenating existing structures- old percolation tanks & bunds.
3. Irrigation through 'Purandar Upasa Yojana' or 'Janai Shirsaee scheme exogenous water
4. Equitable distribution of water or formation of Pani Panchyayats

Many of the villagers agree to the fact that initiatives like Pani Panchyayat can be effective in this area. Pani Panchayats were in existence in villages like Naigaon and Malshiras, which are not functional today due to a plethora of factors (COMMAN 2005). The revival of such schemes may be effective in today's scenario as the groundwater condition is critical and prudent use of water is the need of the hour. Some villagers also believe that water user groups can be developed.

Revival of old Pani Panchayats is a huge task and needs plenty of sensitization among villagers. This can be achieved by aggressive publicity of water management activities, by the use of audio-visual films and posters. Young and popular local leaders can be involved in this activity as and when they are active in village gram sabhas. There is a need to bring a major change in peoples thinking. This can be achieved by practical implementation of modern techniques through experimental plots or farms. (similar to what Mr. Vilasrao Salunkhe attempted back in the 1970s and 1980s, including the Naigaon Pani Panchayat Experiment).

Government of Maharashtra has recently introduced a new scheme called "*Purandar Upasa Yojana*". Under this scheme, the waste water from Pune city is treated and piped to some villages in Purandar. Villages like Rajewadi, Amble, Waghapur, Pondhe and Tekwadi are the villagesthat may be benefited through this scheme. Initially, people were quite enthusiastic but lately they are somewhat skeptical. They feel that this scheme will benefit only 20% to 30% of the farmers who are financially well off and have lands adjacent to the water outlets of the scheme. A few villagers are also worried about the quality of this water, as this is a treated wastewater, and they feel that it may contaminate aquifers (if treatment is not sufficient). The impact regime includes 28 villages and two towns of eastern Purandar, hence the concern is well-founded. Moreover, the farmers of this area will have to buy this water at cost and only rich or large land owners may be able to afford to pay back, considering the income levels from current agricultural productivities. There is another fear of increase in the cash crops like sugarcane or banana by a chosen few, after the water is available, and therefore people are not clear about the benefits of "Purandar Upasa Yojana". However in a drought prone area like Purandar people are willing to gain water access through any means. A few villagers also suggested bringing water from the Gunjavani river or the Veer dam, which are in the western part of Purandar taluka.

Minor irrigation structure constructed in Purandar

4.12.5: Changes during the last 10 years:

1. Water availability: In Purandar, till the early 1990's, groundwater use was limited but after the mid 1990's the boom of drilling of bore wells caused serious overabstraction of groundwater and today the aquifers remain overexploited. Farmers have dug bore wells as deep as 300 to 400 ft (more than 100m.). Despite intensive watershed development including percolation tanks, check dams and other soil-water conservation measures, the groundwater abstraction rates far exceeded the natural and artificial recharge quantities, creating an imbalance between the recharge and the discharge of groundwater leading to a long-term crisis in many of the project villages.
2. Water use: Water use in this area has increased manifold. Every farmer wishes to tap the available water in his area. A few farmers also use modern, water efficient techniques of irrigation like drip and sprinklers but their percentage is small as compared to the total population of the area. In Pondhe village, villagers have come together and have formed water user groups under the principles of Pani Panchayat. This initiative is being looked upon as one of the models to tackle the complex water crisis in the region.
3. Cropping pattern: Until about 1990 – agriculture was predominantly rainfed and kharif was the main season of cropping. From 1990 to 2000, farmers were engaged in mixed cropping as they grew cereals along with different vegetables. Jowar, bajra and onions were the main crops then. Post 2000, farmers tend to grow one crop like tomato or onions or flowers on a large scale, and therefore, marketing addition to the vagaries of water, the economics is largely determined by market fluctuations. If the market prices slash then farmers have to bear heavy losses. (In 2006-2007, due to bumper crop of tomatoes, many farmers incurred severe losses..the market crashed and tomatoes were dumped on the roads!) Wheat has become a dominant crop for the rabi season in many of the villages, especially following good rains. Horticulture is also coming up in a big way as many farmers are planting trees like custard apple, figs and pomegranate and intending to secure fixed incomes over the longer-run.

4.12.6: In conclusion

The socio-economic survey in the project area highlighted the importance and the need for a sustained, focused programme on groundwater management, to mitigate effects from the three sets of problems in the overall typology of groundwater resources in the region. Whether it is the problem of overexploitation, groundwater salinity or lack of systematic groundwater resources development, the integration of science, technology, sociology and economics will play a crucial role on the sustainability and equity of water resources in the region. The problem is far more challenging considering the status of groundwater resources in these 15 odd villages. Hence, it would make sense to carry forward the Pondhe model to its logical outcome and seek

Check dam in Pondhe

Mrs Kalpanatai Salunkhe addressing villagers in Purandarduring the inauguration of the AWS in Naigaon

possibilities of scaling it up to other villages in the region, albeit with a different flocus.

4.13: Pondhe Initiative

Clearly, the best formula for developing groundwater management in Indian villages is to combine good groundwater science with strong social skills in order to establish a balanced mode of groundwater use. Two levels of balances are important in this regard:

1. The balance between recharge and discharges from the aquifer.
2. The balance between annual and long-term availability and the demand for water equated through a sustainable supply system

In order to establish such balances, detailed studies of groundwater at the village level are desired. So is a process of strong social mobilization of the community. The process of understanding aquifers in a village involves mapping the geology of the area in great detail. This is not just a desired goal in the process of understanding groundwater but is a necessary one as rock types and rock structure in an area are the basic framework in which groundwater accumulates and flows. The process of 'mapping' may draw on tools like remote sensing and geophysics but again the output must be a geological map rather than a geomorphological one. Once such a geological picture emerges, it becomes imperative through other hydrogeological indicators like groundwater levels, aquifer properties and even hydrogeochemical information to map out individual aquifers in the area, how these aquifers relate to the watershed geometry and whether or not these are interconnected with each other. The characterization of aquifers and wells that tap them is important in understanding recharge-discharge balances and also provide tools in planning well-use. This is the broad process of aquifer mapping that was undertaken in Pondhe village, defined as a separate 'type' during the typological classification of study watersheds. Pondhe watershed falls under the 'unexploited' groundwater type, with a clear need for managing the aquifer system through a community effort.

Pondhe village is one of the few "non groundwater overexploited" villages in Purandar, although it falls within an overexploited block (declared by the State Agency – GSDA). Clearly, Pondhe poses a unique case, wherein it is caught between the conditionality of a notified 'overexploited' situation and the lack of any direction in moving towards a water management system. In this light, ACWADAM's study has proven significant in attempts to establish a community based groundwater management in Pondhe. Initially, some 30 wells were identified by the GGP team for this exercise. After various meetings with the villagers 16 groups were formed in early 2007. These groups were registered with the Tahsildar office in Saswad, the taluka headquarters. Moreover, the ACWADAM study for Pondhe helped GGP obtain recognition of its 'non groundwater overexploited' status by the State Authorities.

Pondhe village

4.13.1: Background

The integrated land-water-energy model that is being envisioned in Pondhe village of Purandar taluka in Pune district is unique in more ways than one. For one, it is a complete "community based" resource management initiative bearing the formal approval from the Gram Sabha of Pondhe village.

The development of registered user groups, the backbone of the Pondhe initiative, has a long history. The process is rooted in the robust perspectives offered by Pani Panchayats developed by Late Shri Vilasrao Salunkhe for the drought prone areas of Purandar. The Pani Panchayat experiment is unique as it is perhaps the only experiment which included supply and demand side aspects of land and water management, at the same time de-linking land and water rights as a means of achieving equitable distribution of water to a community; however, the greatest threat to the initiative remains in the form of 'regional overexploitation' patterns that have played out in such areas (*COMMAN, 2005*). The Pondhe model uses an upscaled version of the Pani Panchayat experiment in a situation where watershed, aquifer and community boundaries are coherent with each other. This scale of operation is expected to overcome the threats imposed by the regional externality and imbibe a greater sustainability factor to the model.

4.13.2: ACWADAM' role in this initiative

The user group development in Pondhe is an outcome of a lengthy process of resource evaluation, participatory planning and social mobilization involving many partners. ACWADAM, through its detailed hydrogeological studies, provided a description of the aquifers in the area. ACWADAM delineated the aquifers and prepared thematic maps improved process planning in Pondhe. Pump tests were conducted on selected wells to estimate the aquifer and well parameters. Along with this, the recharge and discharge zones were identified for the effective development and management of groundwater. A broad watershed treatment plan was also provided to GGP during the course of this study. However, the salient outcome of the study led to the structuring of well-user groups and to a plan of how water will be used from each of the identified wells – through user groups. *Figure 4.48* indicates the recharge and discharge zones of Pondhe based on the initial studies in the area.

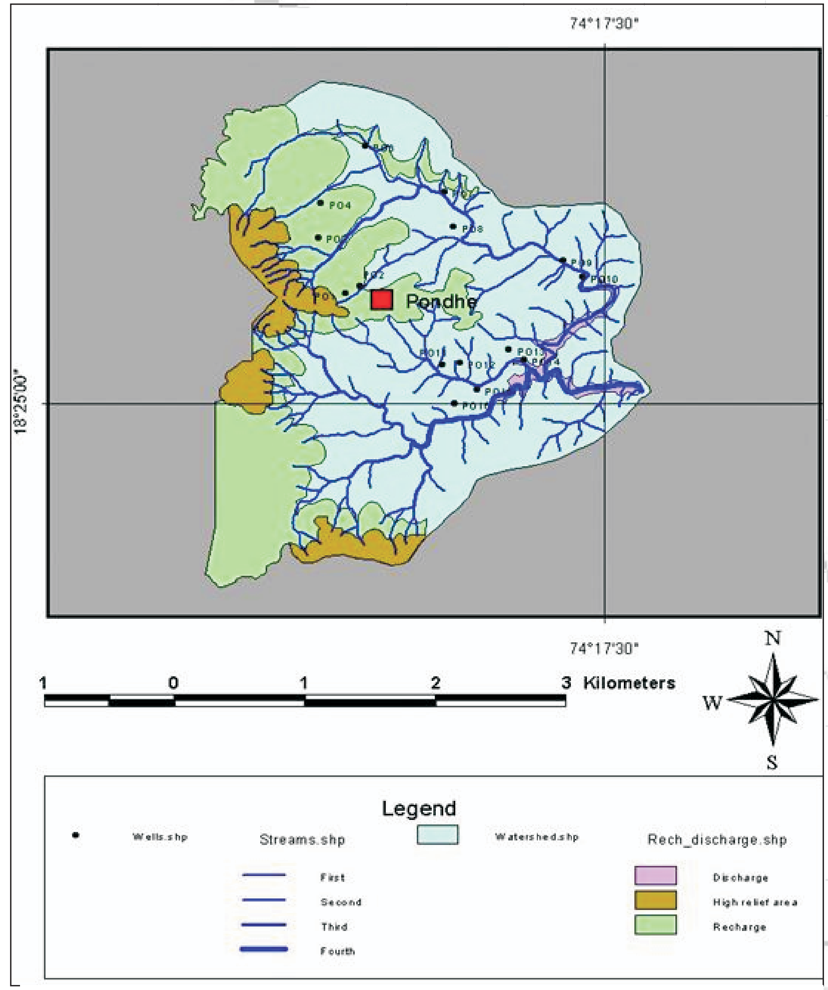


Figure 4.48: Drainage map of Pondhe along with the recharge and discharge zones

The Pondhe water balance

During an average rainfall year (350 mm)

- Water allocation per family = 5000 m3
- Each family can irrigate 1 ha only

This means the requirement is 5000 m^3 per hectare
For 140 families, the irrigated area works out to 140 ha.

The total requirement, for protective (kharif) irrigation and rabi irrigation is 700000 m^3

This means an average of about 77 mm from the Pondhe aquifer

[4]This also implies that a minimum of **77 mm of recharge would be required for the Pondhe aquifer each year.**

Digging of new dug well in Pondhe

.4.13.3: The initiative

GGP had divided the Pondhe watershed in three sub watersheds; A, B and C. In sub-watershed A, eight groups were formed. In sub-watershed B, two groups were formed while in sub-watershed C, six groups were formed. Watershed C was a totally new area where there were not many dug wells prior to GGP's intervention. ACWADAM's hydrogeological studies recommended maximum and minimum depths for each well in order for operationalising the respective well-user groups – many of which were possible through a support for well-construction made available through a grant from Arghyam to GGP. Most wells were partially penetrating, so recommendations included deepening plans; sites for the construction of three new wells in sub-watershed C were also identified during this process. All the wells have been deepened as per ACWADAM's recommendations. Hence, the current study was able to provide a blueprint for deepening existing community wells on the basis of the mapped aquifers. *Table 4.11* gives the recommendations of ACWADAM for the well-user groups formed in Pondhe.

Today in Pondhe there are 9 groups are in operation. A total of 83 farmers have already formed the water user groups. In 2009, there was a delay in monsoon and the crops needed some protective irrigation. Farmers are collectively irrigating 24 acres of land through 10 dug wells. The main crops grown in the area under protective irrigation are onion, vegetables and flowers. Some farmers are also irrigating bajra and pulses. *Table 4.12* gives details of the water user groups currently operational in Pondhe.

The major task left in this initiative is of resolving the “Energy” crisis. MSEB

Well No.	Name of owner	User Group Name	Recommended maximum depth	Recommended minimum depth
1	Ramdas Bapurao Waghale	Vairanginath (1)	10.5mts	8mts
2	Poapt Baburao Waghale	Vairanginath (1)	15 mts	10mts
3	Vasant Narayan Waghale	Mhasoba (1)	14 mts	11mts
4	Vasant Narayan Waghale	Mhasoba (1)	15 mts	9.9mts
5	Mahadev Bhikoba Waghale	Dnyaneshwari	15 mts	11mts
6	Ramdev Dagadu Waghale	Dnyaneshwari	15 mts	11mts
7	Nathu Maruti Taskar	--	13 mts	10mts
8	Nana Sona Gaikwad	--	16 mts	12mts
9	Jaisingh Sarjerao Waghale	--	16 mts	13mts
10	Kashinath Baba Waghale	--	13 mts	10mts
11	Sonba Khandu Kokare	Jai Malhar	15 mts	12.5mts
12	Bapu Gunaji Kokare	Jai Malhar	12 mts	10mts
13	Ramchandra Baba Waghale	Bhairavnath	15 mts	12mts
14	Laxman Bhikoba Jadhav	New well	15mts	12mts
15	Sadhu Bhima Waghmode	New well	12mts	10mts
16	Narayan Biru Kokare	New well	15mts	12mts

Table 4.11: Details of the groups formed in Pondhe under community based GW management scheme

Crops irrigated through different groundwater user groups in Pondhe

(Maharashtra state Electricity Board) is still not in a position to provide three phase connections to any farmer in Purandar, which has caused a major hurdle in this whole exercise. Diesel pump are not a feasible solution as the energy requirement is large. GGP studied the feasibility of alternative energy sources, but a longer lead time would be required for such operationalisation. GGP is following up the matter of electricity connection with the Electricity board at the Minister level and there is a hope of lifting a ban on three phase connections if the user groups are in place and the community based groundwater management is attempted in Pondhe.

4.13.4: Implication of Pondhe initiative

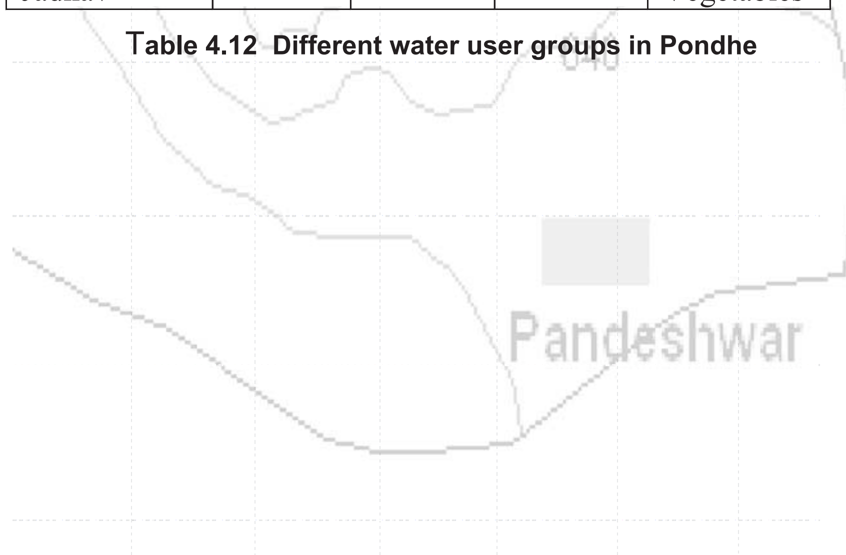
The integration of well-user groups will obviously be into a larger "Society" but this will only evolve if a small group of 14 user groups demonstrate a complete process of how the Pondhe model will function. The user groups will need to run this system as a group as per the rules and regulations of a registered agreement which can be presented as a stand alone example of community based groundwater management in a drought-prone dry land area. If this initiative is implemented successfully, it would enable Pondhe village to be self reliant by supporting the villagers in aquifer-based water management, equitable distribution of water and management of water demand through crop management. This would have three-pronged impacts.

1. The village becoming water self reliant.
2. A demonstration model for water self reliance in a drought-prone village from a rain-shadow region.
3. The potential to impact the government water policy.

The last is especially important in veering policy thinking away from the present supply driven, generic management to a more complete supply-demand management including aquifer-based management, at the same time attempting to vest control for collective decision making through local community institutions. The potential for replication of such a model in other drought prone dry land areas of India, as an example of community based demand driven groundwater management system, is huge.

Name of the farmer	No. of farmers in the group	Pump capacity	Irrigated land	Crops grown
Laxman B. Jadhav	7	5 HP	3 acre	Flowers, Onion, vegetables
Bapu G. Kokare	10	5 HP	5 acre	Vegetables
Narayan B. Kokare	10	10 HP	3 acre	Vegetables, Bajra
Sadhu B. Waghmode		8 HP	2 acre	Bajra
Poptrao B. Waghale	15	5 HP	2.5 acre	Flowers, Onion, Vegetables
Vasantrao N. Waghale	16	5 HP	2.5 acre	Flowers, Onion, Vegetables
Sonaba K. Kokare	10	7.5 HP	2 acre	Flowers, Vegetables
Nathu M. Taskar	9	5 HP	2 acre	Pulses, Vegetables
Namdeo B. Jadhav	6	3 HP	2 acre	Onion, Vegetables

Table 4.12 Different water user groups in Pondhe



4.14: Remote sensing

Remote sensing is method by which information (about an object or area) is gathered without coming in direct contact with the object or area. There are different methods of collecting information but use of aerial photographs and satellite images is most popular. Today, with the advent of technology, more and more people use satellite imageries for getting precise information about an area. With high resolution images information about geological features, cropping pattern, vegetation cover, land use pattern etc. can be obtained. This data is also useful for undertaking temporal analysis, where more than one image is obtained for the same area over different time periods.

In this three year study, four satellite imageries were procured by ACWADAM from the National Remote Sensing Agency, Hyderabad. The details of the images are given in *table 4.13*.

The images represent the winter or rabi season as that is the period of the year when one can get cloud free, clear images for areas in south-western India. Also this is the time when farmers irrigate lands and groundwater use is at a maximum. Therefore, three out of four images are for the month of February. ACWADAM wanted to study the changes in the cropping pattern during the last 15 years. Through the socio-economic surveys, it emerged that 1997 was part of the period when groundwater abstraction was at its peak. The image for February 2000 was not available, so an image of April 2000 was procured instead, which gave some indication about the summer cropping in the drought prone area as well. ACWADAM was also keen on procuring the data for Jan-Feb 2007 or 2008 but the National Remote Sensing Agency showed its inability to supply the cloud free data for the period and therefore the team had to settle with these two sets - 2004 and 2009 data. The images of February 2004 and 2009 gave an idea about the present cropping scenario in Eastern Purandar in contrast to the situation in 1997.

This satellite data was used for two main purposes. First, it was used for locating the lineatments (fractures zones) in the field, which fed into the geological mapping exercise. There are a number of lineaments observed in Pondhe village and marking those on the map was easier using remote sensing data, the advantage being that many of these were already identified in the field prior to procurement of images. The images made extrapolation of these lineaments easy. This data was also used to prepare land use maps for different watersheds. A land use map was prepared for Pondhe village using remote sensing data where three types of land are identified: barren land, irrigated land and irrigable land. *Figure 4.49* indicates the land use map for Pondhe watershed prepared using remote sensing data procured in February 2004.

Image data	Type of image
February 2009	IRS P6; LISS III
February 2004	IRS P6 – PAN – LISS merged
April 2000	IRS 1D – PAN – LISS merged
February 1997	IRS 1D – PAN – LISS merged

Table 4.13: Type and time of satellite data

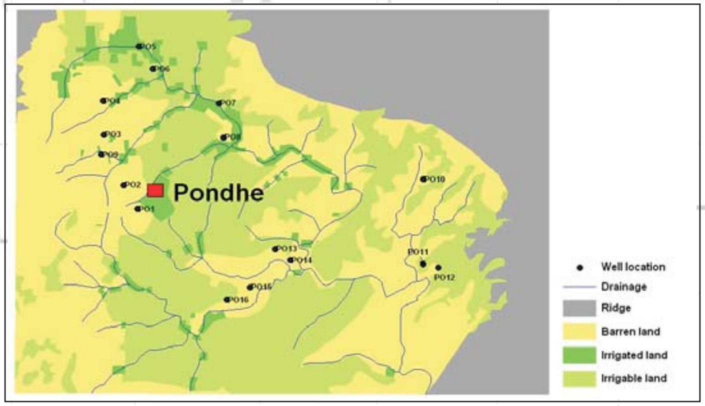


Figure 4.49: Land use map for Pondhe watershed using remote sensing data

4.14.1: Temporal analysis

Remote sensing data was also used for understanding the changes in the cropping pattern, especially with regard to the problem of groundwater overexploitation for the region. For this analysis, two images were selected; image for February 1997 and for February 2004. Both the images are for the same month but there are a lot of changes observed in the two images during the seven year span. *Figure 4.50* indicates the changes in land use during the two different seasons.

In February 1997, the proportion of irrigated crop as compared to the February 2004 image, is significant. It is estimated that nearly one third of the total area was cropped under Rabi cropping – most being groundwater irrigated. Significant amount of water can also be seen in the water harvesting structures in the image. In contrast, in February 2004, the amount of irrigated crop has gone down significantly and can only be seen in a few red patches – negligible at most. Most of the land is barren indicating black or grey colour in the image, corresponding to the non-cropped surfaces – soils and regolith respectively. A gross analysis of the five watersheds has been attempted using software like Geomatica 10 and Map Info Professional 8.5. The results indicate that there is a significant decrease in the cropped area from 1997 to 2004. One reason for this decrease is groundwater depletion on account of overexploitation. Another reason could be the low rainfall in2003 as compared to rainfall in 1997. There is a significant decrease observed in the cropped area in the four overexploited watersheds. There is a marginal increase in the cropped area in Pondhe watershed. *Table 4.14* indicates the increase or decrease in the cropped area in the five watersheds.

Watershed	Increase or decrease in cropped area in % in February1997 and February 2004
Amble	Decrease by 89.73%
Tekwadi	Decrease by 87.9%
Naigaon	Decrease by 89.13%
Pimpri-Pandeshwar	Decrease by 75.93%
Pondhe	Increase by 3.57%

Table 4.14: Increase or decrease in the cropped area in the five watersheds

This summary analysis of the changes to cropping from the remote sensing data also confirms that the Pondhe watershed is not a part of overexploited region. It clearly shows an increase in the cropped area, whereas there is a distinct decrease in cropped area in the other watersheds during the same period.

The April 2000 imagery is for the summer season when there is very little

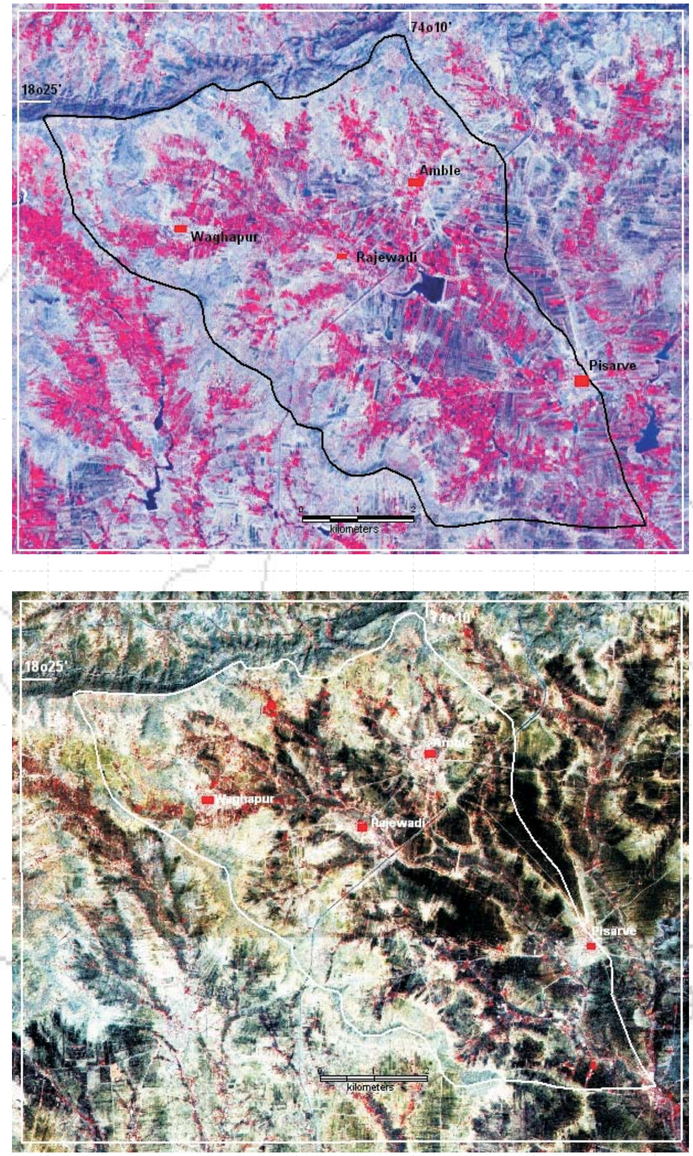


Figure 4.50: Changes in land use during February 1997 and February 2004

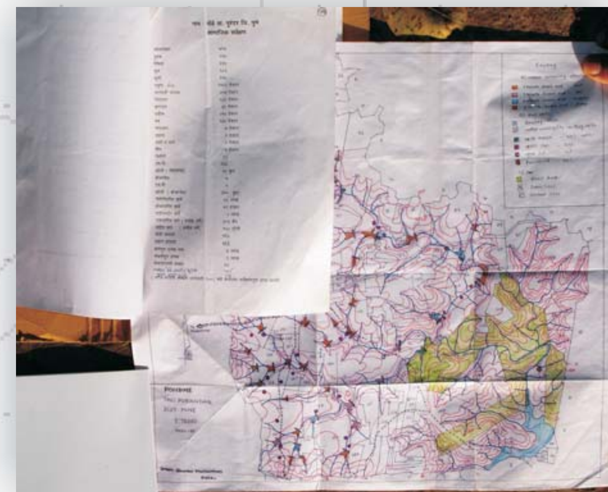
cropped area in Purandar. The cropped area is seen in small patches around some of the wells.(*Figure 4.51)*) Farmers in eastern Purandar usually grow fodder in this season which is irrigated by the wells.

Figure 4.51: Image for Amble watershed for April 2000

Chapter 5: STRATEGY FOR THE FUTURE

5.1: Summary of results

ACWADAM has conducted a detailed hydrogeological study in the 10 villages of Purandar for the last three years. During this study, systematic has been generated. A time series data for groundwater levels, base flow, weather parameters, groundwater quality etc. is now in place for three years. This data can be used by GGP, the implementing agency for better implementation at the field level. Earlier this study has meant some degree of perspective and capacity building of GGP, part of which was evident during the site selection of newer and redesigned community dug wells in Purandar.



Plan for Pondhe village

ACWADAM has used this data in understanding the aquifer characteristics and calculating potential recharge in the four watersheds as well as the radius of influence of each well. The information generated from the current study also has the potential to develop water balances for the three typologies evolved for Purandar. ACWADAM intends to develop detailed water balances in the coming year as an additional scientific tool for decision support, both on the ground and within the policy advocacy framework. At the same time, some estimates on potential recharge have been derived for different watersheds, on the basis of average specific yield values, obtained in case of the respective aquifer systems. The estimates take into consideration factors like the watershed area (obtained from the watershed map), the effective shallow aquifer area (geological map), thickness of the aquifer (hydrogeological information, including well-logs, cross sections etc.), specific yield (pumping tests) and storage capacity of the aquifer (product of aquifer surface area, aquifer thickness and specific yield). The potential recharge equals the maximum storage capacity of the aquifer, when such aquifers are completely desaturated (in most watersheds aquifers in the overexploited typology remain desaturated). *Table 5.1* indicates the potential recharge calculations for the four watersheds.

Among the four watersheds, Pondhe has the maximum potential recharge (50 mm.), which is 14% of the average annual rainfall (350mm. for Pondhe). Tekwadi, Amble and Naigaon watersheds have 41mm, 43mm and 33 mm of potential recharge capacity of the aquifer respectively. This indicates that less than 10% of the rainfall can be converted into recharge in the three watersheds, if maximum potential for recharge needs to be achieved.

Watershed	Watershed area (Km^2)	Aquifer surface area (Km^2)	Aquifer thickness (m)	Specific yield of aquifer (fraction)	Storage capacity of aquifer (m^3)	Potential recharge (as % of normal rainfall)
Amble	46.88	16.19	7	0.005	113348	8.6% (43 mm.)
Tekwadi	20.45	6.69	7	0.005	46854	9.11% (41 mm.)
Naigaon	54.78	12.22	7	0.01	85584	8.25% (33 mm)
Pondhe	9.03	5.67	10	0.008	56717	14% (50 mm.)

Table 5.1 indicating the potential recharge of the four aquifers

The maximum radius of influence is calculated for the wells in the study area using a simple model based on the BGSPT Simulation Routine (Barker et al 2000). The maximum radius of influence in metres is calculated as a function of Transmissivity and Pumping Duration, the model using an average storage coefficient of 0.001 and being pumped at a constant rate of 450 m^3/day (313 litres per minute) approximating the average rate of pumping for wells in the area. The transmissivity of the well is considered using BGSPT results. *Table 5.2* indicates the radius of influence for different wells as a function of transmissivity and duration of pumping.

Transmissivities in basalts are quite variable (Deolankar, 1980; Kulkarni et al, 2000). The transmissivity in Purandar varies across the three typologies. In Amble and Tekwadi, the transmissivity values are between 50m^2/day and 100 m^2/day which indicates that after 24 hours of pumping the radius of influence is less than 50m. Similarly, Pondhe aquifer show transmissivity values between 50 m^2/day and 100 m^2/day with occasional well like PO8 having transmissivity values above 180 m^2/day. In Naigaon watershed, the transmissivity values are between 1 m^2/day and 5 m^2/day indicating less than 20 m of radius of influence after 24 hours of pumping. In Pimpri Pandeshwar, the transmissivity is more than 100 m^2/day and therefore the radius of influence for the wells in this area is around 100m. On an average aquifers in Amble, Tekwadi and Pondhe have transmissivity between 50 m^2/day and 100 m^2/day which indicates that the radius of influence of all these wells in less than 50 m even after 24 hours of pumping. In Naigaon, because of low transmissivity, the radius of influence is less than 20m. while in Pandeshwar due to high transmissivity the radius of influence is above 100m. Government has a guideline of 500m. as a radius of influence for drinking water wells, which remain too gross to be implemented for such areas.

Transmissivity m^2/day	Time of pumping (in hours)			
	2.5	**5**	**10**	**24**
1	7.5 - 10	7.5 - 10	7.5 – 10	10 - 20
5	10 - 20	10 - 20	10 - 20	10 - 20
10	10 - 20	10 - 20	10 - 20	10 - 20
50	20 - 50	20 - 50	20 – 50	20 - 50
100	20 - 50	20 - 50	20 – 50	20 - 50
500	50 - 100	50 - 100	50 – 100	100 and above

Effects within the aquifer studied over one day from start of pumping

Table 5.2: Radius of influence for wells as a function of transmissivity and duration of pumping at fixed pumping rate (313 lpm) and storage coefficient (0.001)

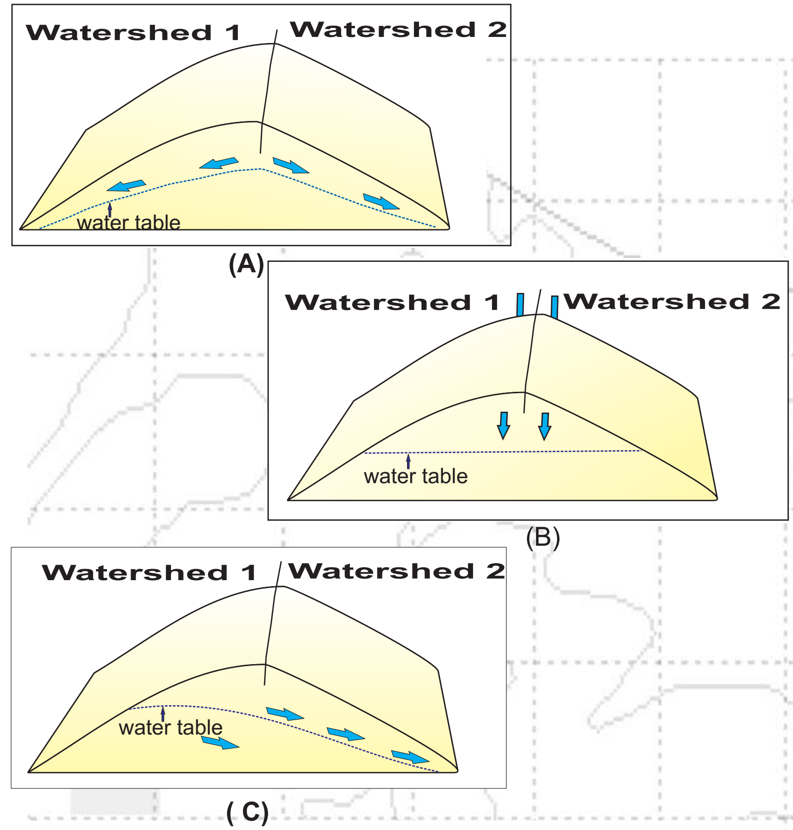
5.2: Aquifer systems in Purandar

The regional map gives a perspective of the different aquifers in the region. It is possible to demarcate aquifer boundaries based on patterns of groundwater flow lines. The groundwater flow lines at watershed boundaries can be classified into four different classes, based on their geometry *(Figure 5.1)*. Of these three typical classes, the patterns represented by *Figure 5.1(C)* is not observed anywhere in the study area. Therefore, no groundwater flow across watershed boundaries; watershed boundaries can be considered coherent with underlying aquifer boundaries at these locations (*Figures 5.1 (A) & (B)*). In other words, watershed boundaries can be recharge boundaries, but not discharge boundaries. Through flow across these boundaries can be neglected.

Watershed boundaries, as described above, help define the lateral extension or limits of aquifers. The vertical boundaries are defined by the geology – mainly by the vertical lithological sequence of basalts, in the present case. In a vertical sequence, the aquifer boundaries can be identified with the knowledge of regional geology of the project area – mainly zones of poor hydraulic conductivity or permeability. Geological studies revealed that the project area consists of rocks arranged in a sequence as shown in *Figure 2.3*. Vesicular Amygdaloidal Basalts (VAB) are permeable and possess significant storage capacity. When exposed at the surface, the upper portions of the VABs, form good locales for recharge – recharge areas. Their transmissivity is also significant, although it may vary from place to place. This makes the VAB the main aquifer type in the project area – capable of storing groundwater. The Compact Basalt (CB) possesses some hydraulic conductivity (permeability) but limited capacities of storage. Most of the storage and transmission of groundwater in the CB occurs in its upper fractured portion, in close contact with the overlying VAB. Largely, the CB being impervious, facilitates discharge of groundwater to the surface, whereever it comes in contact with the upper VAB. *Figure 5.2* is a conceptual diagram showing the cross section of basalt units from the project area. The vertical boundaries of aquifers in the area, can be considered to be within the compact basalts (CBs), at depth just below the upper contact of a CB with the (overlying) VAB.

A combination of the lateral (watershed) boundaries and the vertical (lithological) boundaries implies a system of nine aquifers, deciphered on the basis of ACWADAM's hydrogeological study (*Refer Figure no. 4.10*). The Pandeshwar aquifer is different in that it has large storage capacity and limited transmissivity. Hence, there are 8 basalt aquifers and one alluvial aquifer in the project area under typology 1 and 2. On similar lines, there are two main aquifers in Pondhe (typology 3).

ACWADAM has delineated the aquifers in Pondhe and demarcated the recharge and groundwater discharge locales in the Pondhe watershed. Pump tests were conducted on all the wells selected for water sharing. GGP needs



Figures 5.1 (A), (B) & (C) Groundwater flow lines with respect to watershed boundaries

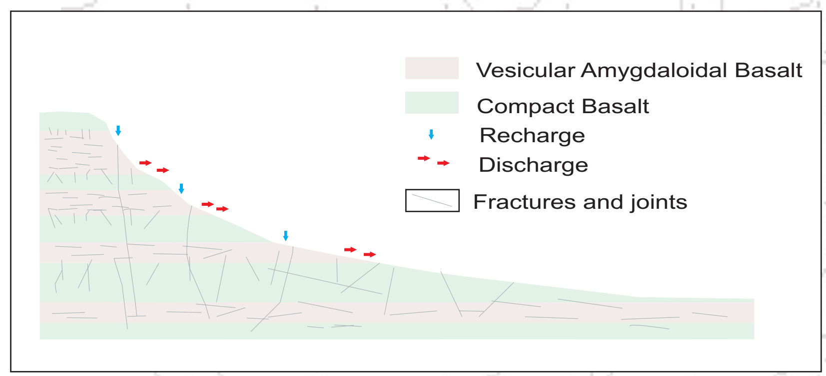


Figure 5.2: Cross section of Basalt Units From Study Area

effectively implement the community based groundwater management scheme as early as possible; data from this study clearly forms a basis for fine tuning the model of water use and for making informed decisions on changes to the rules and regulations, if and when envisaged. GGP could implement a few pilots on the ground, as a starting point so that it will have a positive impact on the community. Such pilots in turn could bring large parts of the community under this process, not only in Pondhe, but also in adjoining areas. Some of the specific interventions that are recommended for each typology in Purandar are presented below.

5.3: Recommendations

The footprint of watershed development in eastern Purandar is quite strong. Drainage line structures abound and there is little scope for construction of additional percolation tanks, masonry bunds or other such water harvesting structures. The soil conservation work, except in patches, keeps getting obliterated; so, there is scope to undertake such work, especially in the upper reaches of the watersheds, which remain largely deforested too. The communities in different project villages understood the limitations of putting new drainage line structures in place; at the same time, they also felt the need for maintenance of such structures, mainly desilting and repairs. Apart from this overarching recommendation, applicable to the watershed development context, every other response in the area hinges on the situations, defined by the three typologies. The specific recommendation for each typology is given in the following section.

5.3.1: Typology I

Overexploited aquifers is the primary problem under typology 1. Of the 12 villages under the study area, 10 fall under this typology. The scale of the problem under this typology is significant, in terms of the interconnectivity or regional implications. Except for a strong legislative framework, there are few options on offer. In fact, as this study progressed, the Government of Maharashtra was already in the process of revamping the 'Groundwater Act of 1993' with a comprehensive Act that would extend the mandate of legislation beyond the provisions for 'drinking water'. This study and some of the results that were emerging stimulated ACWADAM, GGP and Prayas to bring certain suggestions to the notice of the Authority involved in preparing the Act, including the Ministry of Water Resources of the State Government (Kulkarni, 2007: Note to the GOM regarding groundwater legislation in the State). The final recommendation in the note, especially with regard to over-exploited areas included the following:

The philosophy behind groundwater legislation is clear! The practice of implementing it raises many questions. The process of getting to a practical implementation is VERY UNCLEAR because of the gaps identified and described in brief above. A series of more than one brainstorming sessions in

Check dam in Purandar

Density of wells and bore wells in Tekwadi

this regard is clearly necessary, involving various groundwater experts primarily. For too long, groundwater related decisions have been taken by allied experts like those in the irrigation sector and it is high time to get groundwater expertise to the forefront in bringing in reforms to manage this very important resource. Other expertise can be brought in as allied expertise to groundwater.

On a wider scale, it is necessary to begin a programme on "groundwater management" as separate from watershed, irrigation and other programmes. Such a "state level" programme will include a process that integrates experts and expert institutions (both government and non-government), community and the government. Only if work is carried out with "groundwater" as a focal point within the natural resources framework, will any effective management be possible. In order to achieve this, the following actions are proposed:

- *Strengthen institutions at the village-level and equip them with decision making, because local aquifers are common in Maharashtra and management ought to take place locally, rather than regionally.*

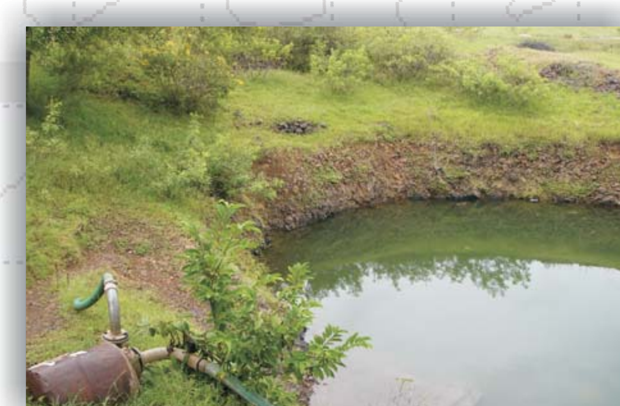
- *Integrate, under a larger umbrella, institutions like GSDA and other experts to work together in developing information and decision support that will be useful at all levels of governance – village, taluka and district.*

- *Bring in practices from existing community based success stories on water and adapt these to local conditions – this will require integration between experts from different disciplines.*

Hence, this study can certainly guide a process of tackling groundwater overexploitation; having said that, it cannot however (as in the Pondhe case) form the only basis for tackling the problem at scale. The attempt by GGP and ACWADAM, would therefore require large support from the Government, especially in protecting the Pani Panchayat initiative on a much larger scale than what is envisaged. Protection of community action, in such areas, through a formal legislation may still be the best possible solution to the groundwater overexploitation problem, something that the new legislation has completely ignored. Nevertheless, even as this report is being finalized, ACWADAM and GGP are making efforts to bring such reforms into the legislative framework, so as to provide a kind of safety net to efforts of community managed systems of groundwater, in overexploited regions.

One of the feasible approaches to revive the diminishing agrarian economy is to strengthen rain-fed agriculture (kharif cropping) through improved systems of community based water management. This will ensure timely 'protective irrigation' to the kharif crops and will not necessarily be as sensitive to the overexploitation effects as those in the rabi season. Hence, GGP could develop strategies for revival of rain-fed agriculture, using protective irrigation practices to ensure kharif productivities, as a clear

Village meeting in Purandar



Groundwater sharing through user groups is being attempted in Pondhe

strategy under this typology and rainfed farming.

5.3.2: Typology II

This typology represents the problem of inland groundwater salinity. ACWADAM, through this study has already identified areas in which recharge to this system of aquifers occurs. A separate, dedicated programme to mitigate groundwater salinity is clearly desirable. The time frame for such a programme will also have to be prolonged, considering the fact that the problem itself may have taken long to set in. The current study would be useful in strategizing such a programme and locating zones where artificial recharge to the saline aquifers could be efficiently strategized – especially along the northern and northwestern portions of the area representing typology 2. More specifically, managed recharge, through programmes like 'dug well recharging' is strategically possible under this typology. The proposed 'dug well recharge scheme' of the Government of India, can help facilitate GGP in making a sound beginning towareds managing groundwater salinity under this typology.

5.3.3: Typology III

In Pondhe the water user groups are already registered and a Pani Panchayat at the scale of an aquifer (and watershed) will become fully operational once the energy for lifting water can be provided on an equitable basis to all the water user groups. In fact, Arghyam Trust has already extended support to GGP towards operationalising at least half of the water user groups in Pondhe, wherein dug well construction was the major support component under the grant. This activity was taken up primarily on the basis of ACWADAM's study and some groups have begun to operationalise the system through diesel powered gensets. In addition, the Pondhe initiative was able to generate plenty of interest for the administration in the State. Hon'ble Union Minister for Agriculture, Mr. Sharad Pawar, Hon'ble Minister for water resources, Govt. of Maharashtra, Mr. Ajit Pawar and Hon'ble Minister for Agriculture and Irrigation, Govt. of Maharashtra, Mr. Balasaheb Thorat have shown a keen interest in this initiative and have been kept abreast of developments including the scientific study by ACWADAM. ACWADAM has helped GGP on various fronts, from advocating this issue in front of the funders to the policy makers as well as in lending technical support to GGP during its dialogue with the village. Now GGP needs to push for a more concrete solution to the energy issue at the earliest and implement aquifer management in the village of Pondhe.

Apart from specific recommendations as part of the typology development, ACWADAM has developed a set of protocols from various results emerging from the study. In fact, a set of protocols in six typological situations has emerged in parallel through another ACWADAM project (with Samaj Pragati Sahayog) in the Dewas district of Madhya Pradesh. The matrix of protocols,

Calcrete nodules in alluvium

Dr. Kulkarni presenting ACWADAM-GGP's work in front of Hon'ble Agricultural Minister Mr. Sharad Pawar

with their effectiveness, as applied to each typology, the ease or degree of difficulty of implementation and such other factors that are likely to make or break protocol implementation, is presented below:

Matrix of protocols and feasibility of their implementation as part of the Groundwater Management Strategy in the study area – part 1

Protocols	Typology 1 (Overexploited area)	Typology 2 (Pimpri-Pandeshwar)	Typology 3 (Community based groundwater management)
Geohydrological science in Watershed Programme (Special reference to recharge area demarcation)	Relevant, but with specific strategy for recharge	Highly relevant, especially wrt groundwater salinity reduction	Not too relevant as there are few sites left for recharge
Recharge area protection (Forest cover & community lands)	Highly relevant, only if groundwater overexploitation is tackled as the single largest issue.	Not too relevant as most of the area is under private ownership	Highly relevant, especially in context to the community managed groundwater effort
Efficient use of individual wells	Of secondary relevance	Relevant, but needs further probing	Highly relevant, especially with regard to community effort.
Pump capacity regulation	Highly relevant	Not relevant	Not relevant, in case of efficient execution of community based system
Regulation of distance between wells (Drinking well protection)	Highly relevant	Highly relevant, only after restoration of water quality in the aquifer (may take years)	Not relevant in case of efficient execution of community based system
Construction of recharge structures for water quality improvement	Not relevant	Highly relevant	Not relevant
Regulation of agricultural water requirement (crop water requirement)	Highly relevant	Relevant	Relevant (built into the community based groundwater system)
Groundwater sharing through community participation	Relevant, but extremely challenging – would need external support (policy, legislation, incentives etc.)	Not relevant in the current context	Relevant (built into the community based groundwater system)
Community sensitization and awareness generation for groundwater use	Relevant	Relevant	Relevant
Government regulations to control overexploitation	Highly Relevant	Relevant, but could not be as stringent as in typology 1	Not necessary

Matrix of protocols and feasibility of their implementation as part of the Groundwater Management Strategy in the study area – part 2

Protocols	Typology 1 (Overexploited area)	Typology 2 (Pimpri-Pandeshwar)	Typology 3 (Community based groundwater management)
Geohydrological science in Watershed Programme (Special reference to recharge area demarcation)	* ?	* ✓	
Recharge area protection (Forest cover & community lands)	* ?		* ✓
Efficient use of individual wells		* ?	* ✓
Pump capacity regulation	* ?		
Regulation of distance between wells (Drinking well protection)	* ?	* ?	
Construction of recharge structures for water quality improvement		* ✓	
Regulation of agricultural water requirement (crop water requirement)	* ?	* ?	* ✓
Groundwater sharing through community participation	* ?		* ✓
Community sensitization and awareness generation for groundwater use		* ?	* ✓
Government regulations to control overexploitation	* ?	* ✓	

*** = (Necessary), ✓ = (Possible to implement), ? =(Uncertainty in implementation).**

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PROJECT LINKS

Documentary film

A short informative film was prepared by ACWADAM regarding the basic process in understanding typologies of groundwater and related problems. The first phase of shooting for this film was undertaken in November 2007 while the second phase was undertaken in April 2008. The following topics and respective locations were covered in the film:

1. Groundwater overexploitation and measurement of water levels – Tekawadi village
2. Automatic weather station and the importance of understanding weather in groundwater studies; geological mapping - Naigaon
3. Community based groundwater management and base flows - Pondhe
4. Groundwater quality monitoring – Pondhe and Tekawadi.
5. Groundwater salinity – Pandeshwar.

This film is also available on India Water Portal *(www.indiawaterportal.com).* This film is also uploaded on the website www.waterchannel.com and is one of the most popular videos available on that site.

Shooting for the groundwater film in Naigaon

A brief about the other activities undertaken during the project period:

1. One day workshop was organized in Pune for a diverse audience (from farmers to academicians and civil society organisations) to disseminate and discuss the findings from the first two years of the project on 19th January 2008. Mr. Manohar Rao represented Arghyam Trust. The experts and local farmers had active discussions on various issues like salinity in groundwater, distribution of groundwater as well as issues like energy and marketing. Looking at the warm response given by the community it was decided to have one more dissemination workshop in September 2008 for a slightly different audience including Arghyam partners working on groundwater related issues from other parts of India.

2. A meeting was organized on 3rd May 2008 as a part of Mr. Sharada Prasad's journey 'K2K: In search of water'. The meeting was more of an experience sharing event where Sharada shared his experiences with the audience. The meeting also helped bring out certain important issues related to water, common to many parts of India.

Dissemination workshop in Hadapsar for farmers and civil society organisations- January 2008

3. In September 2008, a two day training-cum-experience sharing workshop was organized in Pune for the Arghyam partners. The main objective of the workshop was to have a focused discussion on groundwater related issues and also to create a certain level of sensitivity and awareness regarding the science behind understanding groundwater. It is necessary to understand the intricacies of groundwater before going in for groundwater management action. In many places, watershed development projects include construction of structures without any reference to the underlying geology, and lesser so, to the aquifers in the watershed. It is necessary to understand the geohydrology of an area before constructing recharge or water harvesting structures like check dams or farm ponds. For instance, percolation tanks are best constructed on natural recharge areas while irrigation tanks would be best located in sites of groundwater discharge. It is also a prerequisite to understand the properties of aquifers, the groundwater availability, quality of water and the demand-supply scenarios in a successful watershed management programme. The ACWADAM team tried to cover all these issues through their short presentations which stimulated plenty of discussion, especially pertaining to the location of structures. Participants from 14 different organizations of India participated in this workshop.

Experience sharing workshop on groundwater-Sept 2008

4. A two day national workshop on ' Groundwater' was conducted in Pune where eminent scholars, including Dr. Tushaar Shah of the International Water Management Institute (IWMI), Dr. Phillip Cullet (ILRC) and others presented their work. Topics like processes of understanding groundwater, demand, supply and availability of groundwater, quality and quantification of groundwater, groundwater in the urban context and groundwater legislation - policy were discussed during the two days. The presentations of the workshop are available on the India Water Portal. ACWADAM is shortly hoping to bring out a compilation of short, illustrative papers that were presented during the workshop.

Workshop on groundwater-May 2009