Saph Pani

Enhancement of natural water systems and treatment methods for safe and sustainable water supply in India

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Documentation of acquired data and conceptual model of MAR impact as input for WP5 modelling

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1 Introduction

This report aims at documenting the scientific evidence at 4 managed aquifer recharge (MAR) sites in India after 18 months duration of the EU (European Union) funded project SAPH PANI. The site investigations include compilation of previously existing data, a wide range of field experiments, surface-/groundwater and sediment sampling, data analysis, interpretation and the development of (preliminary) conceptual models. The MAR sites are realised under a wide range of geological and hydrological conditions and the covered aspects can be summarised as:

1.1 Mitigation of seawater intrusion in Chennai (chapter 2)

Salinity ingress in surface- and groundwater is a major constraint for social and economic development. In a worst case scenario it was estimated that 1.1 billion people are currently affected by salinity ingress on a global scale[1]. In Chennai (Tamil Nadu) public water supply and agriculture depends on groundwater to various extents and the valuable resource has shown increasing salinity over the last decades. Several check dams and *anicuts* (local term in Tamil language, standing for a water diversion structure) exists and one check dam was investigated in detail. Additionally, a small scale percolation pond was constructed at the coastal aquifer where groundwater is brackish to saline. This study aims at evaluating the qualitative and quantitative effects of MAR structures on catchment and local scale. On the catchment scale interactions of surface- groundwater, density stratification of groundwater at the coast line, the ratio between groundwater recharge and abstraction for agriculture and drinking purposes make numerical modelling necessary. On a local scale infiltration amounts and qualitative aspects such as ion displacement by refreshment of brackish aquifer plays an important role.

1.2 Temple tanks in urban Chennai (chapter 3)

India’s temples play an important social and religious role also in modern society. The ancient knowledge of water storage and groundwater replenishment finds its expression, among others in temple tanks. The investigated temple tanks in Chennai, some of them were constructed several hundred years ago, are nowadays surrounded by the ever growing urbanity. The new surroundings also pose threats to the tank water quality by contaminated surface run-off. Here, a set of water quality parameters were analysed at 4

[1] van Weert, F., van der Gun, J., Reckman, J. (2009) Global Overview of Saline Groundwater Occurrence and Genesis, report nr GP 2009-1, International groundwater resources assessment centre, Utrecht, Netherlands

different temple tanks and nearby groundwater wells. This study aims at investigating the role of temple tanks for groundwater replenishment and consequences for the water quality.

1.3 Percolation pond in Maheshwaram (chapter 4)

Vast parts of the Indian subcontinent is covered by hard-rock formations. The hydraulic interaction of infiltrating surface water with the groundwater is complicated by the preferential flow through fissures and fractures and low storage capacity. At the same time the purification and retention capacity of the fractured media is lower compared to unconsolidated media. This study investigates the role of MAR to enhance recharge and groundwater quality in a typical overexploited hard-rock aquifer in Maheshwaram (Andhra Pradesh). Major aims of this study are the development of water budgets on site specific and catchment scale and the investigation of MAR impact on contaminants such as fluoride.

1.4 Urban storm water management in Raipur (chapter 5)

Most of the rainfall in India is limited to the monsoon seasons and large amounts of rain fall within a few days only. In Raipur (Chhatisgarh) a feasibility study commenced to study the role of lakes within an urban storm water management system. Quantification of surface runoff from rainfall was performed by computation of the SCS-CN (Soil Conservation Service-Curve Number) model. Groundwater table maps for various seasons and aquifer depths give insight on the subsurface flow regime. The characterization is supplemented by electrical resistivity tomography (ERT) profiles.

The work presented in this report is on-going and the interpretation of the results must be considered as preliminary. This report contains a vast collection of methods and results and the primary datasets are available in the annex.

2 Mitigation of seawater intrusion in the AK aquifer

2.1 Site description

2.1.1 AK aquifer

The study area forms a part of the Arani-Koratalaiyar (AK) river basin located north of Chennai, Tamil Nadu, southern India (Figure 1). The Arani River is on the northern part of the area while the Koratalaiyar River is in the south. The eastern side of this area is bounded by the Bay of Bengal. Near the eastern boundary running parallel to the coast is the Buckingham Canal which carries saline water. This area is having a tropical monsoon climate with January and February as the dry periods. The average annual rainfall is around 1200 mm/yr, 35% falling in the south west monsoon (June- Sep) and 60% during the north east monsoon. These two rivers are non-perennial and normally flow only for a few days during north east monsoon i.e. from October to December. After monsoon saline water enters up to 4 km and quality of water is fresh to brackish.

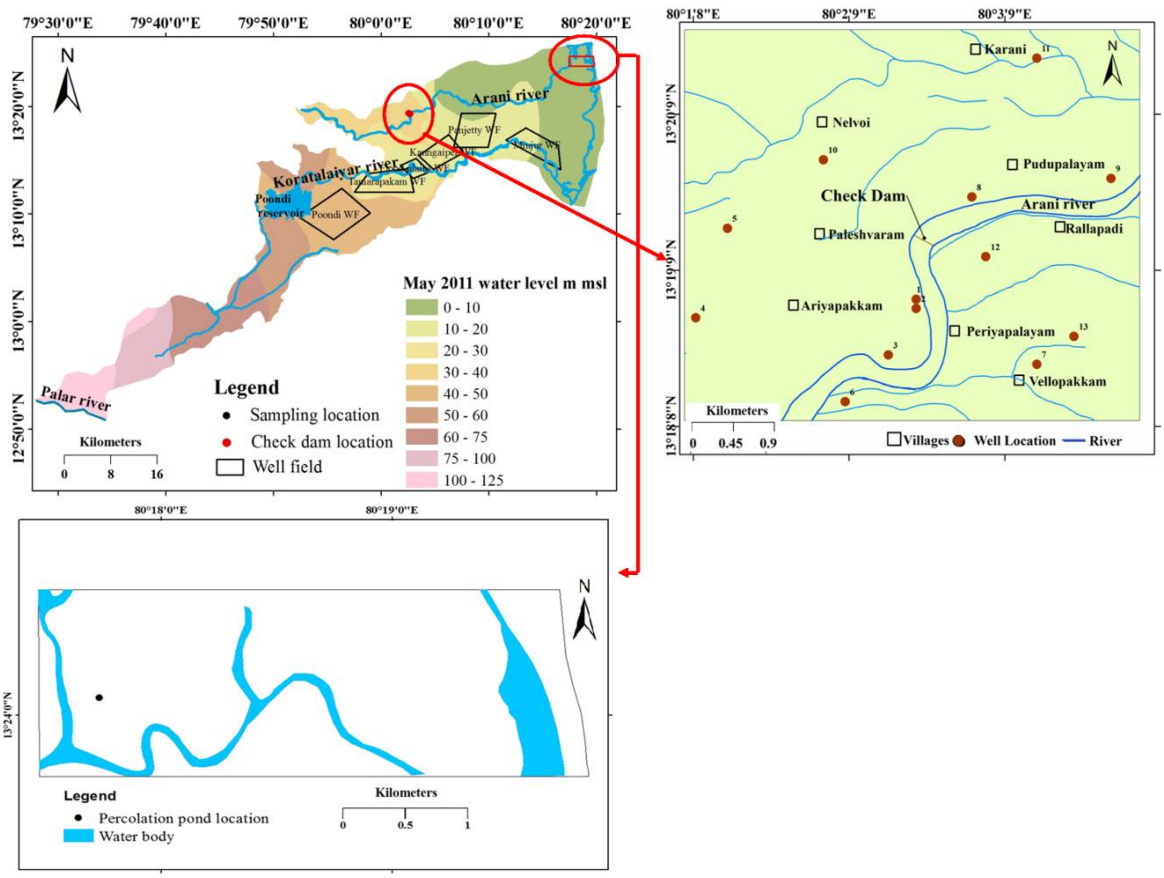

Figure 1 Location of the study area and groundwater level in (m) during May 2011.

The drainage pattern in this area is mainly dendritic (Figure 45, see annex). This area is generally having a flat topography and gently slopes towards the east (Figure 46, see annex). There are a few hillocks in the north western region having a maximum elevation of about 90 m. This area comprises landforms of fluvial, marine and erosional sediments. It includes alluvial planes, beach ridges, mudflats and paleo abandoned channels in the eastern region. The geology of this area is given in Figure 47 (see annex).

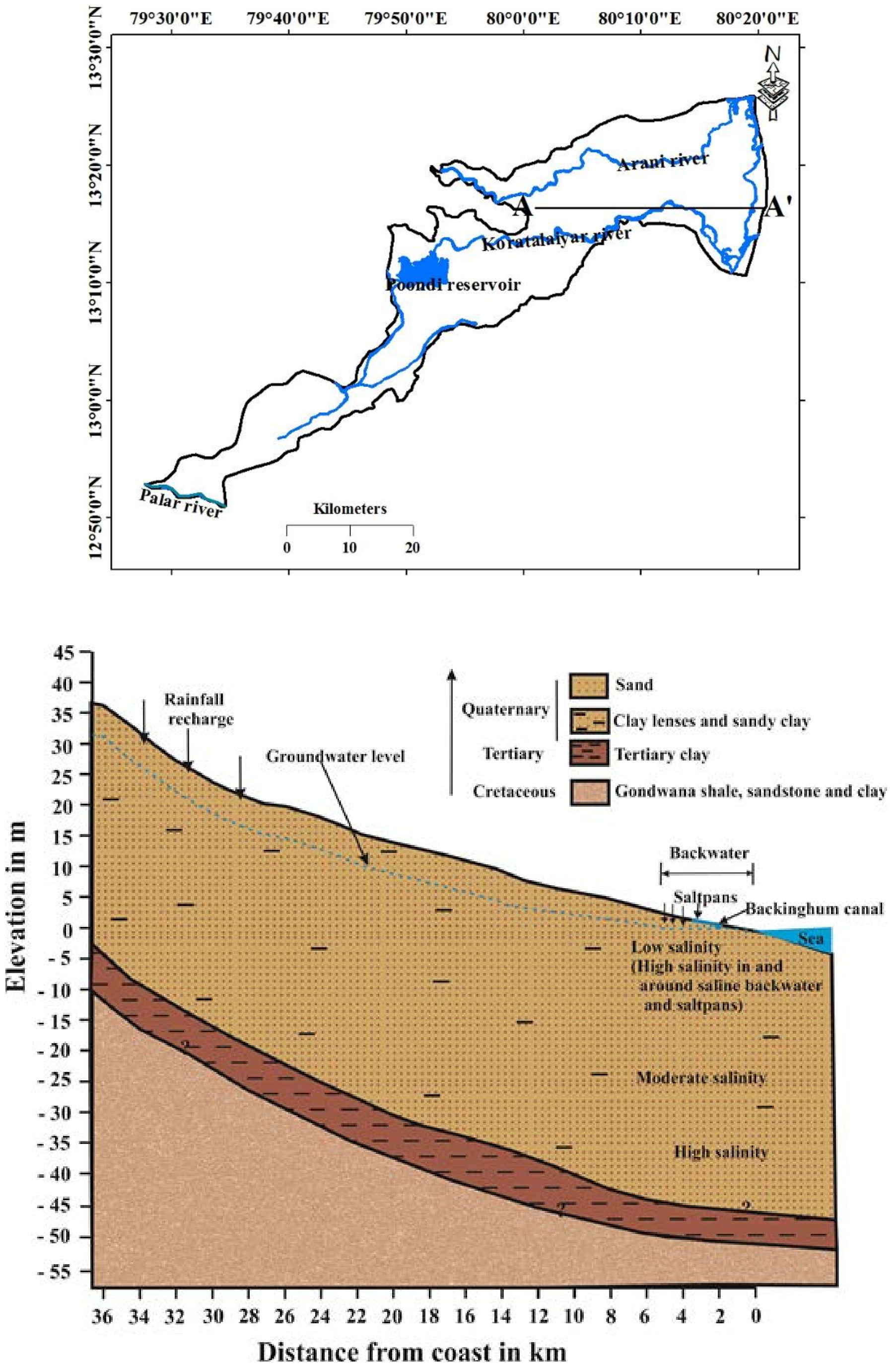

Figure 2 Geological cross section along A-A’.

The studies based on maximum depth of boreholes of 50 m in the AK basin show the thickness of the coastal alluvium as 35 m. Groundwater in the area occurs in the shallow weathered zone near the coast and the depth to groundwater increases with the elevation of the area. The thick clay lenses form a semiconfined aquifer system. The groundwater levels in the unconfined aquifer ranges from 2 to 6 m bgl (below ground level) and in semiconfined aquifer it ranges from 14 to 20 m bgl. A west to east geological cross section in the area is given in Figure 2. In general the regional groundwater flow is towards the sea; however there may be variations in local hydraulic heads due to the difference in pumping pattern. Groundwater recharge relies mainly on rainfall which feeds the non-perennial streams at the same time. The open/dug wells in this area are up to 25 m deep and bore wells up to 120 m deep. The water from these wells is used for domestic and irrigational purposes.

The impact of two MAR structures i.e. one check dam and one percolation pond located in this area were studied in detail. The descriptions of these two sites are given in detail below.

2.1.2 Check dam - Paleshwaram

The check dam was constructed in the year 2010 across the Arani river, near Paleshwaram village. This check dam is of 260 m length with the crest height of 3.5 m from the river bed and has a storage capacity of 0.8 million cubic meter of water. The location of check dam is shown in Figure 1.

The study area consists of sand, clay and recent alluvium overlying on a thick pile of Gondwana shales, clays and sandstones rocks. Alluvium is dominant in this area and the northern side is covered by laterite. Geomorphic units of this area include alluvial plains, flood plain and weathered pediplain. The stratigraphic succession of the geologic formations is given in Table 1.

Table 1 Stratigraphic succession of the geological formation.

Stratigraphic age and Thickness	Geological description
Quaternary (up to 40m)	Fine to coarse sand gravel, laterite clay and sand clay with *Kankars**
Tertiary (45-50m)	Shale, clay and sand stone
Mesozoic	Gondwana shale and clay
Archean	Crystalline rocks

*Indian expression, often used for detrital and rolled calcium carbonate nodules formed in soils, mostly in semi-arid regions.

The major part of this area is used for agriculture. Cropping pattern in the study area can grouped under pulses, cereals and oil seeds. Paddy is the major food crop in this area.

2.1.3 Pilot percolation pond

The percolation pond is situated at Andarmadam in the Thiruvallur district of Tamil Nadu. The site is bounded by Arani River in the west and south, Bay of Bengal in the East and Pulicat Lake in the Northeast. Topography of the area is smooth. The pilot pond is constructed in an agricultural field (Figure 1), which lies nearly 0.2 km east of Arani River and nearly 3.8 km west of Bay of Bengal. Pulicat lake is located approximately 2.5 km north of the study area. The location of the pilot site is selected according to the slope of the terrain in such a way that a maximum run off can be recharged in the pilot pond during rainy season. The area mostly consists of sand, clay, and shale mainly of marine estuarine, the geology is composed of recent Alluvium overlying quaternary laterite and boulder followed by Tertiary sandstone, shale and clay followed by Gondwana sediments and crystalline Archean rocks (UNDP, 1987)

The district gets scarcity of flow records and the mean annual flow is about 3 m^3/s (Elango et al. 1989; Charalambous and Garratt, 2009). Very small amount of surface run off will be infiltrated to recharge the groundwater and the remaining water will be drained to the sea. The effect of the rainfall recharging in the aquifer is very less in the area. So artificial recharge technique was used to construct a small water harvesting structure such as percolation pond, which can impound the surface run off for a considerable time period, and may result in positive effects for improving the quality of groundwater.

2.2 Problem statement

Chennai is the largest city in South India located in the eastern coastal plains. Water supply to the Chennai city is met from reservoirs and by pumping groundwater. The total surface water basin area of Chennai region is 7282 km^2, divided between Andhra Pradesh and Tamil Nadu. The north east monsoon is significant as it replenishes the surface reservoirs and also recharges the groundwater. Water is stored in reservoirs and used cautiously. They are virtually empty before the next annual rainfall. The shortfall in surface water storage systems is met from groundwater resources. More than one third of the water demand is met by groundwater from three well fields known as Minjur, Panjetty and Tamaraipakkam situated about 40 km north of Chennai (Elango and Manickam, 1986). The average rainfall on the basin is 7-9 billion m^3/year, which corresponds to 950-1250 mm/year. Even though the annual rainfall on the basin is moderate, extreme cases of very high daily rainfall was recorded in past in the Chennai basin. Severe rainfall during short period of time combined with high percentage of impervious areas in this region is the major source of flooding. The city has two major rivers namely Adyar and Cooum. Both rivers usually carry sewage and only heavy rain events can flush these rivers. The city itself has very meager groundwater resources due to very little rainfall recharge. However, a considerable amount of groundwater is pumped to the city from the well fields located in the Arani and Korattalaiyar river basins, north of Chennai. Severe pumping from these regions for supply to the Chennai city and for local irrigational needs has also resulted in seawater intrusion. The Minjur well field lies nearest to the coast (9 km) and it is hydraulically connected with the sea. Several studies have been done on seawater intrusion in the North eastern coasts of Tamil Nadu (Elango and Manickam, 1986, 1987; UNDP, 1987; Elango, 1992; Rao et al. 2004; Elango 2006, 2009; Ganesan and Thanumayavan, 2009). Thus, the Chennai region on one hand is affected by floods and on the other by severe shortage of water. This study will undertake a comprehensive assessment of MAR for coping with seawater intrusion and groundwater overexploitation and to develop recommendations and management plan for implementing MAR systems in Chennai that utilize excess monsoon water to counteract seawater intrusion.

2.3 Objectives

- To determine the quantitative and qualitative effects of monsoon water recharge to an overexploited peri- urban aquifer through check dam and percolation ponds
- To assess the impact of existing measures for monsoon water infiltration on counteracting seawater intrusion into a coastal aquifer used for urban drinking water production and develop an alternative low cost and low tech measure
- To evaluate the impact of MAR through percolation tanks on groundwater recharge and quality in an overexploited aquifer
- To derive general recommendations for the implementation of MAR under the specific conditions met in India

2.4 Documentation of acquired data

2.4.1 AK aquifer

The data used for the modelling such as aquifer types, borehole lithologs, rainfall and long term groundwater level observations were collected from various departments of the Government of Tamil Nadu, India. Base map was prepared from topo sheets obtained from Survey of India (Figure 1). Differential Global Positioning System (DGPS) survey was carried out to improve the topographical information at about 45 locations. The model area has a maximum elevation of 120 m amsl (above mean sea level). Geology map of the study area was derived from the geological map procured from Geological Survey of India (GSI) (Figure 47, see annex). To understand the geological formation of the area, lithologs and aquifer types were collected from Chennai Metropolitan Water Supply and Sewerage Board (MWSSB). The groundwater level data from January 1996 to December 2011 was collected from Public Works Department (PWD). Most of the area is occupied by unconfined aquifer and semi-confined aquifer present in less part. Aquifer thickness of the model area was derived from Charalambous and Garratt (2009) and Elango et al. (1989) and it was updated by lithologs data. Also, rainfall data from January 1985 to December

2011 in 6 raingauge stations were collected from PWD. Table 2 lists the data used for modelling.

Table 2 Data used for modelling.

S.No.	Data	Source
1	Toposheet	Survey of India
2	Topographic elevation	Differential Global Positioning System survey
3	Geology	Geological Survey of India
4	Lithologs	Metropolitan Water Supply and Sewerage Board
5	Aquifer types	Metropolitan Water Supply and Sewerage Board
6	Rainfall	Metropolitan Water Supply and Sewerage Board

Measured hydrochemistry and stable isotopes ($\delta^{18}O$, δD) are shown in Table 29 and Table 30 (see annex). Samples from the sites SW2 (backwater, river mouth Aranyar River), SP (salt pan), CGWB3 (Central Ground Water Board), DW2, DW3, DW4, DW16, BW44, seawater, TW1, BW15, BW14a are used for the interpretation of salinity ingress on aquifer scale.

Regional hydrochemistry of major ions is displayed by stiff diagrams of potential hydrochemical binding partners (Na-Cl, Ca-HCO_3, Mg-SO_4) in Figure 3. Water samples are classified into groups with similar hydrochemical characteristics, according to mineralisation (expressed as electrical conductivity EC) and water type.

Water types of samples proximal to Minjur are brackish (EC >1500 µS/cm) and of Ca-Na-Mg-Cl-HCO_3 (BW 14a) or Na-Ca-Mg-Cl-SO_4 (CGWB 3) or Na-Ca-Cl (BW 15) type. All samples show a molar predominance of Cl over Na, which indicates ion exchange during flushing of fresh water aquifer with brackish or saline water. Mixing calculation based on conservative Cl^- species yields a sea water share of 3 %, 2 % and 6 % for BW 14a, CGWB 3 and BW 15, respectively.

Samples from shallow dug wells DW 2, DW 4 and DW 16 are fresh water and represent the local groundwater recharge to the shallow ground water table. This group is characterised by low mineralisation (EC < 1100 µS/cm). Water types for this group vary from Ca-Na-HCO_3-Cl (DW 16) to Ca-Na-Mg-HCO_3-Cl-SO_4 (DW 2). Only DW 4 shows predominance of Na over Ca (Na-Ca-HCO_3-Cl type). Normally, recent ground water recharge will consist of Ca-Mg-HCO_3 type. The presence of Na in all water types may indicate ion exchange processes of fresh water flowing through an aquifer where the exchange sites are occupied by sodium.

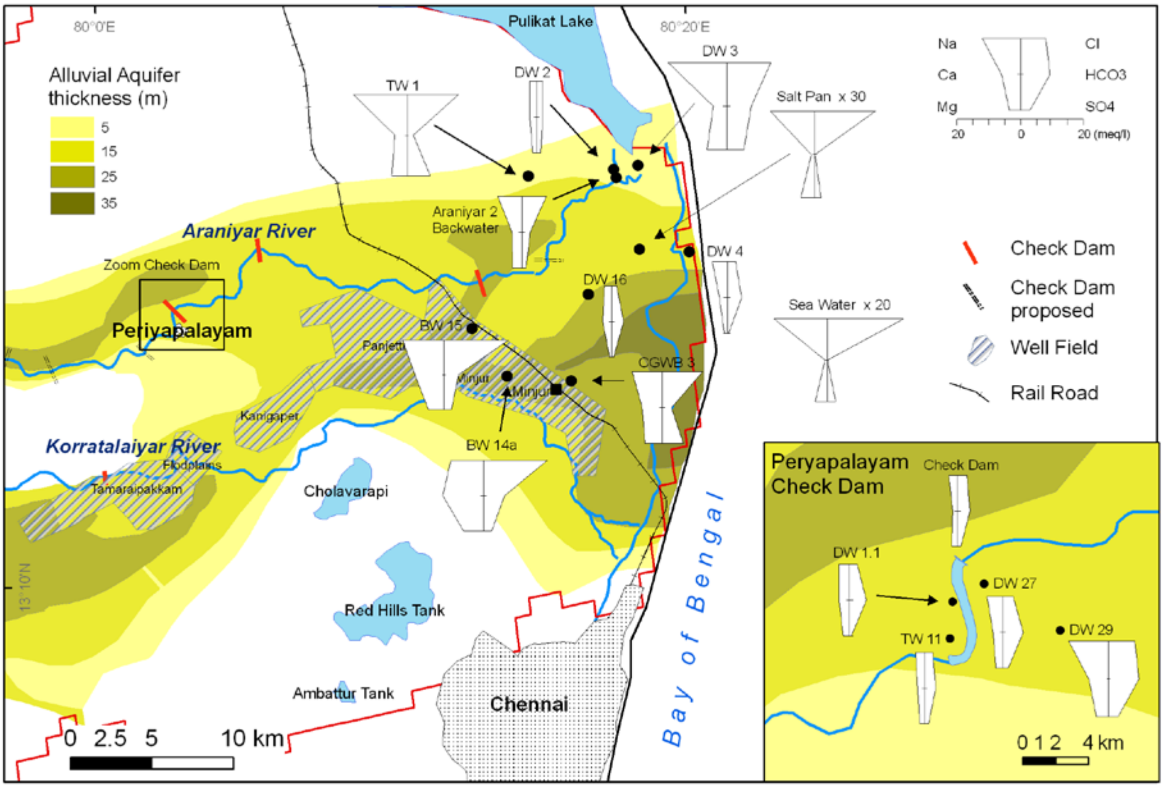

Figure 3 Stiff diagrams of ground- and surface water samples in the A-K catchment. (TW=tube well, DW=dug well, SW=surface water, BW=bore well).

The groundwater sample at the salt pan (EC = 83 200 µS/cm) is 1.6 times higher mineralised than seawater (EC_{SMOW} = 53 000 µS/cm). Water type of this sample is not simply Na-Cl (i.e. the standard mean ocean water, SMOW) but of Na-Mg-Cl type. Sanford and Wood (1991) investigated the hydrochemical brine evolution and mineral deposition during the evaporation of sea water. The authors state that halite precipitates after ~90 % of evaporated volumes and Mg bearing mineral phases (i.e. polyhalite, kainite) precipitates afterwards. Despite of the precipitation of Mg bearing phases, the concentration of Mg in the residual water increases disproportionally compared to Cl. This disproportional increase of Mg against Cl may explains the predominance of Mg in the salt pan ground water. The molar Na/Cl ratio in sample TW 1 is balanced, EC is increased with 4230 µS/cm and conservative mixing yields 5 % sea water share.

2.4.2 Check dam - Paleshwaram

Water level in the check dam and groundwater level in the wells located around the check dam was measured from February 2012 to January 2013. Groundwater samples were collected from 12 wells, one tube well and surface samples were collected from the water stored by the check dam. EC, pH and temperature were measured immediately after sampling using YSI 556 field multiparameter kit.

2.4.2.1 Hydrochemistry

The pH value of groundwater varies from 6.0 to 7.9 with an average value of 7.0 and pH of water stored in the check dam varies from 6.0 to 8.5. The EC of the groundwater samples showed medium to high salinity (662 µS/cm to 3100 µS/cm), whereas the EC of water stored in the check dam shows low conductivity (323 µS/cm to 600 µS/cm) during the period of study. Very high EC (more than 1500 µS/cm) was recorded in five wells (well numbers 5, 9, 10, 11, 13). The concentration of chloride in groundwater varied from 91 mg/l to 638 mg/l. High chloride concentrations were recorded in seven wells (well numbers 4, 5, 7, 9, 10, 11, 13). Chloride concentration of water stored by the check dam varied from 70 mg/l to 128 mg/l. The groundwater was mostly fresh to brackish and water stored in the check dam is fresh in nature as per the classification suggested by Freeze and Cherry (1979) (Table 3).

Table 3 Classification of water samples based on total dissolved solids (TDS in mg/l).

TDS (mg/l)	Water type (Freeze and Cherry 1979)	Groundwater samples	Water from check dam
<1,000	Fresh	1,2,3,6,7,8,9,10,11,12	All samples
1,000 - 10,000	Brackish	4,5,13	Nil
10,000 - 1,00,000	Saline	Nil	Nil
>1,00,000	Brine	Nil	Nil

Intensive agricultural activities are being carried out throughout the study area and quality of water for irrigation purpose is assessed based on the United States salinity laboratory (USSL) classification (Table 4). This table indicates that most of groundwater samples are classified under permissible and only one sample is classified as unsuitable for irrigation. Water stored by the check dam is classified under excellent category.

Table 4 Suitability of groundwater for irrigation based on USSL classification.

EC (µS/cm)	Salinity class and remarks	Groundwater sample numbers	Water from check dam
<250	Excellent or low	Nil	Nil
250-750	Good or medium	Nil	All samples
750-2250	Permissible or high	1,2,3,4,5,6,8,9, 10,11,12,13	Nil
2250-5000	Unsuitable or very high	7	Nil

2.4.2.2 Interaction of surface- and groundwater

The plot between electrical conductivity (EC), which is a function of TDS and chloride, a dominant conservative anion show that some wells plot closer to the origin, whereas the other wells plot away from it (Figure 4).

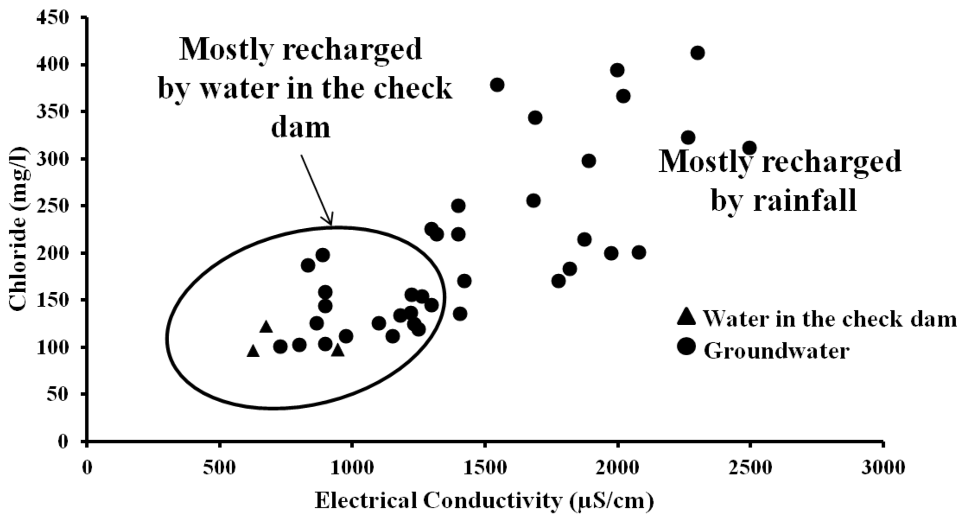

Figure 4 Plot on EC and chloride of groundwater and surface water.

This indicates that the wells closer to origin have the EC and chloride values closer to that of the water stored by the check dam. That is, the group of wells closer to the origin are the wells that are recharged from the check dam.

Efficiency of the check dam in augmenting the groundwater recharge was assessed by comparing the temporal variation between water level in the check dam and groundwater level in the wells (Figure 5).

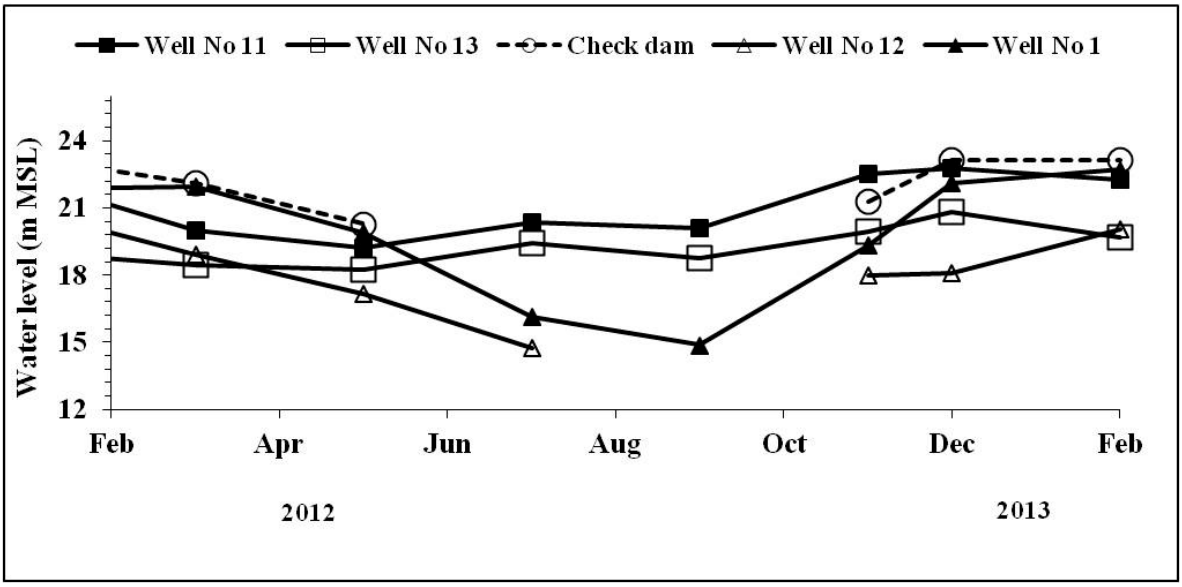

Figure 5 Water levels in the check dam and monitoring wells.

Based on the similarity between the water level fluctuation in the check dam and groundwater level, the wells could be classified into two groups. An example plot of four wells (Well no 1, 11, 12, 13) is shown in Figure 5. In the first group of wells (Well no 11, 13) groundwater level raise twice a year coinciding with the north east and southwest monsoon. These indicate that rainfall is the major source of recharge at these locations. Whereas in the other group of wells (Well nos 1, 12) fluctuation in groundwater levels are very similar to the water level fluctuation in the check dam. This similarity indicates that surface water stored by the check dam is the major source of recharge at these locations.

2.4.2.3 Isotope signatures

Measured hydrochemistry and stable isotopes ($\delta^{18}O$, δD) are shown in Table 29 and Table 30 in the annex. The sites SW1 (surface water in the check dam), DW1.1, DW1.2, DW1.3, TW11, TW77, DW29, DW18 and DW31 are situated close to the Paleshwaram check dam and used for data interpretation. TW11 is equipped with a pressure transducer. The measured water level, compensated by barometric pressure, and groundwater temperature is shown in (Figure 63 , see annex).

Surface water in the check dam shows low mineralization of 444 – 861 µS/cm of Na-Ca-HCO_3-Cl water type. Similar hydrochemical facies is found in the samples DW1.1, TW11 and DW27. DW29 is higher mineralized (1772 µS/cm) and shows predominance of Na over Cl (Figure 3, insert).

The surface water samples from the Paleshwaram check dam show, as expected under the climatic conditions, an evaporative enrichment with time (Figure 6). At the beginning of the monsoon November 2011 isotope values are on the LMWL with -3.7‰/-18.6‰ and the following samples show a successive enrichment with a composition of -0.19‰/-1.2‰ in March 2012 leading to overall enrichment of $\delta^{18}O$ of 3.51‰. Regression line calculated with the 5 surface water samples is $\delta D = 4.8 \times \delta^{18}O - 1$ (r^2=0.96), the slope of 4.9 is very typical for evaporation from open water bodies (Clark and Fritz 1997).

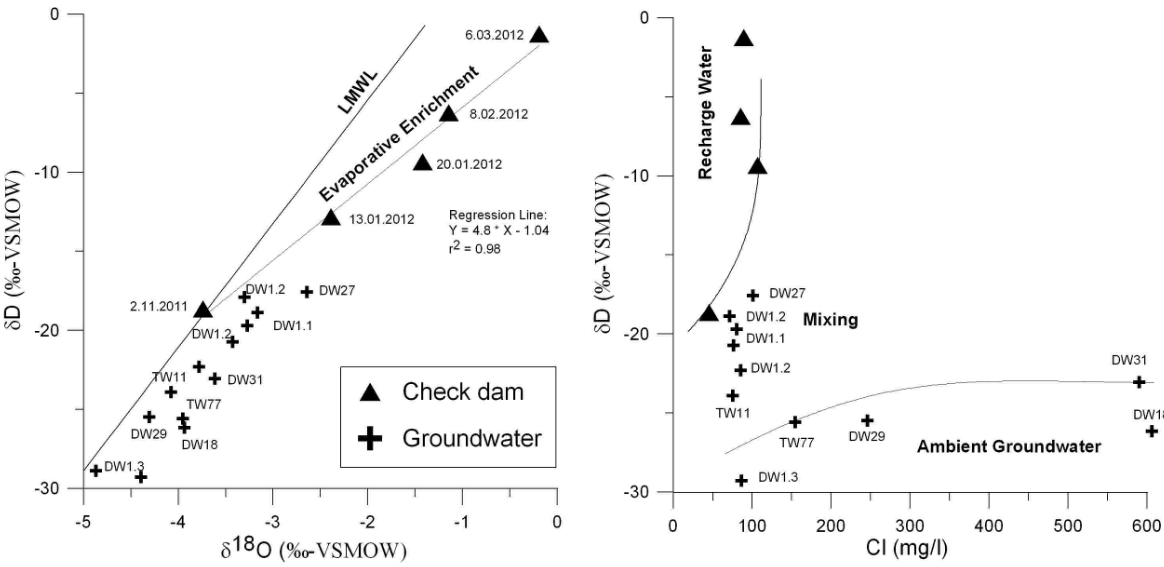

Figure 6 Chloride and stable isotopes of water ($\delta^{18}O$, δD) in check dam (Recharge water) and groundwater.

Chloride and stable isotopes of water ($\delta^{18}O$, δD) are used as tracers to indicate recharge and mixing of ambient groundwater (not influenced by the check dam) with recharge water from the check dam. Isotopic composition and chloride concentration of surface water from the check dam and groundwater is shown in Figure 6. Surface water from the check dam is characterised by low chloride concentration (<120 mg/l) and enriched isotopic composition. Isotopic composition of the surface water shows increasing evaporative enrichment with time. Ambient groundwater is characterised by high chloride concentrations (80 – 600 mg/l) and depleted isotopic composition. Samples of groundwater which are influenced by check dam infiltration can be found in between the composition of ambient groundwater and the recharge water composition (Figure 6, right). Mixing of ambient groundwater with recharge water takes place with water from the beginning of the recharge period between November 2011 and January 2012. It may be concluded that recharge is limited or absent during February to March 2012.

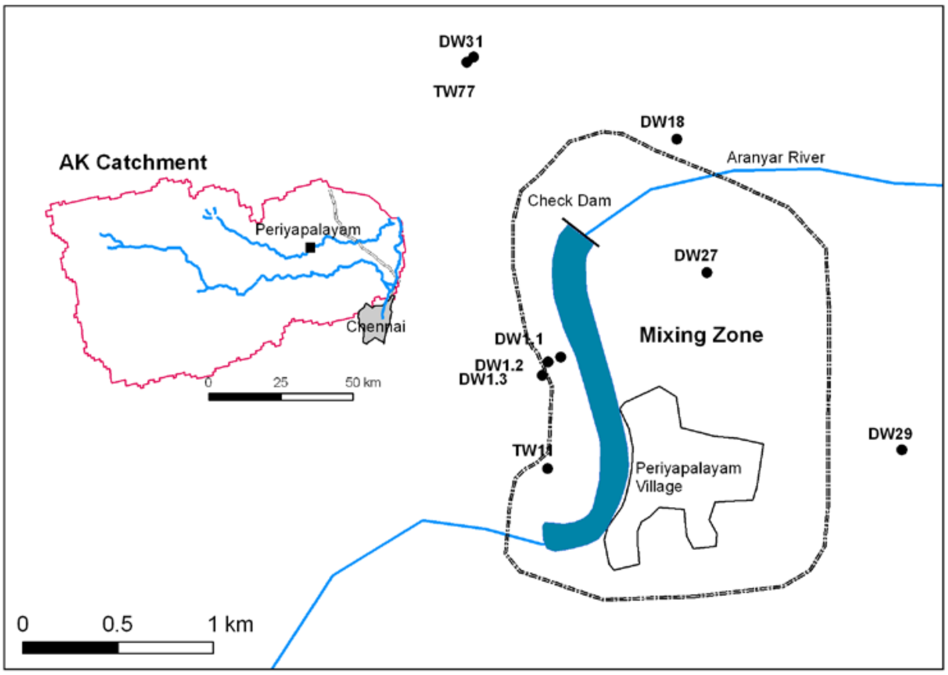

Figure 7 Location map of check dam close to the Paleshwaram village and sampling stations. (DW = dug well, TW = tube well).

The spatial extent of check dam recharge is shown in Figure 7. The mixing zone from the recharge water with the ambient groundwater is limited to a few hundred meters around the check dam. To the east the mixing zone is prolonged due to the regional flow direction from west to east.

The investigated check dam at Paleshwaram stores surface water from the beginning of the monsoon in October until May. Evaporative loss based on mean monthly evaporation rates from the years 1959-1982 (UNDP 1987) was used to estimate actual losses of the check dam. The accumulated loss from October to May is therefore approx. 1200 mm. Assuming an average bathymetric depth of 2m, it is clear that more than 50% of the stored water evaporates. This is only a rough calculation and detailed calculations will follow. It is clear that evaporation rates are highly dependent on local climatic conditions and vary from year to year, but the long term storage of water which is intended to infiltrate may pronounce adverse effects and could make the MAR structure ineffective. Main adverse effects of long term surficial storage are: i) water allocation without any benefit for human or ecology ii) contamination of surface water body by discharges from agriculture and adjacent villages. These adverse effects may be managed by opening the sluice gates during time of low infiltration and high evaporation.

Conclusions for numerical modelling

- substantial infiltration of check dam water limited to first 2-3 months of recharge period (development of clogging layer and/or decrease of hydraulic gradient with time)
- scenario modelling may investigate the effect of water release to enhance downstream infiltration
- area of influence is limited to approx. 1 km to the east and few hundred meters to the west (general groundwater flow from west to east)

2.4.3 Pilot percolation pond

2.4.3.1 Geology

The lithology of the area was studied by drilling four bore holes (depth 6 m) at the four corners of the school compound where the pond is located. The soil samples were collected and were analysed in the laboratory. Sand is predominant which is intercalated by silt and is shown in the lithologic fence diagram (Figure 8). The textural analysis of soil samples collected from the study area shows that the pond location is dominated by silty sand up to a depth of 2 m from the surface and sandy silt below 2 m from the surface.

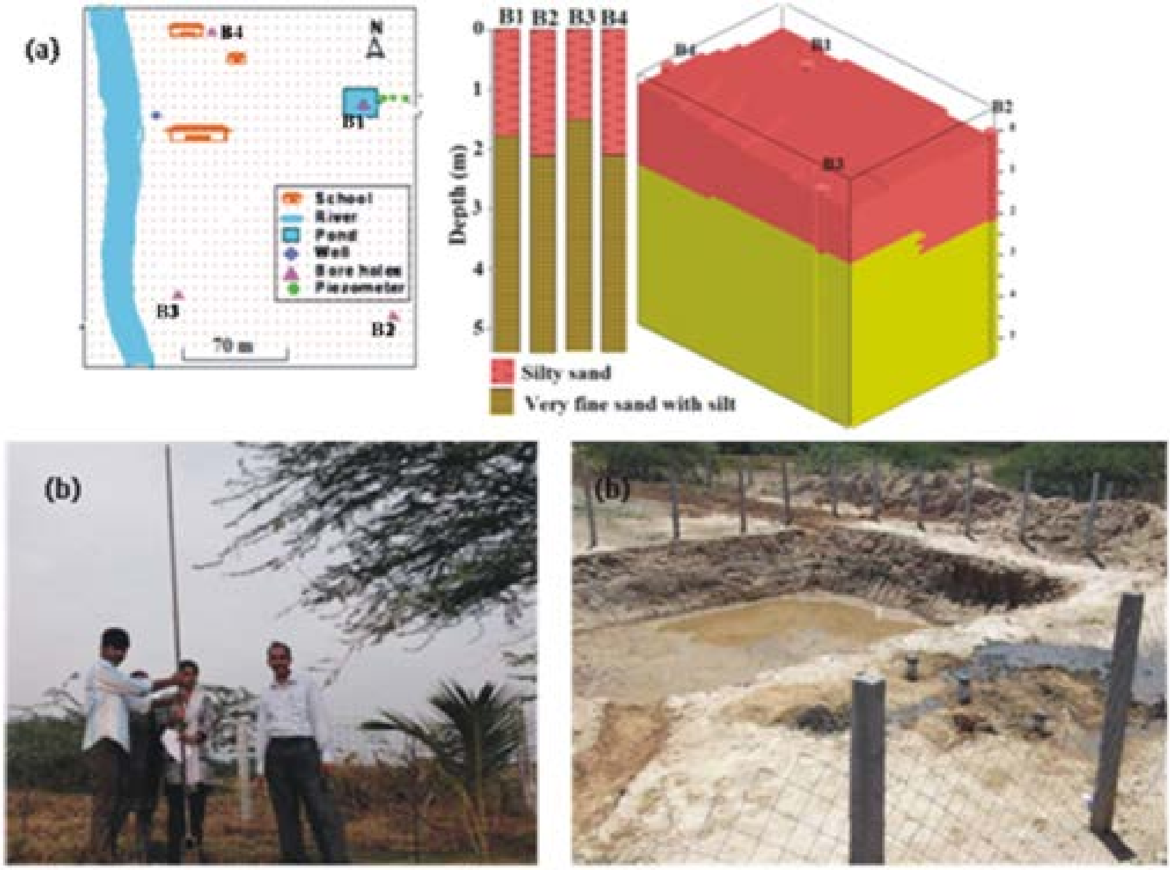

Figure 8 (a) Bore hole logs, lithologic fence diagram of the area and (b) some photographs from the field.

The subsurface geophysical signatures of the area were mapped using Ground Penetrating Radar (GPR) with 50 MHz antenna (Figure 9) and resistivity meter (Figure 10). The GPR profile is taken parallel to the Arani River and Bay of Bengal. The maximum depth of penetration of electromagnetic waves, which depends on the velocity of the medium and frequency of the antenna, ranges from eight to nine meters from the surface. This may be due to the higher signal attenuation by saline water. In Figure 9, three types of subsurface signatures are visible which are indicated by layer 1, 2 and 3. Layer 1 extends to a depth of nearby 4 m and layer 2 extends from 4 to 7 m depth. In the first layer, parallel and continuous layers can be seen whereas in layer 2, distorted signals with maximum attenuation can be seen. The high attenuation below 4 m may be due to the high salinity and EC of water below 4 m. Clay patches occupying smaller area are also present in the area, which are marked in the Figure 9. Layer 3 is characterised by poor conductivity of electromagnetic radiations. Water table is not visible in the radargram. Layer 1 is characterised by sand with silt and layer 2 is dominated by silt with very less concentrations of sand.

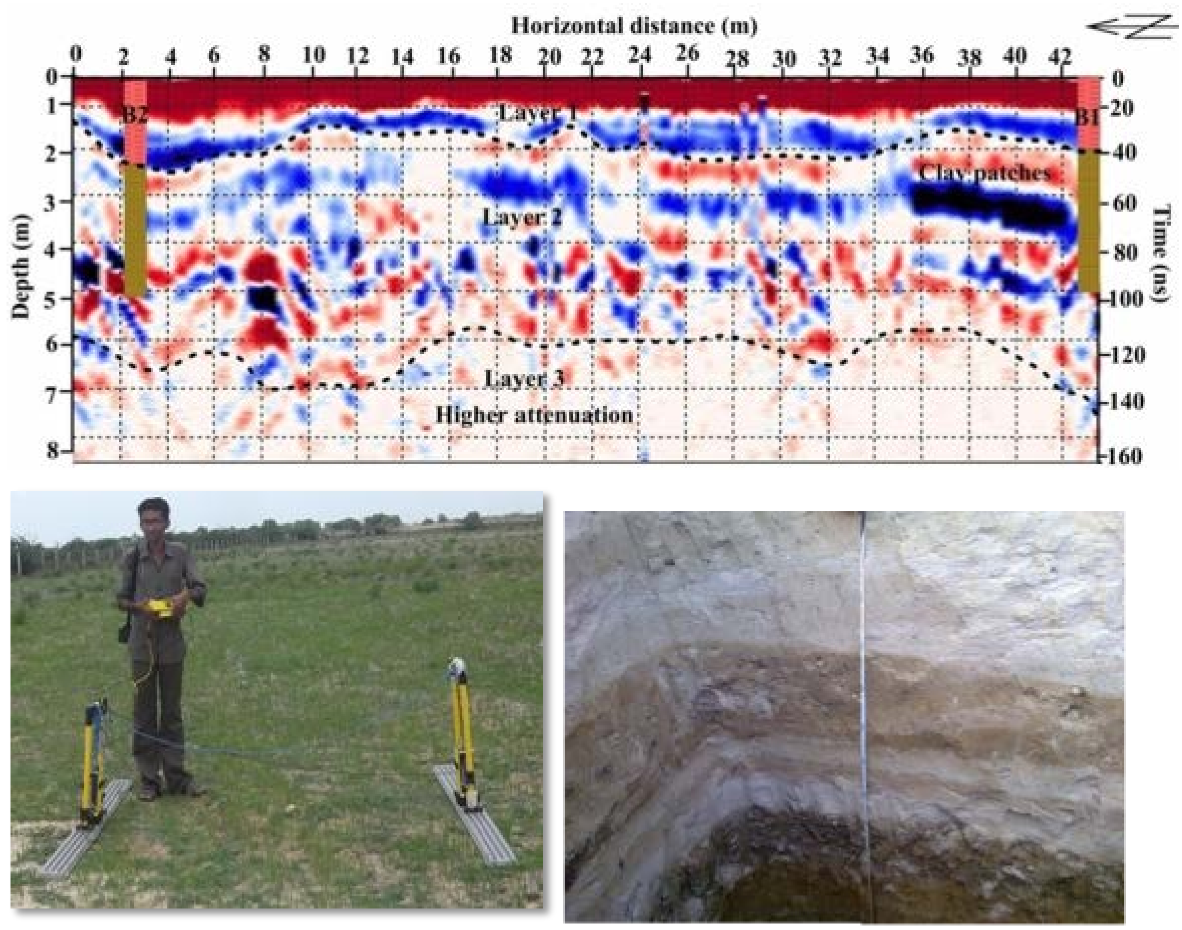

Figure 9 GPR survey under progress and the radargram obtained showing interpreted subsurface layers in the area.

Resistivity survey was carried out in the study area to understand the subsurface lithological information using Vertical electrical sounding. Electrodes were arranged using Schlumberger method with a total length of 33m; current electrode spacing (AB/2) were ranging from 2 m to 33 m and that of potential electrodes (MN/2) were ranging from 0.5 to 2 m. The thickness of subsurface layers was determined by curve matching method using IX1D software. In this method the three different layers were identified in the study area and are shown in the Figure 10. The top soil is encountered up to a depth of 0.5 m and sand is dominant in the second layer which extends from 0.5 to 1.4 m depth. The resistivity of first and second layers ranges from 34 to 600 ohm m and from 34 to 10 ohm m. Third layer is characterized by low resistivity of 0.45 ohm m and the layer is dominated with silt which is indicated that the signature of high saline in the study area.

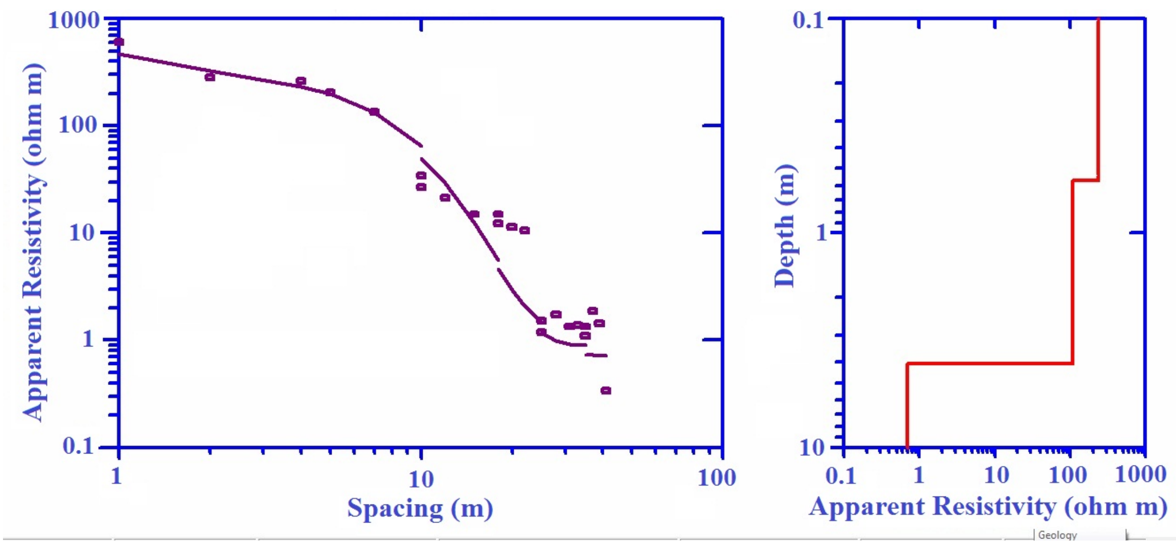

Figure 10 Resistivity curve of the area obtained from vertical electrode sounding.

The results of bore hole logging, GPR survey and resistivity survey were compared to study the geophysical and lithological characteristics of the area.

2.4.3.2 Hydrochemistry

As far the hydrogeological conditions of the area are concerned, groundwater salinity shows seasonal variations according to the water level fluctuations. Buckingham Canal, one of the most contaminated surface water body of the area, which runs parallel to the eastern boundary of the study area, plays an important role in the variations of ionic concentrations of sodium and potassium in groundwater as the river overflows during monsoon. Groundwater salinity is also caused by groundwater over exploitation for agricultural, domestic and municipal purposes which has caused the seawater to intrude towards land. The EC of water in Arani River, close to the study site, ranges in between 2500 and 7000 µS/cm. The salinity in the Arani River has been mainly attributed to the entry of seawater from the Bay of Bengal through the Pulicat Lake towards the land. EC of groundwater at different depths at the pilot site were measured and were nearly 12000 µS/cm at 2 m, 37000 µS/cm at 4 m and 68000 µS/cm at 6m below ground level.

2.5 Conceptual model

Several hydrological, hydrogeological features and practices in the past and nowadays contribute to salinity ingress in the A-K catchment. Groundwater at the coast line is saline and unfit for irrigation purposes. During field visits it was observed that only the salt pan operators abstract groundwater for commercial solar salt production. The residual water from salt pan evaporation is discharged to the environment and percolates through the soil and thereby contributing to salinity ingress. The highly mineralised residual water mixes with the ambient groundwater (which is already saline) and density stratification is developed at the coast line. Spatial extent of this stratified groundwater is difficult to measure, because deep groundwater wells are absent or abandoned. Anyhow, because of lack of substantial groundwater abstraction the groundwater table at the coast line is shallow and builds up a positive hydraulic barrier which counteracts further seawater intrusion. It can be assumed that this positive hydraulic barrier was not existent during the past decades, but developed only in recent years when groundwater abstraction for irrigation was not feasible anymore due to salinity ingress. Shallow dug wells at the coast line often show low electrical conductivity and Na-Ca-HCO_3 composition. Based on the measured hydrochemistry of shallow dug wells it can be concluded that a thin fresh water lense, representing groundwater recharge, is developed above a brackish/saline groundwater body. The dominance of Na over Ca may indicate ion exchange of fresh water infiltration into a brackish/saline aquifer.

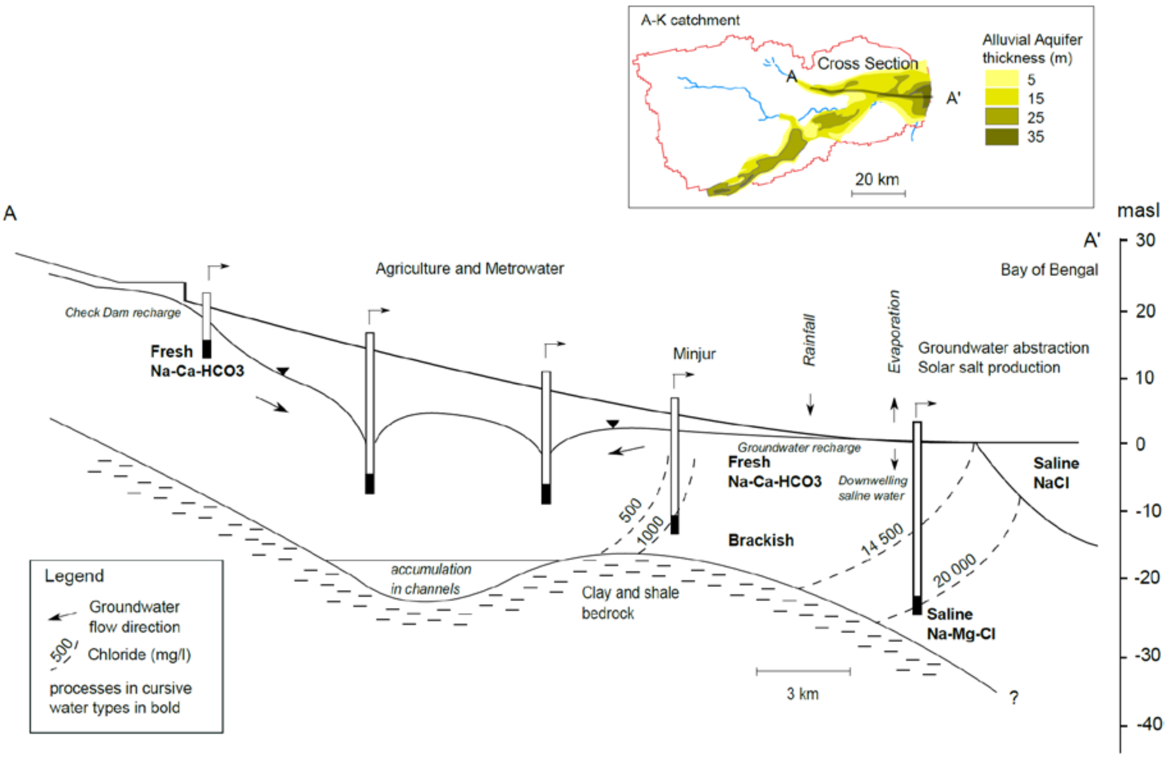

Figure 11 Preliminary conceptual hydrogeochemical model of the A-K aquifer.

Further inland, approx. at Minjur, groundwater abstraction is very common and the groundwater table is locally below mean sea level. Pumping at this area may mobilise brackish/saline water from the coast line and contribute to salinity ingress. The mobilised high mineralised groundwater also descents into sedimentary channels (i.e. paleo channels) and is accumulated over time. The positive effect of check dam infiltration is limited to local scale.

Conclusions for numerical modelling of AK river basin - Shallow groundwater table at the coast line builds up a positive hydraulic barrier - Consideration of historical changes of pumping pattern is essential - River conditions change from ephemeral in the headwater to intermittent at the check dam to perennial at the coast line

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3 Temple Tanks in urban Chennai

3.1 Site description and background information

Out of the 39 temple tanks existing in the pre-expanded Chennai City the following 4 tanks have been selected for the study (Table 5). These are Hindu Temples. Temple tanks are believed to be constructed at the time of construction of the temple itself. The first three have Lord Shiva as presiding deity and the last one has Goddess Suriamman. Interestingly, in the first three cases Vaishnavite temples (where the presiding deity is Lord Vishnu or Perumal) also exist adjacent to the Shiva temple. Devotees of both use the common temple tank. The Temple tanks are considered by the religious minded as sacred as the temple itself. The temple tank water was usually used for temple rituals such as ritual bath of the deity, maintaining temple garden and for the common man for a bath or washing feet and hands before entering the temple. Presently for the temple rituals and gardening, water from a well inside the temple is used. Now the temple tanks are protected with compound wall and gate. Only in the case of Kurungaleeswarar temple tank public are allowed to bathe and perform some religious rites regularly.

Table 5 Name, location, temple tank size and position of groundwater sampling.

Temple Name	Age/ Time of construction	Temple Tank Size (m)	Location	Total depth of well (m)	Distance of well from the temple tank (m)
Aadhipureeswarar	Constructed in 1734 by Adhiappa Naicker	35×33×3.45	13°4'34.90"N 80°16'4.73"E Chindadripet	9.5	35
Agatheswarar	About 500 years old constructed by Bommaraja of Bommarajapuram	45.72×30.48×3.01	13°3'36.13"N 80°14'30.82"E Nungambakkam	9	25
Kurungaleeswarar	About 1000 years old, constructed by King Raja Raja Cholan I of Chola dynasty	54.9×53×3	13° 4'25.41"N 80°11'52.26"E Koyambedu	9.5	32
Suriyamman	About 750 years old	180×100×3	12° 58'21.69"N 80°07'58.29"E Pammal	8.5	15

The tanks are rectangular in shape with maximum water spread ranging from about 800 m^2 to 10 000 square meters and about 3 m deep. The sides are lined in masonry and the last tank has earthen bund. Steps are also provided. There are inlets to the tanks from the adjoining streets to enabling entry of surface run off. Some historical and other information is furnished in Table 5.

The locations of the tanks are furnished below and shown in the index map (Figure 12).

Figure 12 Index map – temple tank locations and aerial views.

Figure 13 Photos of temple tanks.

3.2 Documentation of acquired data

The water quality data and lithology data acquired are presented. Lithology in the vicinity of the first three tanks has been ascertained by drilling bores using hand bore set and analyzing the soil samples collected at different strata. The tanks are located in different sub strata.

- Adipuriswarar Temple Tank at Chindadripet is located in coastal alluvial sub stratum
- Agatheeswarar Temple Tank at Nungambakkam has sub stratum consisting of alluvium of fluvial origin
- Kurungaleeswarar Temple Tank at Koyambedu is in a clayey sub stratum
- Suriamman Temple Tank falls in hard rock terrain consisting of weathered and fractured rock (Charnockite) as sub stratum.

The lithology at the first three sites is shown in the Figure 48 (see annex). Water samples from the temple tank (stored surface water) and observation well (groundwater) at each location was collected periodically and analysed to ascertain the quality parameters.

Table 6 Sampling frequency at selected temple tanks.

S.No	Location	Date of sampling			
1	Aadhipuriswarar Temple -Chindadripet	Jan.2012	Apr.2012	Jul. 2012	Nov.2012
2	AgatheeswararTemple - Nungambakkam	Nov.2011	Apr.2012	Jul. 2012	Nov.2012
3	Kurungaleeswarar Temple - Koyambedu	Nov.2011	Apr.2012	Jul. 2012	Nov.2012
4	Suriyamman Temple-Pammal	Dec.2011	Apr.2012	Jul. 2012	Nov.2012

Analysis was done for about 34 physical, chemical and bacterial quality parameters (desirable/permissible limits) for drinking water as per Bureau of Indian Standards IS 10500-1991 (reaffirmed 1993/2012, BIS 2012) in a reputed private laboratory in Chennai.

Table 7 Summary of critical quality parameters.

Name	Temple Tank	Groundwater
Kurungaleeswarar Temple Koyambedu	All parameters except Aluminium and Mercury in one sample within desirable /permissible limits or below detectable level In April 2012 Aluminium was at 0.452 mg/l against permissible level of 0.2 mg/l In April 2012 Mercury was at 0.004 mg/l against permissible level of 0.001 mg/l Cyanide is absent	All parameters within desirable limits or within permissible limits Zinc, Mercury, Cadmium, Lead, Chromium below detectable level (Nov.2011, April 2012 and July 2012) Selenium below detectable level in 2 samples (Nov.2011 , July 2012) and within desirable limits in April 2012 Aluminium below detectable level in 2 samples(April 2012, July 2012) and within desirable limits in November 2011 Iron below detectable level in 1 sample (April 2012) and within desirable /permissible limits in three, Cyanide is absent
Agastheeswarar Temple Nungambakkam	All parameters except Iron in 1 sample within desirable limits or within permissible limits Iron in July 2012 was at 1.7 mg/l against permissible level of 1.0 mg/l Mercury, Cadmium, Selenium, Lead, Chromium below detectable level Cyanide is absent	All parameters within desirable limits or within permissible limits Aluminium, Copper, Mercury, Cadmium, Selenium, Lead, Chromium below detectable level (December 2011, April 2012 and July 2012) Manganese as Mn was higher than permissible limit in December 2011 at 2.094 mg/l and in July 2012 at 0.77 mg/l against 0.3 mg/l Cyanide is absent
Suriyamman Temple Pammal	All parameters within desirable limits or within permissible limits Copper, Mercury, Cadmium, Selenium, Arsenic, Lead, Chromium below detectable level Cyanide is absent	All parameters except Manganese within desirable limits or within permissible limits. Manganese as Mn was higher than permissible limit of 0.3 mg/l at 0.445 to 0.66 mg/l in December 2011, April 2012 and July 2012 Aluminium, Copper, Mercury, Cadmium, Selenium, Lead, Zinc, Chromium below detectable level (December 2011, April 2012 and July 2012) Cyanide is absent

Table 7 - continued

Name	Temple Tank	Groundwater
Aadhipureeswarar Temple Chintadripet	All parameters except Iron in 1 sample within desirable limits or within permissible limits. In July 2012 Iron was at 1.7 mg/l against permissible level of 1.0 mg/l Cadmium, Selenium, Chromium below detectable level Mercury was below detectable level in January 2012 and July 2012 It was more than permissible limit at 0.002 mg/l against 0.001 mg/l in April 2012 Arsenic was below detectable level in April 2012 and July 2012 and within desirable level in January 2012 Cadmium, Selenium, Chromium below detectable level, Cyanide is absent	All parameters within desirable limits or within permissible limits Copper, Mercury, Cadmium, Selenium, Lead, Zinc, Chromium below detectable level (January 2012, April 2012 and July 2012). Iron below detectable level in April 2012 and November 2012 Aluminium below detectable level in January 2012 and April 2012 Cyanide is absent

The critical quality parameters for drinking water in the samples analysed are mostly within the desirable/permissible limits/below detectable levels. Cyanide, Phenolic compounds and Mineral oil were absent. Only one sample of surface water contained higher levels than prescribed for the following:

Aluminium - 0.452 mg/l against 0.20 mg/l
Mercury - 0.004 mg/l against 0.001mg/l

In the groundwater sample at this location both Aluminium and Mercury were below detectible level. In the subsequent surface water sample these were within the levels and hence the above can be considered an isolated incident.

The rain water runoff collected and stored in the temple tank does not contain any heavy metal or other contaminants at more than the permissible limits. Temple tank water has lesser hardness, total dissolved solids, chlorides and sulphate than the ground water at these locations.

Summary of bacterial quality is furnished in Table 8. Bacterial quality parameters indicate that *E.coli* is absent in all surface water and groundwater samples. Total Coliform in tank water and groundwater was seen to be in the range 8 to 161 MPN /100 ml.

Faecal coliform was absent in the surface water of Suriyamman temple tank. In the other tanks in 4 samples contained Faecal coliform. Thus out of 16 samples Faecal coliform was indicated in 4 samples (November 2011, December 2011, January 2012, November 2012). Out of 16 samples of ground water Faecal coliform was indicated in 7 samples. Faecal coliform in ground water was indicated particularly in the post monsoon period. The possibility may be due to infiltration due to runoff during monsoon rains. In other months it was absent. For Faecal coliform the MPN/100 ml was between 8 and 13. This is within manageable level for local disinfection wherever required. It may be inferred that the temple tank water which is run off from adjoining streets does not have alarming level of bacterial contamination. Temple tank water or the nearby ground water sources analysed are not used by public for drinking purpose.

Table 8 Summary of bacterial quality.

	Aadhipureeswarar Temple		Agastheeswarar Temple		Suriyamman Temple		Kurungaleeswarar Temple	
	Temple Tank	Ground water	Temple Tank	Ground water	Temple Tank	Ground water	Temple Tank	Groundwater
Total Coliform (MPN/ 100 ml)	Present in all 4 samples 28 – 161	Present in all 4 samples 24 – 161	Present in all 4 samples 92 to 161	Present in all 4 samples 54 to 161	Present in all 4 samples 8 to 92	Present in all 4 samples 54 to 161	Present in all 4 samples 28 to 161	Present in all 4 samples 54 to 161
E.Coli (MPN/ 100 ml)	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent
Faecal Coliform (MPN/ 100 ml)	Absent in 3 samples 11	Absent in 2 samples 8 - 13	Absent in 3 samples 11	Absent in 2 samples 8 - 8	Absent in all samples	Absent in 3 samples 8	Absent in 2 samples 8 -13	Absent in 2 samples 8 - 13

3.3 References

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4 Percolation pond – Tummulur tank in Maheshwaram

4.1 Site description

The percolation pond studied in the Saph Pani project is included into a watershed investigated by numerous studies (geology, hydrogeology, geophysics, GIS, geochemistry) over the last two decades. The experimental watershed monitored for MAR studies is located around the town of Maheshwaram. With a total area of 54 km^2, it is located in a semi-arid hard-rock context typical of the region where the saprolite layer (10-20 m thickness) is usually unsaturated and where the fissured layer of crystalline rocks is the main productive zone. Hydrodynamics of the region has been previously well documented (Dewandel et al. 2006). It is a watershed with a high density of groundwater production wells (>700 wells) mostly used for paddy irrigation. Changes in land use have occurred since 2006 due to the new Hyderabad international airport located less than 10 km away. The area is expected to become peri-urban within the coming years as significant housing projects are planned. Intensive groundwater exploitation for irrigation has resulted in aquifer over-exploitation (Dewandel et al. 2010) and deterioration of groundwater quality including fluoride above maximum permissible limit of 1.5 mg/L (Pauwels et al. 2010, Pettenati et al. 2012), salinization (Perrin et al. 2011) and important increase of agricultural inputs as nitrates (Khan et al. 2010). MAR is an attractive concept for groundwater augmentation and to enhance groundwater quality on nearby wells exploited for domestic uses. Implementation of MAR structures is recommended by the state of India and the Central Ground Water Board (CGWB, 2000, 2002, 2007, 2011). The government of Andhra Pradesh set the objective to increase aquifer recharge from 9% of the total rainfall under natural conditions to 15% by 2020 using MAR at the state level. The number of MAR structures in India is estimated to be 0.5 million, with 0.25 million installed in hard rock area (Sakthivadivel 2007). Despite of the common view and some studies (Sophocleous 2000) show that aquifer management is an essential tool to face the actual water scarcity problems, various authors as Dillon et al. (2009) point out the lack of data available for assessment and that little evidence exist on the positive impact at local scale. Some authors (Glendenning et al. 2012, Sakthivadivel 2007, Calder et al. 2008) even point out the possible negative impact on watershed scale. Following Glendenning et al. (2012) watershed studies are underrepresented and that this scale is mainly approached by modelling with limited focus and limited data. Therefore field data collection and modelling need to be developed in tandem (Silberstein 2006). Even if limited in number, some studies exist on those percolation tanks (Perrin et al. 2009; Metha et al. 1997; Gale et al. 2006), no clear statement exist about their efficiency and the methodology for its assessment. For example CGWB (2011) record efficiency (ratio $^{infiltrated\ volume}/_{total\ stored\ volume}$) up to 98% while most of the studies record lower efficiency (44% in Perrin et al. 2009 and 57% in Metha et al. 1997). Glendenning (2012) highlight the absence of data particularly in semi-arid area where rain water harvesting structures seems the most suitable.

4.2 Problem statement/motivation

MAR has been implemented throughout the Maheshwaram watershed in the form of percolation tanks, check dams, defunct dug wells, etc. over the last decade. Three percolation tanks are present in the watershed.

The objective of the tasks in WP2 for the case study site in Maheshwaram is to investigate the potential of percolation tanks to enhance recharge and groundwater quality in the underlying overexploited hard-rock aquifer by implementing a monitoring strategy for groundwater levels and quality, conducting hydrogeochemical analyses and investigating the hydrodynamics with the support of a reactive groundwater model developed in cooperation with WP5.

Modelling has been done previously for water level prediction (Dewandel et al. 2010) but is not able to take into account explicitly effect of percolation structures on water quantity, availability and quality at a local level. Further developments are needed to fill those gaps and to develop efficient tools which may be used on other areas to enhance the management of those structures.

4.3 Objectives

Maheshwaram is an overexploited watershed and therefore groundwater management should be improved. MAR through percolation tanks may be part of the solution. Some percolation tanks already exist in the watershed but no clear data is available on their efficiency from a quantitative and qualitative point of view in an area prone to important fluoride contamination. Understanding those processes is of prime importance as the number of structures is high and only few data on hard rock aquifers is available (Perrin et al. 2009; Metha et al. 1997; Gale et al. 2006). The main questions are the following:

- How do these structures act on local and on watershed scale?
- Do these structures increase water quality by dilution or enhance geogenic production of fluoride?

Hard rock hydrodynamics are complex. By integrating all relevant elements (intensive rainfall, preferential flow path through fractures) estimations and predictions of the tank behaviour can be carried out by numerical modelling. Chemistry is also important and mainly related to fluoride problems (Pauwels et al. 2010, Pettenati et al. 2012) as fluorosis affects an important part of the children population (Bouzit et al. submitted). Complex interacting mechanisms such as cation exchange, precipitation, mineral dissolution, thermodynamic equilibrium should be taken into account as shown by Pettenati et al. (2012). To tackle those problems data collection and modelling should be done conjointly.

The objectives of numerical modelling are to identify the main relevant mechanisms to predict the effects of those structures both on quality and quantity and extrapolate the results to the watershed scale. Effects of the highly variable monsoon and different management options can be tested by scenario modelling.

4.4 Documentation of data used for modelling

Documentation available for modelling can be divided in two groups of different scales:

- The first group gathers data and knowledge previously acquired on the watershed hydrogeology
- The second group focus on the local hydrogeology of the tank

The first set of data is at the watershed scale and comes from previous works carried out at the Indo-French Centre for Groundwater Research (IFCGR) through various projects. The data is listed in the following:

Geology

- Various drilling reports and observations
- Geological map
- Weathering thickness maps

Hydrology

- No permanent streams

Hydrogeology

- Water levels records: 2 wells IFP9 & IFP5 monitored from 2002 to 2012 (15 minutes time step); more piezometers monitored previously
- Piezometric campaigns: twice a year from 2001 to 2012 (~100 wells)
- Piezometric monthly data in 25 selected wells (2000 to 2008)
- Infiltration, pumping tests on IFP wells (~25)
- Well inventory with discharge measurements (2002)

Meteorology

- Monthly rainfall 1984 to 2012
- Instant rainfall: 2000 to 2010
- Temperature, wind velocity, evaporation: (2000 to 2008)

Landuse

- Two interpreted satellite imagery (2003, 2008)

Soil structure

- PhD, de Condappa et al. (2008)

Chemical data:

- Sampling campaigns at the watershed scale:
  a) 2006 – 4 campaigns (January, March, June, November) - 22 boreholes – anions, cations, traces
  b) 2008 – 1 campaigns (June) - 10 boreholes – anions, cations,
  c) 2009 – 2 campaigns (February, September) - 10 boreholes – anions, cations, traces
  d) 2011 – 1 campaigns (June) - 10 boreholes – anions, cations, traces
- Groundwater dating: 2 Campaigns – June 2008, February 2009 – CFC, SF_6

Specific location: Experimental paddy field: 03/02/09 to 19/03/10 – anions, cations, traces

Rainwater: Since 2008, anions, cations, traces, stable isotopes (O^{18}, D)

All data is available at IFCGR, included in a data base and relevant data are included in a GIS. The available set of data is already good, but significant data is still missing or incomplete.

4.5 Acquired data and conceptual model development

On the tank scale, the data acquired during the Saph Pani project allows the definition of a reliable conceptual model for one year. This document focuses on the tank data acquired during the Saph Pani Project (Table 9).

Table 9 List of data collected during the Saph pani project.

Data type	Starting date
Drillings logs	
Water level measurements -piezometers	06/07/2012
Water level measurements -tank	06/07/2012
Tank area monitoring	01/05/2012
Geophysics	
Electrical resistivity tomography (ERT) profiles	
Topography - DGPS measurements	
Rain, Evapotranspiration and Temperature Measurements	01/01/2012
Hydrodynamic experiments	
Slug test MHT2	
Irrigation bore wells discharge measurements	

Drilled bore well locations are provided Figure 14.

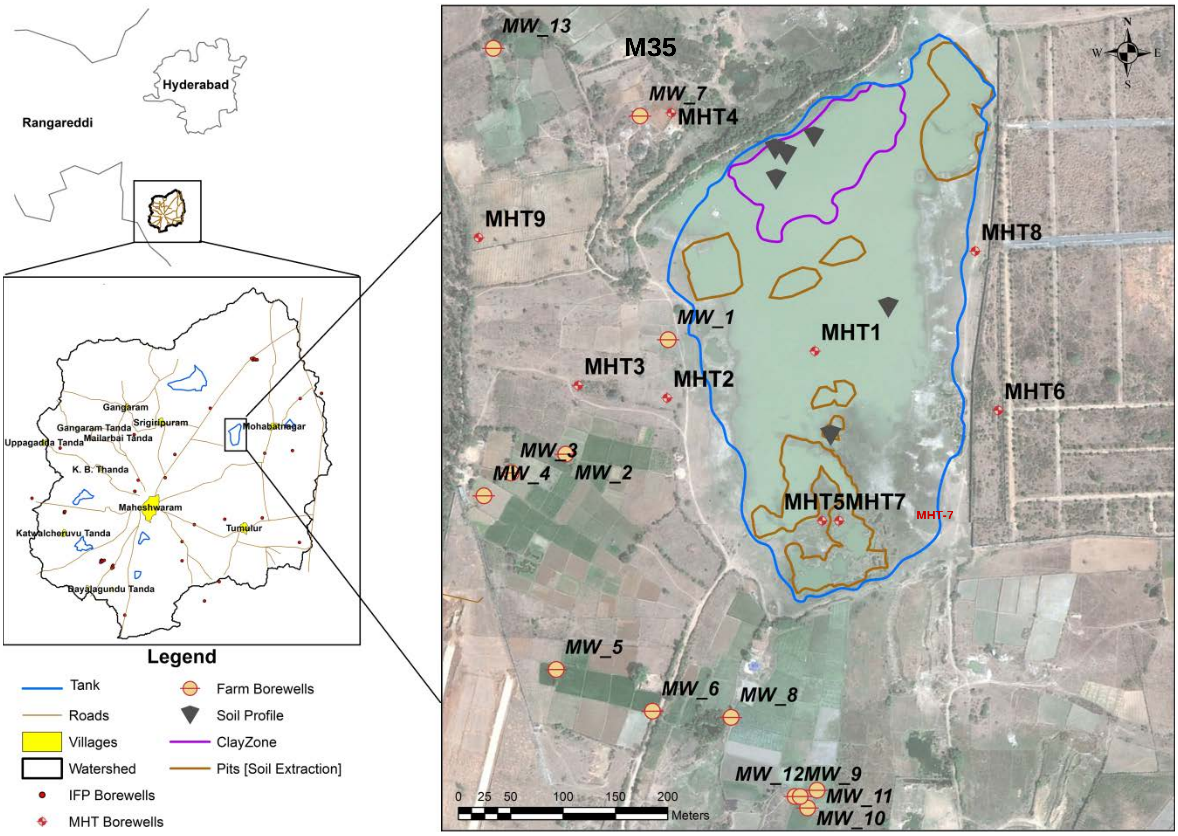

Figure 14 Location and map of the study area with in red bore wells drilled for the SaphPani project (named MHT's) and in yellow the farming bore wells (named MW's). The blue contour represents the maximum tank extension, the brown contour the clay zone and in purple the pits where clay has been extracted to be used by the nearby brick industry. Soil profiles (triangles) are shown in Figure 51 (see annex).

The main data gap at the actual state of development of the project is from chemical data. During the first year of the project no data were collected. However, previous existing data highlight the fluoride problem in the study area.

Variability of the monsoon is important and, as it will be shown further in this document has an important impact on the tank behaviour. To tackle this problem the tank should be monitored at least one more year.

4.5.1 Meteorological data

Instant rainfall is continuously recorded. Rainfall occurs following the monsoon from June to November with an important variation in the intensity. In 2012 cumulative rainfall was 698 mm while cumulative evaporation was 2320 mm/year, showing an important stress on the area. The rainfall evolution over the year in Maheshwaram is given Figure 49 (see annex) and the measured daily evaporation as well as temperatures are provided in Figure 50 (see annex). A correction factor may be needed for evaporation due to location change, an open class A evaporation pan is also installed on the study site.

Rainfall can be highly variable on the area. The data recorded on the Maheshwaram meteorological station other the last 10 years provide an average of 853 mm/year, with a maximum of 1523 mm in 2008 (Table 10).

Table 10 Yearly cumulative rainfall on the Maheshwaram watershed.

Year	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	Mean
Rainfall (mm/ year)	594	896	575	1042	733	791	1523	792	1206	535	698	853

4.5.2 Tank soil structure and surface infiltration

The tank has a maximum potential surface area of 113 500 m^2 (blue contour in Figure 14), but its filling depends on the yearly monsoon conditions. The tank soil structure is not homogeneous and therefore infiltration rates vary spatially. In 2012 due to moderate monsoon rains, the flooded area was only of 21 300 m^2, limited to the low lying clayey zone of the tank with low infiltration capacity (brown contour in Figure 14). Except the clay zone, most of the tank surface is composed of a sandy-silty soil with shrinkage cracks. However, pits created by clay removal by a nearby brick industry, displayed by red contours in Figure 14, are preferential zones for infiltration.

The flooded area in 2012 and the spatial extent of the clay zone are almost identical, showing the impact of this clay zone to retain water while infiltration is substantial in the rest of the tank. The tank clay zone has a low permeability when initial shrinkage cracks close due to swelling.

Auger drillings have been done and reveal that the thickness of the clay zone is around 80 cm. Profiles obtained from the auger drillings are given Figure 51 and localisation is shown Figure 14 (grey triangles). Soil composition is mostly sandy to silty as shown Figure 52 (see annex). In situ infiltration measurements by double ring infiltrometer, give infiltration rates of 190 mm/day for the cracked silty/sandy zones of the tank. Laboratory saturated permeability measurements, give lower permeabilities ranging from 1.16×10^{-8} m/s to 3.63×10^{-8} m/s. Those permeabilities are low and highlight a low potential infiltration rate in the absence of shrinkage cracks. However, drying conditions varied a lot over the year and numerous shrinkage cracks are present most of the time on the complete tank surface. Except on the flooded zone, the water added by a raining event is not sufficient to allow saturation and complete swelling of the shrinkage cracks. Consequently, despite of a low saturated permeability, during rain events initial infiltration rates can be higher than expected by those measurements. Moreover, strong drying before water addition maintains the structure of the cracks and cracks can still be active as preferential flow paths (Greve et al. 2010).

4.5.3 Tank water level and area

Tank water levels are continuously monitored using 1) automatic water level recorders and 2) a scale installed in the middle of the tank for direct visual observation. Water level evolution during the year is shown in Figure 15. No stagnant water was observed outside the clay zone of the tank in 2012.

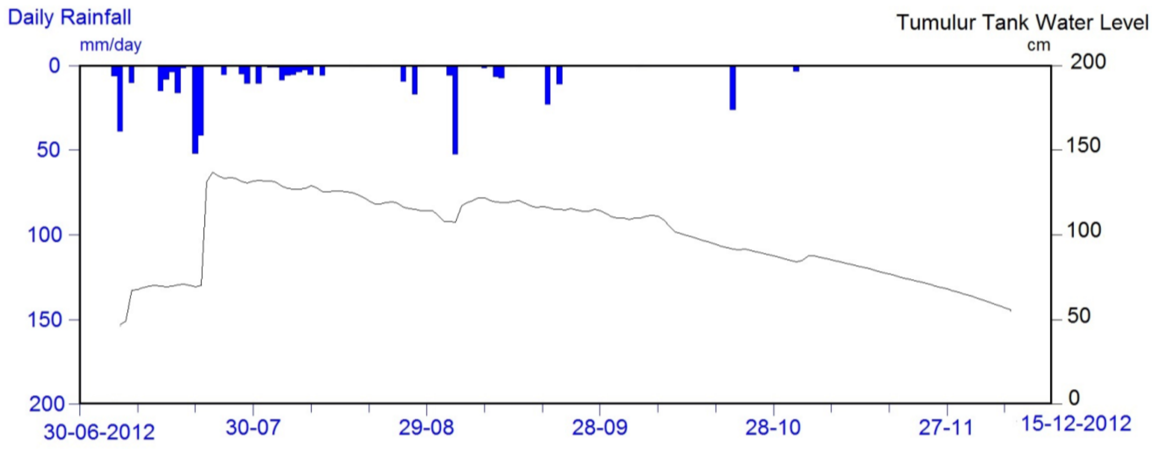

Figure 15 Recorded water level in the tank in 2012.

Comparison between daily rainfall and water level show that tank replenishment occurs as a step function with strong and fast increase only during main rainfall events. Rainfall events above 39 mm/day are contributing to most of the tank fillings. Study of instant rainfall intensity will provide information on the tank filling mechanisms.

The decay slope is 8 mm/day and includes infiltration plus evaporation. This tank was not used for irrigation, and the cattle output appears to be very limited; therefore this water budget component can be neglected. Mean evaporation during this period is 4 mm/day. Hence, large part (~50%) of the stored water is evaporated while the rest infiltrates. This result is in accordance with the study of Perrin et al. (2009) conducted under similar conditions.

The spatial extent of the tank monitored by GPS allows the observation of the tank area evolution (maximum: 21 330 m^2). Strong uncertainty exists below 7 000 m^2. The integration the daily water level change and the tank surface area allows estimating the tank volume (maximum: 12 660 m^3). By the end of December the tank was dry. The present measurements system does not allow recording values of tank water level below 40 cm. Evolution of the tank area is given Figure 16.

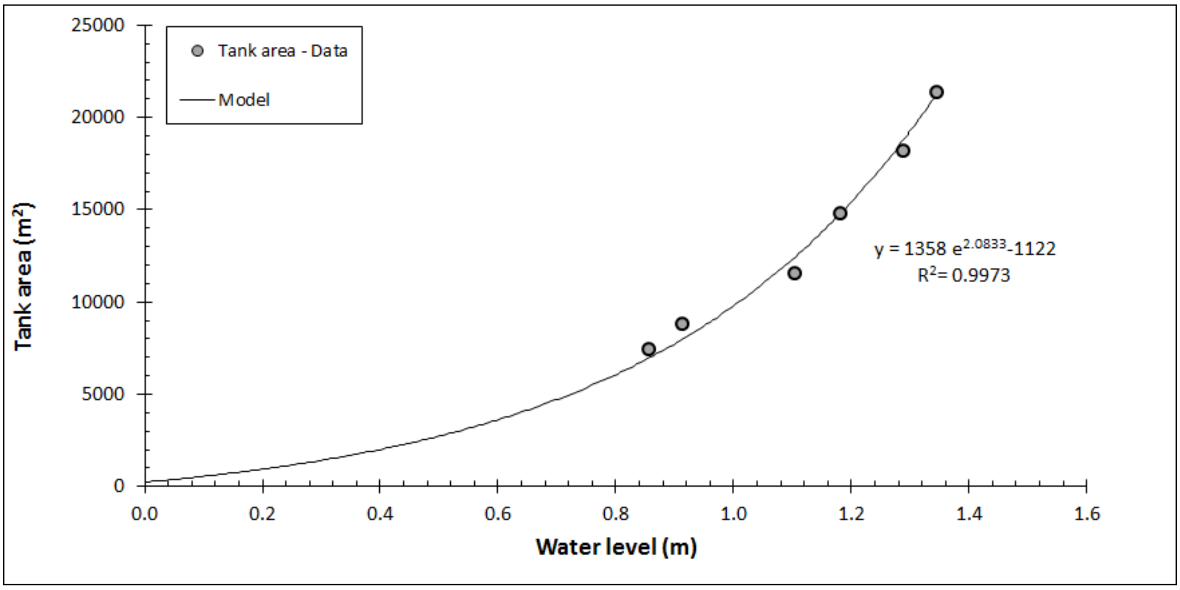

Figure 16 Tank area variations with water levels.

4.5.4 Geological structure and hydrodynamics

During drilling of the MHT's bore wells for the Saph Pani project, cuttings were collected approximately every meter (3-4 samples for each rod). Change of color, soil mineralogy and humidity are observed. Cuttings were kept in labeled plastic bags. After drilling, samples were washed and spread successively on the ground for comparison (work carried out on campus). Geological logs were made based on field and lab observations. The cutting samples for each hole were kept in metal boxes at IFCGR, NGRI, Hyderabad for record and further investigations.

Summary of the drilling depths, alteration profile depths and localization of productive fractures are given in Table 11. Geological logs are presented in the annex (Figure 53 - Figure 58) and more details are available in the report of Viossanges et al. (2012).

Table 11 Drilling depth, alteration profile depth and productive fracture localization in the MHT's bore wells.

Bore well name	Drilling depth (m)	Saprolite bottom depth (m)	Fissured granite bottom depth (m)	Productive fractures	
				Number	Depth (m)
MHT1	73	16	50	1	14
MHT2	78	12.5	70	1	17
MHT3	45	20	30	-	-
MHT4	32	6	25	-	-
MHT5	87	14	70	1	20
MHT6	45	10	40	1	15

The drillings show a low thickness of the saprolite layer and a low density of productive fractures located at the bottom of the saprolite or below. Other fracture zones have been observed by mineral alteration due to fluid flow (oxidation marks as iron oxide presence) but only few where hydraulically productive. Those observations are in accordance with the conceptual geological model developed by Dewandel et al. (2006) summarized in Figure 17.

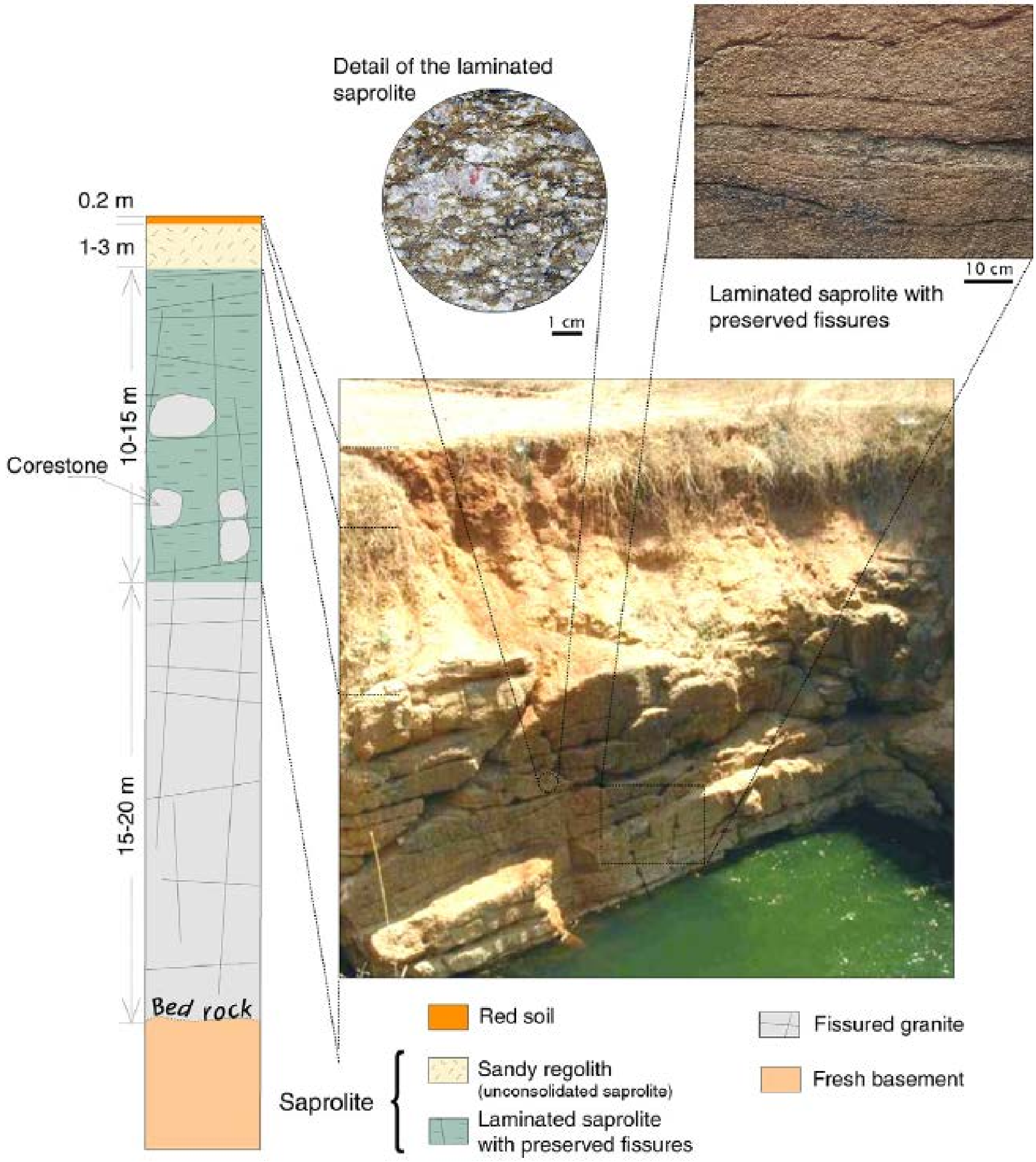

Figure 17 Weathering profile of Maheshwaram area. The dug well, located in the biotite granite, shows the upper part of the weathering profile: sandy regolith (1m), and more than 2m of laminated saprolite with unusual subhorizontal and subvertical fissures (Dewandel et al. 2006)

The previous studies carried out on the Maheshwaram watershed characterized the hydrodynamics of the different alteration layers (Dewandel et al. 2006, 2012; Maréchal et al. 2004). On weathered hard rocks aquifers, saprolite is considered as the main storage reservoir while the fracture zone may store only a limited volume. Saprolite is often considered as a porous media. From the measurements done on the Maheshwaram watershed, (Dewandel et al. 2006) permeability is found to be variable from 1×10^{-7} m/s to 3×10^{-5} m/s, with a geometrical mean of 2×10^{-6} m/s. Total porosity is considered to be relatively high (up to 10%), (Compaore et al. 1997; Wyns et al. 1999, 2004; White et al. 2001; Begonha and Braga, 2002). Nevertheless, as clayey materials are characterized by small pore sizes the effective porosity is only a few percent (0.5–10%; Bodelle and Margat, 1980; Compaore et al. 1997; Wyns et al. 2004).

Hydrodynamic properties are different in the fissured layer. Information from pumping tests interpretations (Maréchal et al. 2004), show a good connectivity between the fissures which induces an anisotropy of hydraulic conductivity. Maréchal et al. (2003a,b, 2004) founded a vertical anisotropy ratio close to 10 (K_{horiz} /K_{vert}), which is in agreement with the geological observations. The effective porosity of the fissured layer is relatively low, about 10^{-2}, and is mainly (90%) ensured by small fissures affecting the blocks (block permeability, including small fissures: 5×10^{-8} m/s, in this area), while the main conductive fissure network contributes only 10% to the effective porosity (Maréchal et al. 2003b, 2004).

Data obtained from the drilling cuttings were compared with five electrical resistivity tomography (ERT) profiles made in the tank area. Localisation of the ERT profiles is given Figure 18.

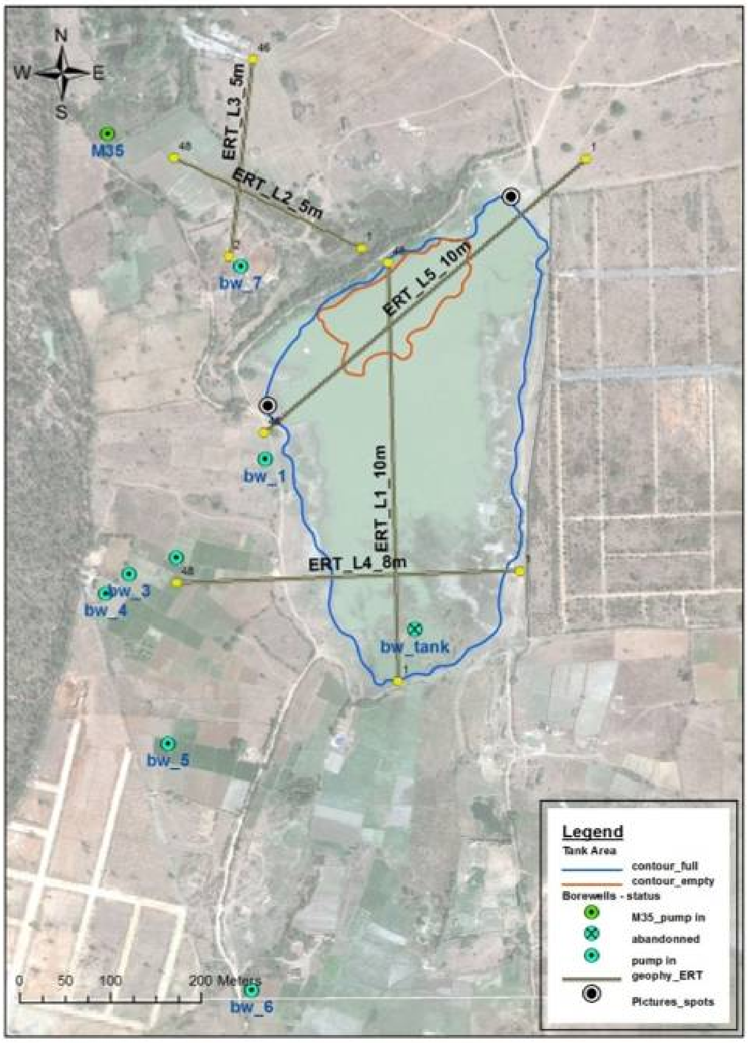

Figure 18 Localisation of the Electrical resistivity tomography (ERT) profiles.

The L1-ERT profile (Figure 19) shows an increase of the saprolite layer thickness from north to south. The obtained data is in agreement with the observations of the bore cuttings as shown in Figure 19. These profiles were used to complement previous data obtained and published (Chandra et al. 2008) on watershed scale to produce maps of saprolite thickness and alternated zone thickness (Figure 20 a & b) on tank scale. ERT data was integrated to the previous datasets by interpolated with kriging method.

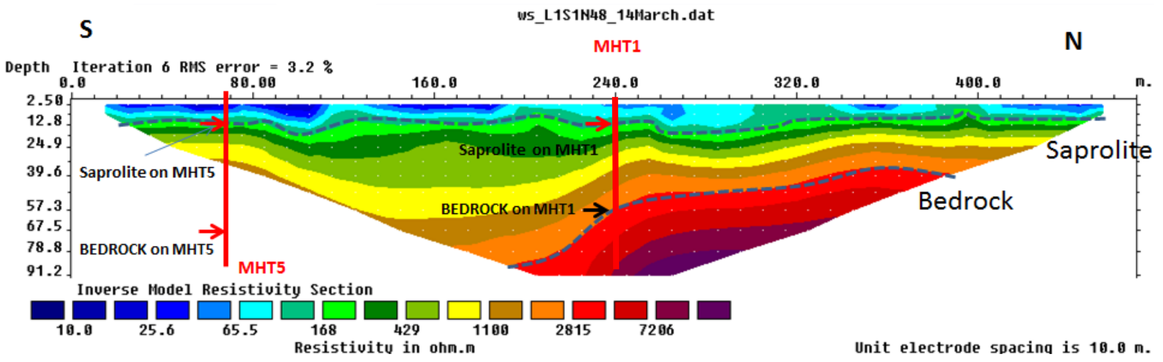

Figure 19 ERT Profile L1.

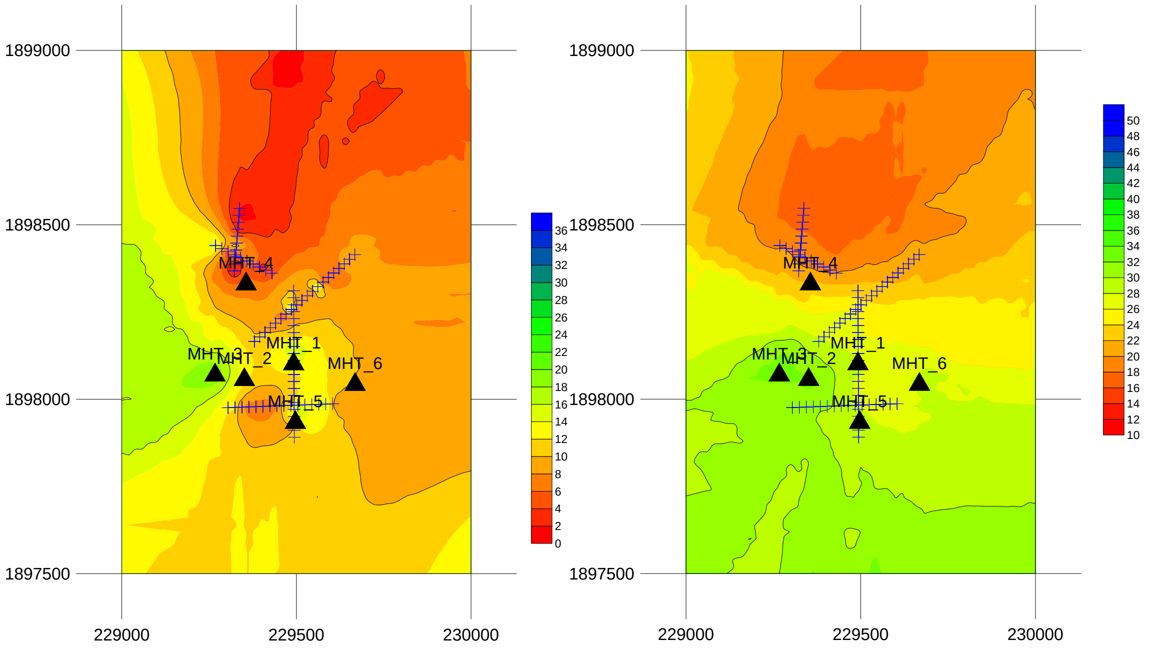

Figure 20 a) Weathered zone thickness (saprolite + fissured zone) and b) saprolite thickness.

Despite the apparent simplicity of the system, those hard rock aquifers are also subject to partitioning depending of the groundwater level (Guihéneuf et al. 2012). On those hard rock aquifers, the decrease of fracture density with depth has been identified (Dewandel et al. 2006). When water levels are high (within the saprolite layer and upper fissured zone), important weathering and fracture connectivity creates conductive networks and therefore aquifer extension can be important. However, when the water levels decreases, productive zones are composed of few poorly connected discrete fractures, which creates isolated aquifer clusters of limited extension. Available volume for pumping from a given bore well is therefore much more limited. Under low water level conditions, permeability and solute transport is then controlled by a few discrete fractures which need to be identified for accurate predictions. This partitioning depends of the fracture connectivity (Perrin et al. 2012) but may also come from special structures as quartz reef at a larger scale (Dewandel et al. 2011).

4.5.5 Groundwater monitoring

Ground water monitoring has been done manually and is now performed automatically using water level recorder. Water level evolutions are presented Figure 21.

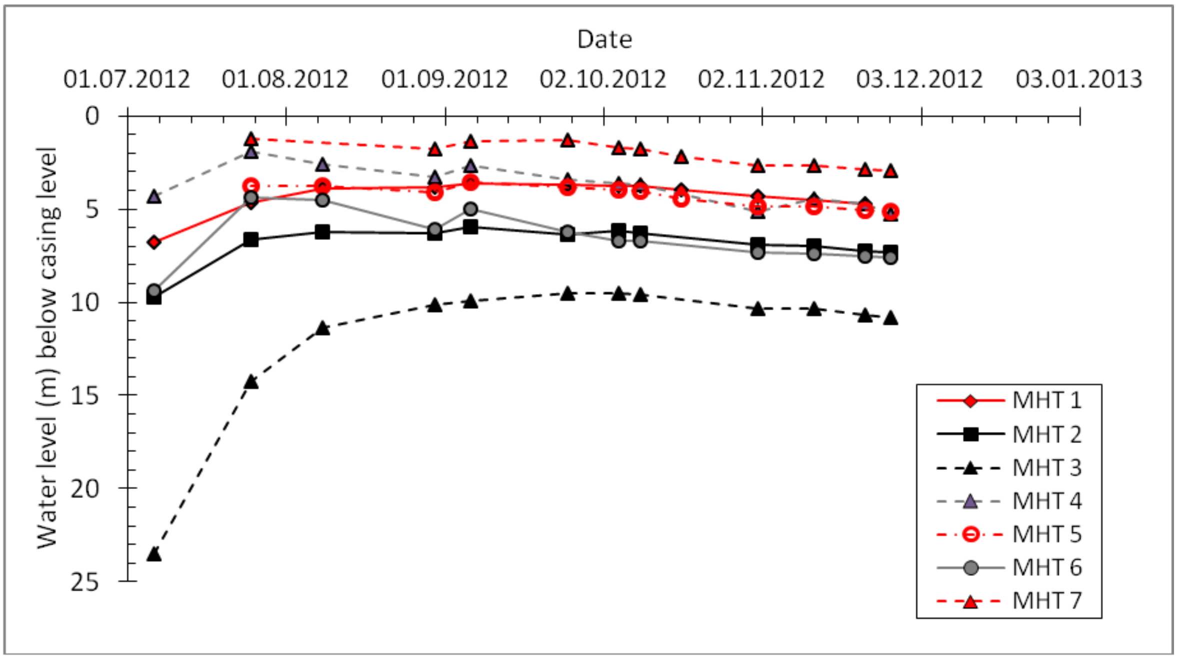

Figure 21 Water level in the MHT's bore wells. All wells are cased until the bottom of the saprolite.

Although a rise of the water levels was observable, infiltrated water was not sufficient to refills completely the aquifer and the water levels start decreasing since the end of September. As no stagnant water was observed in the tank except in the clay part, it highlights that infiltration rate are important and that to flood the complete tank area the soil should be completely saturated. The high infiltration rates on this area do not allow sustaining perched surface water body. This is of great importance for the tank behaviour as only above average monsoon can fill the tank. The first rain induces a strong rise of the water levels (eg: MHT3) due to the low porosity in the deeper part of the aquifer (controlled mostly by few fractures), and then reaching the saprolite the rise is lower due to a higher porosity.

High frequency data accessible by the automatic water level recorder show rapid rise of the water level after a raining event, highlighting the presence of preferential flow paths Figure 22.

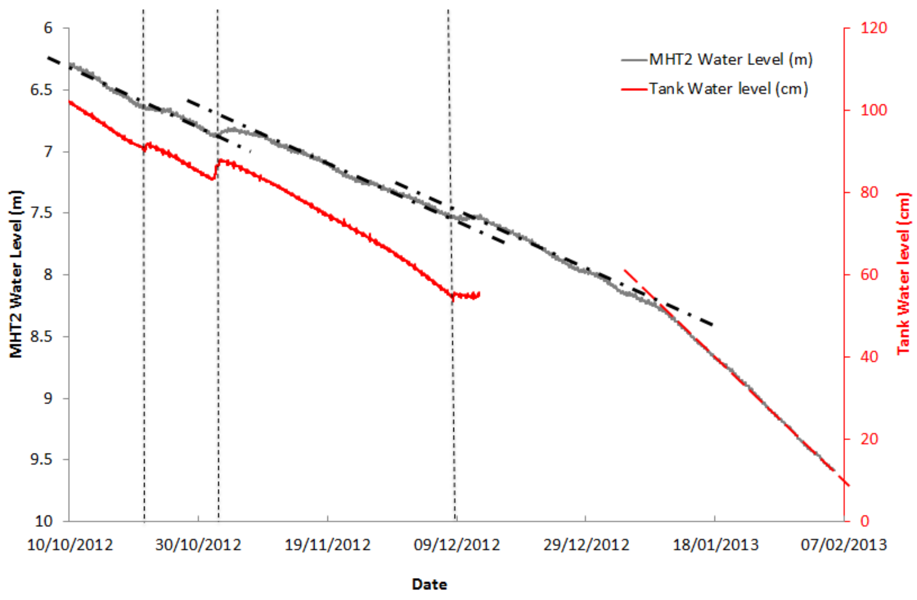

Figure 22 Water level evolution in the tank (in red) and in the bore well MHT2 (in grey). Vertical dashed bar highlight the raining events and the black and red lines the slope change in the MHT2 bore well.

Comparison between MHT2 water levels and the water level recorded in the tank show important correlation. Each event induces as expected by runoff an increase of the water level in the tank but also in the bore well where levels are below 6 m depth. This shows the possible presence of rapid vertical flow paths and/or a connection with the tank. Decay slope of the water level in the bore well is almost constant (black lines on Figure 21) except after the 6 of January where the decay slope is more important (red line). This date may be in correlation with the drying date of the tank which has not been recorded below 50 cm. Those slope changes are not correlated with any change in the weathering profile structure of the rocks. Further investigation on the possibility of vertical flow path or connectivity of the bore wells with the tanks is needed.

A slug test carried out in MHT2 show a permeability of 2×10^{-6} m/s in accordance with the results of Dewandel et al. (2006) on the complete watershed (average 2×10^{-6} m/s for the saprolite).

4.5.6 Land use and groundwater extraction

On the surrounding of the tank, various crops are grown (rice, vegetables, maize), irrigated by 15 bore wells where extraction has been monitored. Flow rates are monitored using graduated bucket and stopwatch. The flow rates monitored on the various bore wells range from 5.8 m^3/h to 22 m^3/h with an average of 12.3 m^3/h. Discharge rates and coordinates are given Table 12 and the localisation in Figure 23.

Table 12 Farmer bore wells localization and flow rate.

Well ID	Coordinates		Discharge rate (m^3/h)
	X	Y	
MW-2	229254	1898002	9.1
MW-4	229176	1897962	17
MW-5	229245	1897795	19.9
MW-6	229337	1897755	8.9
MW-7	229382	1897726	9.1
MW-8	229395	1897761	10.8
MW-9	229412	1897749	10
MW-10	229494	1897679	16.4
MW-11	229473	1897673	9.1
MW-12	229485	1897662	5.8
MW-13	229185	1898392	22
Average			12.3

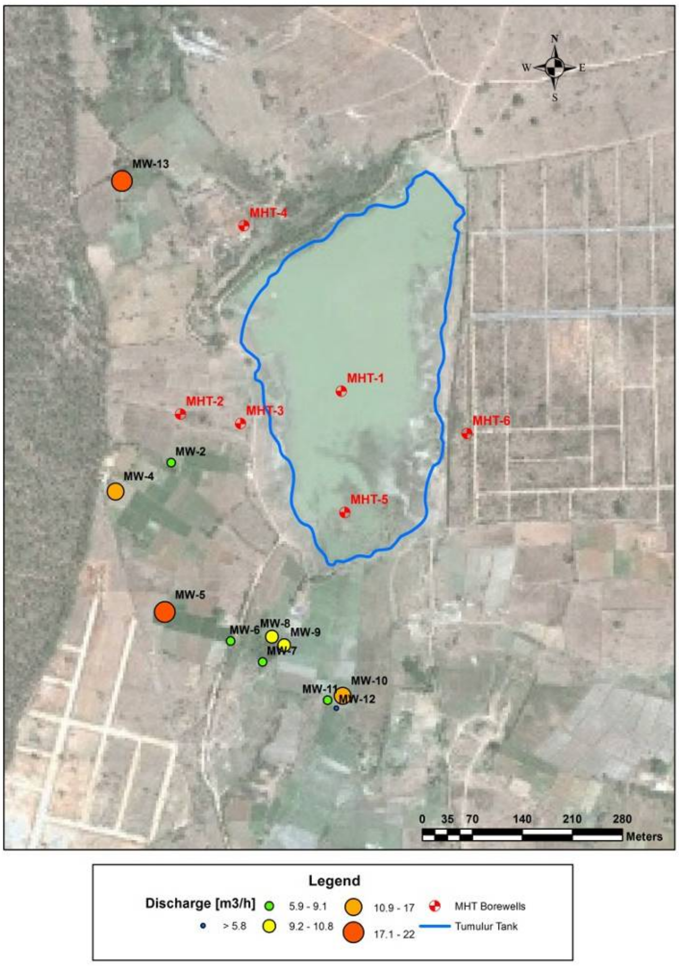

Figure 23 Farmer bore well localization and discharge rates in the surrounding of the tank.

Irrigation duration and pumping times are controlled by the electricity available provided by the Andhra Pradesh Central Power Distribution Company Limited (APCPDCL). Cost-free power is supplied about 6 hours a day according to a fortnight alternating schedule: (1) from 01:00 to 07:00 or (2) from 22:00 to 01:00 and from 10:00 to 13:00 on two different sectors. Anyhow, the duration and start/stop times of power supply are variable and subject to power cuts. For an accurate monitoring, ibuttons for temperature measurement on pump pipes are installed for each sector as described in Massuel et al. (2008). This will allow the accurate measurement of pumping schedules.

4.5.7 Water quality

To date no chemical sampling has been done during the Saph Pani project. However previous monitoring and studies on water quality have been done on the area. Those studies highlight the importance of the fluoride problem in the area, mostly related to rice paddy irrigation due to an important return flow (Pauwels et al. 2010).

Over the 240 water samples collected on the watershed between 2006 and 2009, 43% reveals fluoride concentrations above WHO permissible limit of 1.5 mg/L and, considering the limit of 1 mg/L recommended by the BIS (2012), this percentage rises to 83.5% with a maximum observed concentration of 4.67 mg/L.

Figure 24 show the fluoride concentration repartition over the watershed from a sampling campaign carried out in 2009.

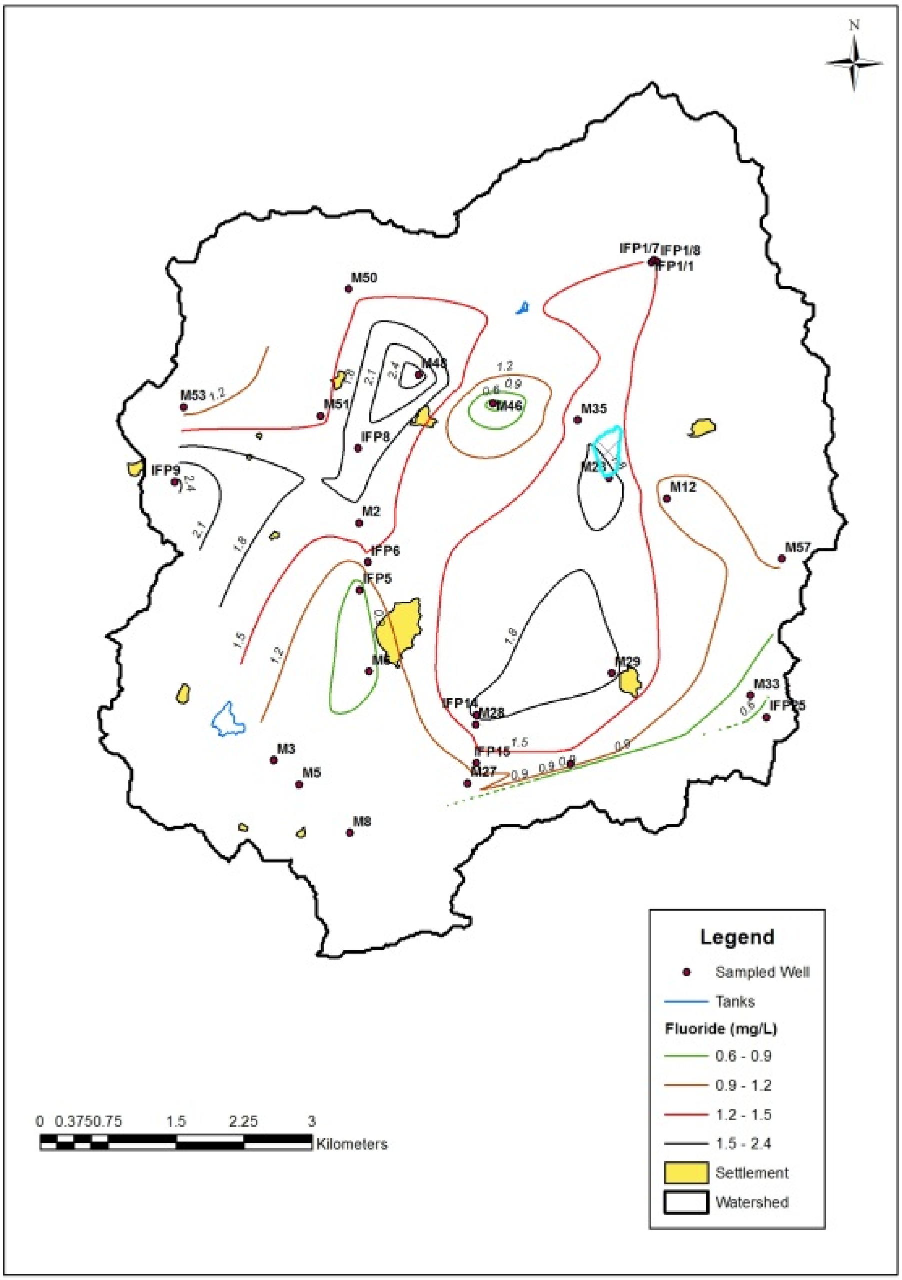

Figure 24 Fluoride concentrations in the watershed during the sampling campaign in February 2009. (Data interpolated through natural neighbor interpolation). Red lines refer to the WHO of 1.5 mg/L. Tummulur tank is highlighted in light blue on the eastern part of the watershed.

Elevated F^- concentrations in drinking water may lead to serious health problems such as fluorosis, skeletal fluoride, and mental dementia especially for children. Impact of fluoride on the watershed population has been identified only recently (Bouzit et al. submitted). This study reveals that large part of the children population is affected by dental fluorosis.

A modelling study by Pettenati et al. (2012) on fluoride release under rice paddy fields with irrigation return flow reveals that among the minerals containing fluoride in granites fluorapatite ($Ca_{10}(PO_4)_6F_2$) is the main contributor. Those results are in accordance with the results of Negrel et al. (2011) who showed through Pb isotopes that the water geochemistry reflect the weathering of the primary mineralogy (plagioclases and K-feldspar) as well as accessory minerals such as fluorapatite, allanite and biotite. The mechanisms controlling the fluoride release are the cation exchange capacity (CEC) in Ca/Na exchange and calcite precipitation, the kinetically controlled mineral dissolution and the possible immobilization by adsorption through precipitation of iron hydroxides. Anthropogenic sources such as fertilizer appear to be limited.

In the surrounding of the Tummulur tank, one well (M35 - Figure 14) was monitored from 2006 to 2009. A total of 17 water quality parameters regulated for potable use were evaluated. The observed pH and TDS values were within the permissible limits, except in June 2008, when the TDS was slightly higher than 1000 mg/L. Results of the average concentration of the major elements were within their corresponding guideline values, except for magnesium, fluoride and calcium in few seasons. The major threat for the human health is high concentration of fluoride (average =1.95 mg/L). Throughout the seasons the well showed an elevated concentration of F^- with a maximum of 2.27 mg/L in March 2006. Those high concentrations may be related to the closely located paddy irrigation which tends to increase F^- concentrations (Pauwels et al. 2010).

As a geogenic contaminant fluoride is present all over the watershed and recent studies carried out in the watershed (Pauwels et al. 2010) highlight the relation between fluoride concentration and land use, especially the impact of rice paddy fields by irrigation return flow. As shown by Pettenati et al. (2012) fluoride release is a complex system involving, kinetic dissolution of minerals, cation exchange, and thermodynamic equilibrium. Fluoride release kinetics determination can hardly be done directly in situ, but good understanding of hydrodynamics on the site, travel time determination coupled with chemical sampling will allow quantifying the positive or negative impact of the structure. Reactive transport modelling should then be done for a better evaluation and quantification of the impact with the help of the collected data. This reactive transport modelling is included in the Saph Pani project where the reactive code PHREEQC, will be implemented in the 3D transport code MARTHE (Thiéry 1990, 1993 and 1995) for an integrative study.

4.5.8 Conceptual model summary

During low intensity rainfall events, most of the water infiltrates directly through the soil mainly due to the presence of shrinkage cracks on the tank surface. Rainfall events above 39 mm/day are needed to generate sufficient runoff to fill the tank (Figure 15). The flooded area is limited to a clay area located in the northern part of the tank. While stored in this area, the water level decreases at a velocity of 8 mm/day. In 2012 the infiltrated volume was equal to the evaporated volume of 6750 m^3 as discussed before. This shows the low efficiency of the structure as 1) 50% of the stored water is evaporating and 2) the recharge volume (6750 m^3) is limited. In comparison to the groundwater extraction in the surroundings (500 meter radius) of the tank, the infiltrated volume corresponds to 91 days of pumping with an average measured pumping rate (12.3 m^3/h) and a pumping time of 6 h due to electrical power supply restrictions. From the study of Dewandel et al. (2008) the average agricultural field size is known to be 7500 m^2 and the average water input for crop irrigation is 15 mm/d. Under these conditions, the total infiltrated volume from the tank represents 60 days of irrigation for one average size field which is equivalent to 1 crop. Integrating the 15 bore wells (total extraction 135 m^3/h during 6 hours) it only represents 8.3 days of groundwater pumping for irrigation in the nearby area (500 m radius). In 2012 no runoff left the watershed and therefore this structure has no net beneficial impact on the watershed water budget as it only redistributes the water. Evaporation is in this case a net loss at the watershed scale.

Monsoon intensity is highly variable and under strong monsoon years the impact of the structure can be beneficial. In December 2011, while the total cumulative rainfall over the year was only 535 mm, the tank was almost completely full. This shows that the replenishment of the tank and its behaviour depends on the past situation and on initial groundwater levels. In order to maintain surface water, the underground porosity should be completely filled or saturation of the (sub-) surface should be sufficient to close the cracks by swelling (inducing lower infiltration rate and lower efficiency of the structure). The monsoon in 2008 (1523 mm), 2009 (792 mm) and 2010 (1206 mm) had allowed this replenishment and therefore adding only 536 mm of rain during 2011 has permitted a good replenishment of the tank. Under those conditions the tank provides storage for a water volume which may otherwise have left the watershed through runoff and can be therefore beneficial on a local scale. However, if the porosity of the geological media is filled completely, then the infiltration rate will be negligible and evaporation will be dominant. In this case, irrigation from surface water can be an effective solution to limit the evaporation of large volumes and to maintain the volume of the underground reservoir for the coming year (Perrin et al. 2009).

This consideration shows that assessment of percolation tank structures are difficult and depend on the actual conditions but also on the history of the structure. Those structures can have a negative impact on the water budget (e.g. in 2012 by enhancing evaporation), or a positive impact as in 2010 when it allowed collecting more water for the watershed.

When evaluating benefits of infiltration tanks we need to take into account (1) net "non-managed" or natural water balance (runoff, infiltration, evaporation) at the watershed scale compared to "managed water balance" and (2) inter-annual variations of precipitation inducing runoff export down to nil, (3) the fact that those tanks are the only form of surface water in the watershed which may be crucial in terms of local water supply. Further investigations are also needed to assess the social and economic impact of such redistribution as well as its impact on water quality.

The complex hydrodynamic parameters at different scales, as well as water quality aspects will be integrated by numerical modelling including scenario simulations in the future.

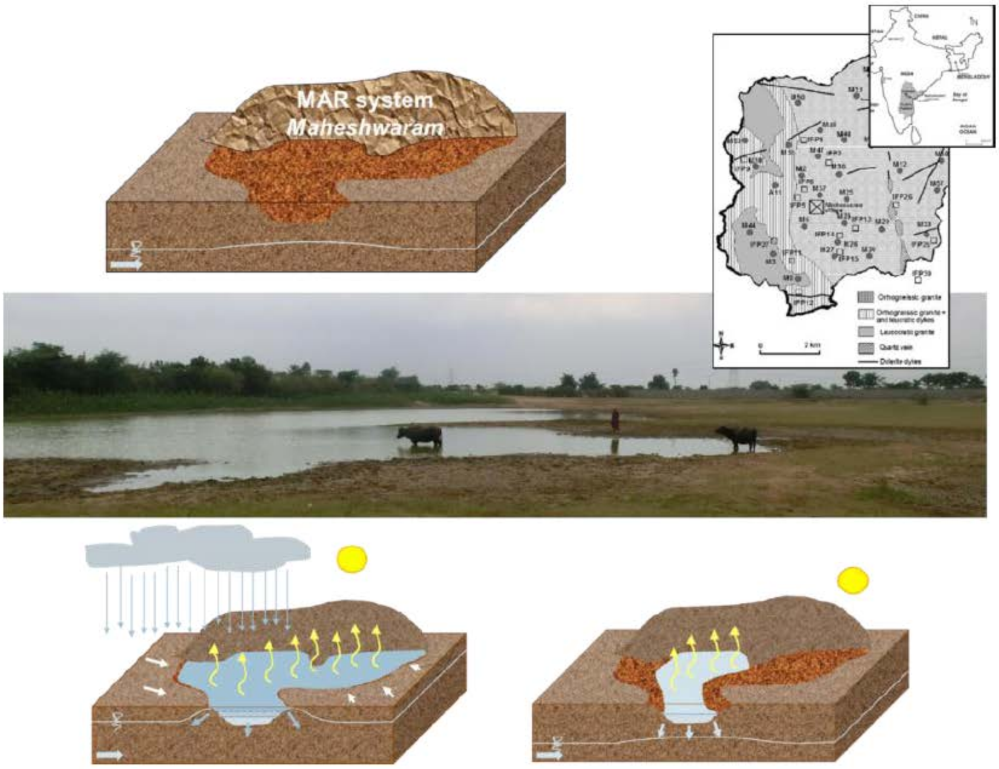

Figure 25 Conceptual model of the Tummulur percolation tank.

4.6 Numerical model development

To understand the capacity of MAR and to improve the quantitative aquifer management sophisticated groundwater balance calculations will be implemented into the MARTHE code adapted to the monsoon climate and semi-arid hard-rock context. This implementation will include the spatiotemporal evolution of the infiltration basin volume and geometry linked to topography, heavy rainfalls during monsoon, evapotranspiration, infiltration, runoff, and groundwater dynamics while respecting the hydraulic mass balance. Rain water is stored on the surface during the monsoon season due to artificial modifications of topography preventing runoff (e.g. dams, tanks). Part of the water infiltrates into the soil (potential unsaturated zone) reaching and eventually raising the water table (saturated zone), whereas part of water is evaporated both during monsoon and dry periods. The 3D MARTHE model will be applied to the Tummulur tank planned to be monitored over a total duration of 3 years. The model will then be up scaled in MARTHE to the whole Maheshwaram watershed in order to evaluate quantitative recharge effects on aquifer flow at catchment scale.

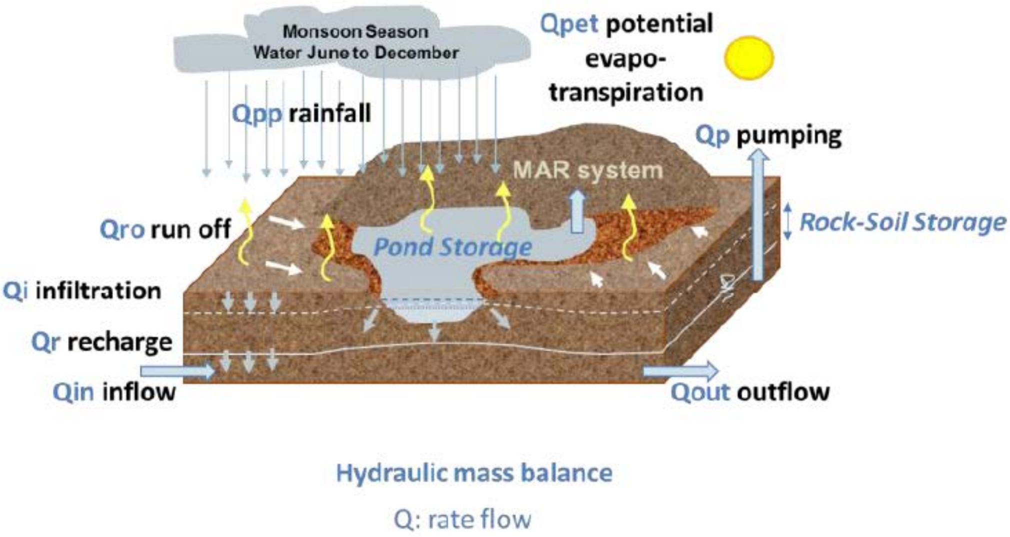

Figure 26 Conceptual model of Tummulur tank studied in Mahesharam in accordance with hydraulic balance.

In a further step, the results obtained at local scale will be used to establish solute mass balances through a watershed scale 3D flow and transport model, in order to evaluate the beneficial or adverse effects of recharge scenarios on soil salinization and fluoride accumulation. To describe the impact on water quality during the recharge on watershed scale, a first step is to quantify the water-rock interaction processes on a 1D vertical geochemical reactive column adapted from the geochemical model of solute recycling (Pettenati et al. 2012, accepted) linking hydrodynamics calculated by MARTHE (infiltration, potential evapotranspiration, unsaturated flow) and geochemical reactions calculated by PHREEQC (Figure 27).

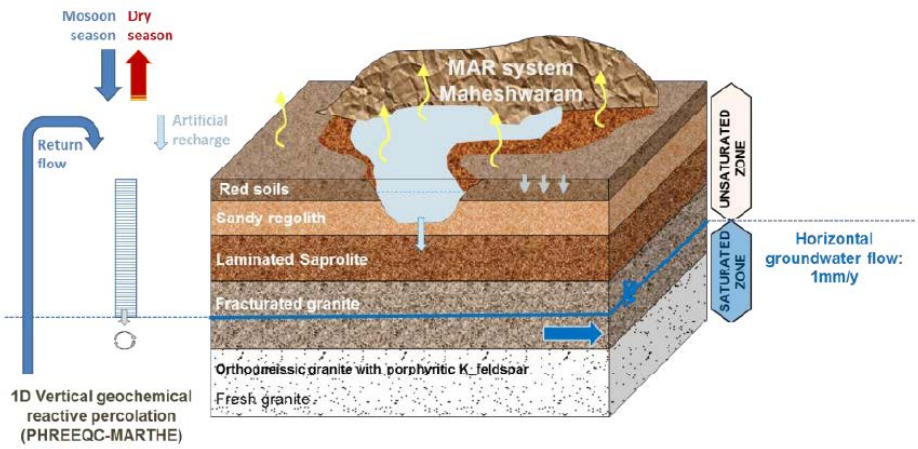

Figure 27 Conceptual model of water-rock interactions processes linked to hydrodynamics.

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5 Urban storm water management in Raipur

5.1 Site description

Hydrogeological formations of the Raipur area comprise mainly of limestone or sandstone/shale layer (CGWB, 2005). The city area has about 85 surface water bodies of varying sizes (2800 - 402000 m^2), occupying a surface area of 2.83 km^2 out of its total area of 147 km^2 (Figure 28). These water bodies are replenished annually by monsoon runoff received from their respective catchments. Some of these water bodies located within the city area also receives both storm drainage and sewerage water, which flow through local drainage networks (locally called '*Nallah*'). During summer months some of the water bodies, mainly small water bodies which are not connected to the city's drainage system, dried up due to evaporation losses and recharge to the aquifer. The water bodies which contain water throughout the year have limited scope in the present context for rejuvenation and conservation because of administrative and technical constraints. The Raipur Municipal Corporation (RMC) have, however, made a plan to rejuvenate and conserve one of the water bodies, called Taliabanda Lake (Figure 28) that has a spread area of 0.12 km^2 and is located within the city area. By diverting and abstaining all sewer drains joining to it and also by improving slum areas around the lake (Figure 29a, b, c and d), it is intended to enable the lake water to get self-purified over the years by the input of replenishable rainfall-runoff. In consultation with RMC the Saph Pani partners involved in the Raipur case study decided to take up the 'Teliabanda Lake' as an existing water body to study the feasibility and impact of MAR. As a test site to assess potential of MAR, the Teliabanda area located at the outskirt of the RMC boundary in the south-east direction (Figure 28) has been identified for detailed investigation.

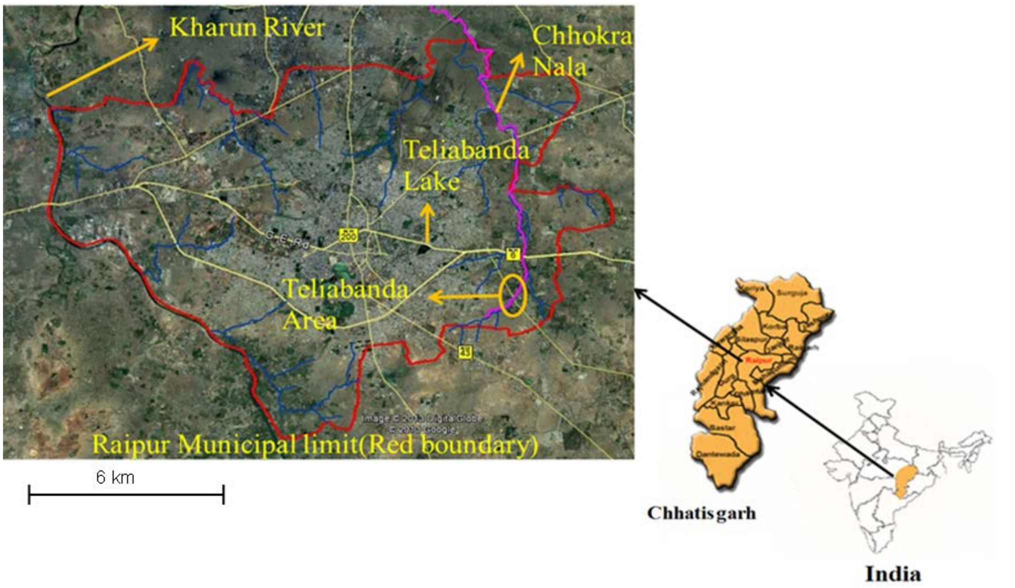


Figure 28 Location map of the Raipur Municipal area highlighting Teliabanda Lake and Teliabanda area selected for the case study.

Figure 29 Photographs show views of the Teliabanda Lake and its on-going rejuvenation works: (a) a view of the lake during monsoon season (August, 2012) (b) showing earthwork along the lake boundary; (c) a view of the earthen embankment and diverted sewer drain; and (d) a view of the diverted sewer drain.

5.2 Objectives

The main objective of this study is to quantify the surface run-off which is available for aquifer recharge in order to design suitable MAR structure and size. The quantification of surface runoff from rainfall for the respective catchment of the Teliabanda Lake and Teliabanda area is an important task to perform. To ascertain the surface runoff, hydrological characteristics of the catchment encompasses by the Teliabanda Lake and Teliabanda area namely, topography, drainage network pattern, land uses/cover, and hydro-meteorological data are, therefore, analysed.

5.3 Documentation of acquired data

5.3.1 Development of rainfall-runoff model

5.3.1.1 Surface drainage network

The maps of drainage networks of the Teliabanda Lake and Teliabanda area were prepared based on the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) data. Figure 30 shows that the Teliabanda Lake with its spread area of 0.12 km^2 covers a drainage area of 1.14 km^2, and the Teliabanda area has two distinct drainage catchments namely catchment 1 and catchment 2 with spread areas of 4.76 km^2 and 12.6 km^2, respectively. The drainage channels orders were derived based on the Strahler stream order classification (Strahler, 1957), indicating that the Teliabanda lake catchment constitutes up to 2nd order drainage channels and that of Teliabanda area varies between 1st and 4th order: catchment 1 has drainage channels order up to 3rd and catchment 2 constitutes drainage channels order up to 4th.

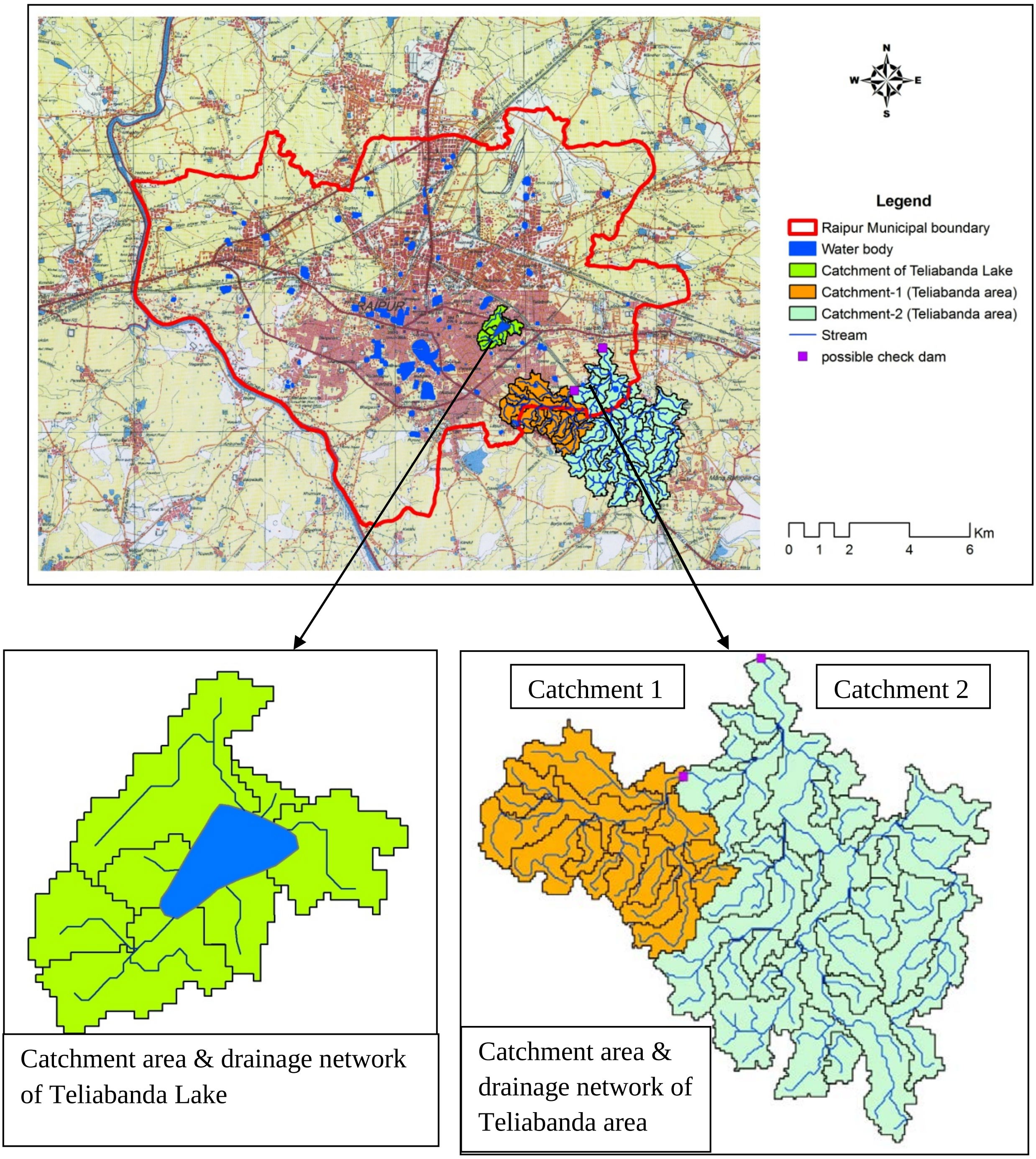


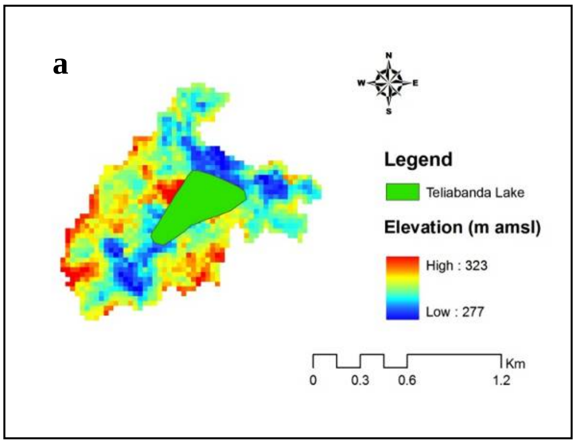
Figure 30 Raipur Municipal boundary, drainage network, catchment area, lakes and possible check dams.

The drainage channels of different orders of the Teliabanda Lake catchment join the lake from all sides. In the Teliabanada area, the main drainage channels of catchment 1 and 2, which follows the slope from west to east for the catchment 1 and south to north in the case of catchment 2, join together to a drainage channel, locally known as *Chhokra*

Nallah. This means that if runoff from catchment 1 is not trapped, it will join the runoff from the catchment 2 and both will thereafter flow through the *Chhokra Nallah*.

5.3.1.2 Topography

The Digital Elevation Model (DEM) of Teliabanda lake and the Teliabanda area, (Figure 31 a and b) based on the 'ASTER' data, show that the Teliabanda area sloping towards north with range in elevation from 257 m to 332 masl (meter above sea level). On the other hand Teliabanda Lake area sloping towards the lake with a range in elevation from 277 m to 323 masl is directed from all directions towards the lake.



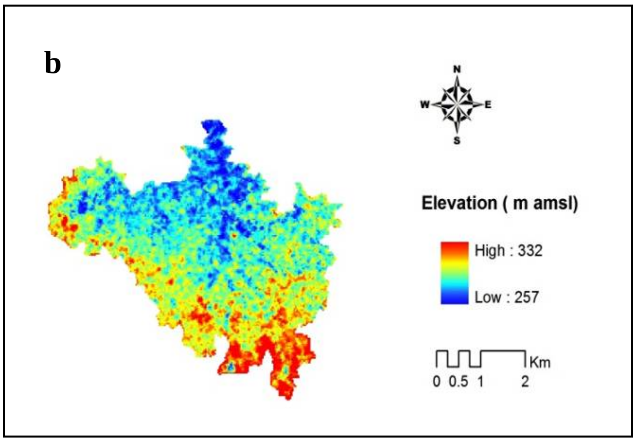


Figure 31 Digital elevation map (a) catchment of Teliabanda Lake (b) catchment of Teliabanda area.

5.3.1.3 Land use

The land-uses/land cover maps of the Teliabanda and Teliabanda Lake area based on Landsat imagery Enhanced Thematic Mapper (ETM+ data) for the year 2000 is presented in Figure 32 a and b. These maps show that Teliabanda area catchment is mostly covered by pasture or range land followed by built up area; and the Teliabanda Lake area catchment has mainly built up area. The distribution of land cover area by different land uses pattern is shown in Table 13.

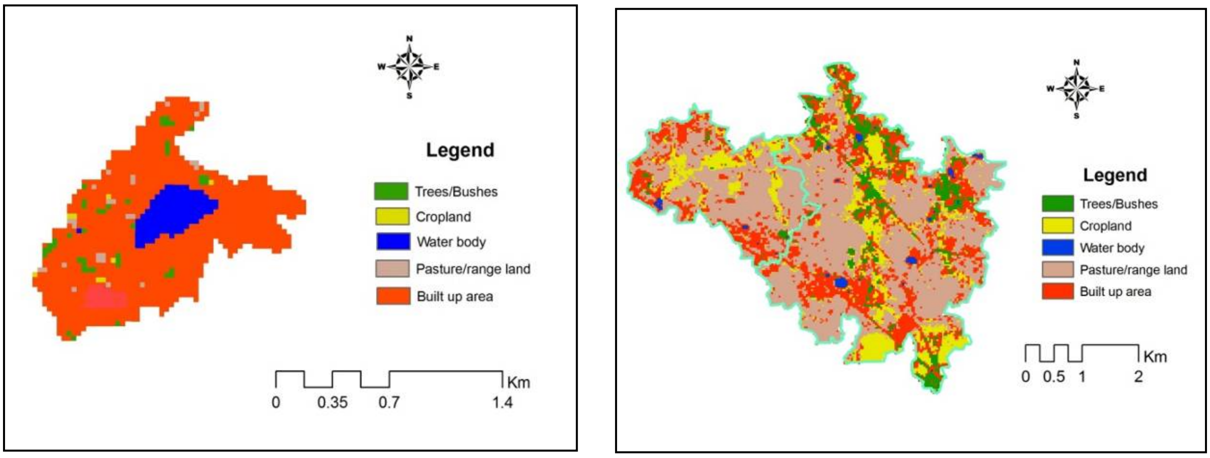


Figure 32 Land use map for (a) Teliabanda area (b) Teliabanda Lake.

Table 13 Land uses of Teliabanda area and Teliabanda Lake.

S.No.	Land cover	Catchment 1 (km^2)	Catchment 2 (km^2)	Teliabanda Lake (km^2)
1	Trees/Bushes	0.07	1.11	0.04
2	Cropland	0.71	1.84	0.01
3	Water body	0.03	0.12	0.12
4	Pasture land	2.84	6.31	0.02
5	Built up area	1.12	3.22	0.96
	Total	4.76	12.6	1.14

5.3.1.4 Climate and rainfall data analysis

In general, Raipur area features semi-arid tropical climate with hot long summer (March to mid-June) followed by rainy season of about four months (mid-June to September). The winter season commences from December and continues till end of February.

To ascertain the variation of climatic parameters in a year, 10 years (2001-2010) of daily data of temperature, relative humidity, wind speed and evaporation was collected from Indira Gandhi Krishi Vishwavidalay (IGKV) and analysed for determining the monthly mean values (Figure 33 and Table 24 in the annex). The maximum temperature varies between 28°C (December/January) and 42°C (May). Whereas; the minimum temperature varies between 11°C (January) and 27°C (May) . The average relative humidity varies during a year from 33% to 85%. The evaporation rate also varies from month to month in a year, between 3 mm/day and 12 mm/day with a maximum in the month of May followed by April. This data will help in determining the water balance of the respective MAR site.

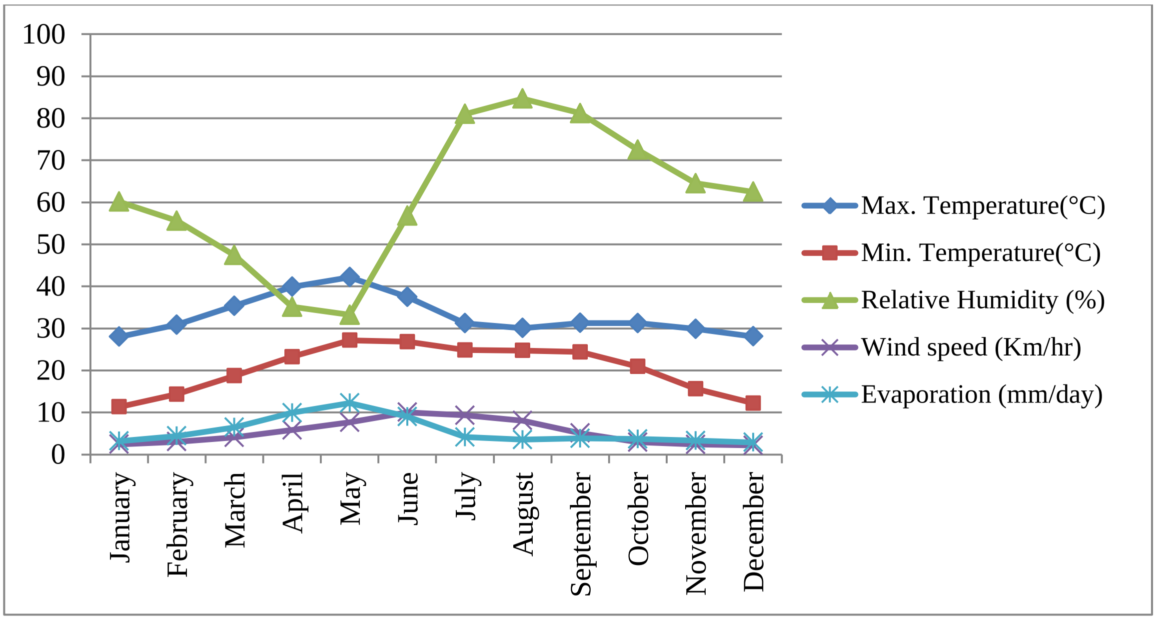


Figure 33 Variation of meteorological parameters in a year of the Raipur area (Indira Gandhi Krishi Vishwavidalaya (IGKV), Raipur).

The analysis of 10 year (2001-2010) daily rainfall data shows that the annual rainfall varies from year to year ranging from 831 mm to 1719 mm (Figure 34). The 10 year annual average rainfall is worked out to be 1207 mm. The month-wise distribution (Table 25 in the annex) indicates that June to September are the wettest months, where about 85% of the annual rainfall is received.

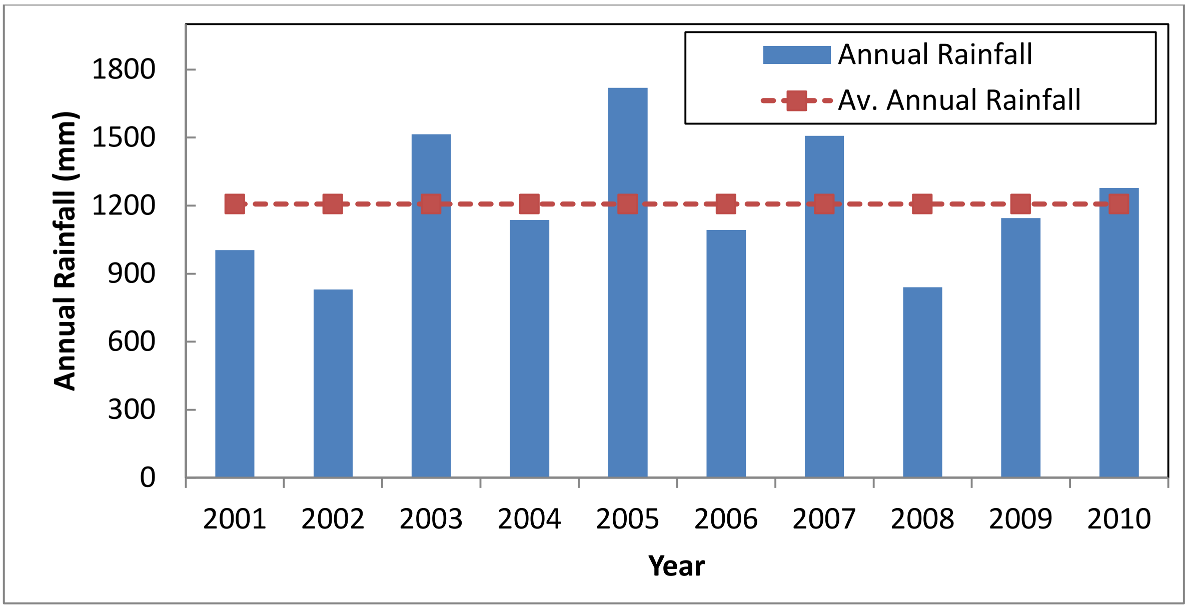


Figure 34 Variation of annual rainfall of 2001-2010 of the Raipur city area (India Meteorological Department (IMD), Pune).

In order to find out the dependability of average annual rainfall of 1207 mm, a probability analysis of the rainfall data was carried out to calculate the probability of exceedance (Chow et al. 1988). Lower probability indicates less assurance of occurrence of rainfall, while higher probability means rainfall has more chance to occur. Average daily rainfall data was converted to average monthly data and thereafter used for different probability of exceedance levels. The probability of annual rainfall at different percentages of probability shows (Figure 35) that if the probability increases the magnitude of rainfall event decreases. This implies more certainty in the occurrence of corresponding rainfall events at higher probability of exceedance. For example, rainfall of 1535 mm at 10% probability of exceedance indicates, there is 10% certainty in the occurrence of 1535 mm rainfall in a year. Likewise, 90% probability of exceedance for 839 mm of rainfall means, the rainfall of 839 mm has 90% chance to occur and therefore, has more certainty.

The probability of exceedance of the average annual rainfall of 1207 mm, determined from the probability graph (Figure 35), is thus worked out to be 45.45%. It means, occurrence of 1207 mm of rainfall in a year has certainty of approx. 45%, and uncertainty of 55%. That is, if the MAR scheme is designed based on the average annual rainfall of 1207 mm, it would be on the higher side. In India the normal practice to plan an irrigation project is 75% dependable flow (Jain et al. 2007); for drinking water supply there must be a 100% dependable flow (Koche and Chawla, 2000). That means a water resource development project is designed based on dependable surface runoff instead of dependability of rainfall. In the present case, we intend to attain 75% dependable surface runoff; therefore, the solution is sought to ascertain the quantity of annual rainfall that would generate 75% dependable surface runoff at the respective site, i.e., in the Teliabanda Lake and Teliabanda area.

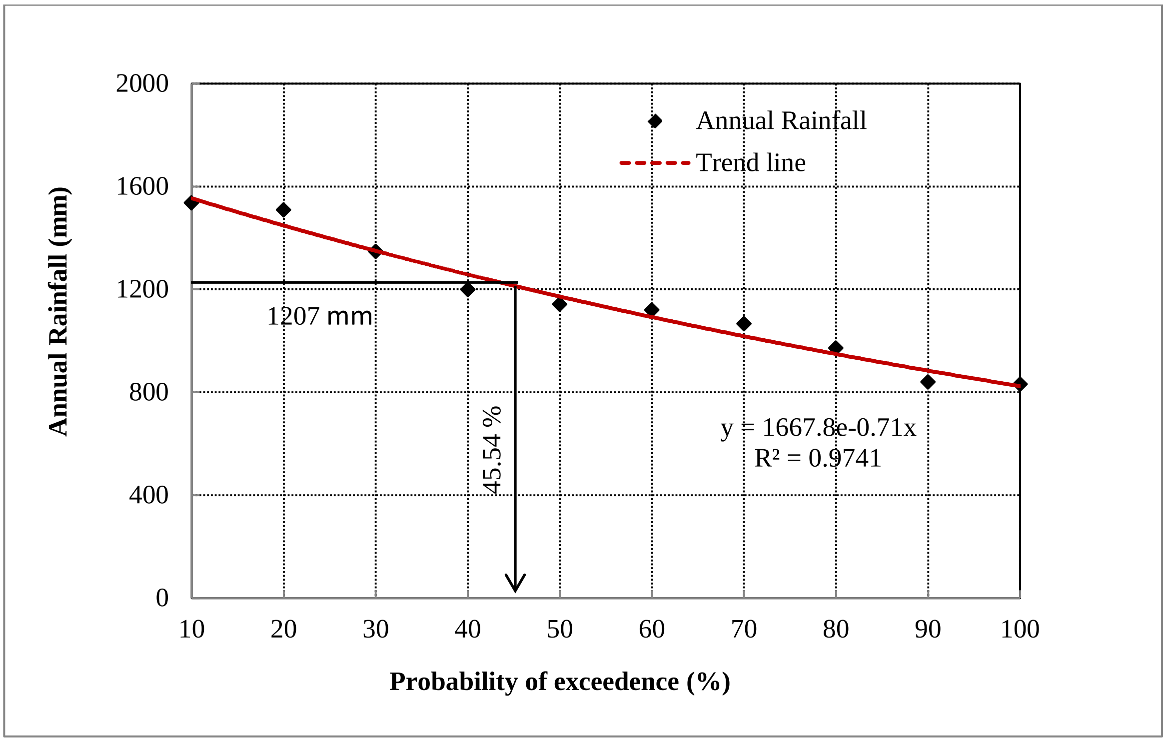


Figure 35 Average annual rainfall of the Raipur city area for different probability of exceedance.

5.3.1.5 Runoff computations

To estimate the runoff from rainfall, the SCS-CN (Soil Conservation Service-Curve Number) model of the US Department of Agriculture (USDA, 1986) was employed. The model requires soil information, vegetation data, abstractions, antecedent moisture conditions, etc. In this model, runoff depth is a function of total rainfall depth and an abstraction parameter, called Curve Number (CN), which is a function of soil group, land cover and antecedent moisture condition (AMC). The SCS-CN model for estimation of runoff (Q) is:

$$Q = \frac{(P - I_a)^2}{P - I_a + S}, P > I_a \qquad \text{......................................(eq.1)}$$

In which, P is the precipitation that causes runoff; Q is the actual runoff; I_a is the initial abstraction and S is the potential maximum retention.

The parameter, S depends on the catchment characteristics. The US-Soil Conservation Service has expressed S (in mm) as a function of Curve Number (CN) according to:

$$S = \frac{25400}{CN} - 254 \qquad \text{..(eq.2)}$$

For Indian conditions, I_a is usually taken as 0.3S for black soil region under AMC I, and 0.1S for black soil region for AMC II and III (Handbook of Hydrology, Ministry of Agriculture, Govt. of India, 1972).

The Raipur urban area mainly consists of two types of soil; vertisols and ultisols. Only one soil type of the vertisols category, namely deep black soil, is found in Raipur. It is characterized by a high content of expanding and shrinking clay. This type of soil has developed mostly in the areas underlying limestone formations (CGWB, 2011). The soil samples analysed by SENES Consultants India Pvt. Ltd. (January, 2011) for the Naya Raipur area had a clay fraction over 45%. Thus for the runoff estimation, black soil region (Hydrologic soil group D) and different AMC conditions are considered.

As our interest is to find surface runoffs for all the catchments at 75% dependability, Figure 36 shows the monthly variation of the surface runoffs for the Teliabanda Lake area and the Teliabanda catchment 1 and catchment (1+2). For all the three catchments, July is found to be the peak month for the surface runoff followed by August (Figure 36 and Table 26, Table 27 and Table 28).

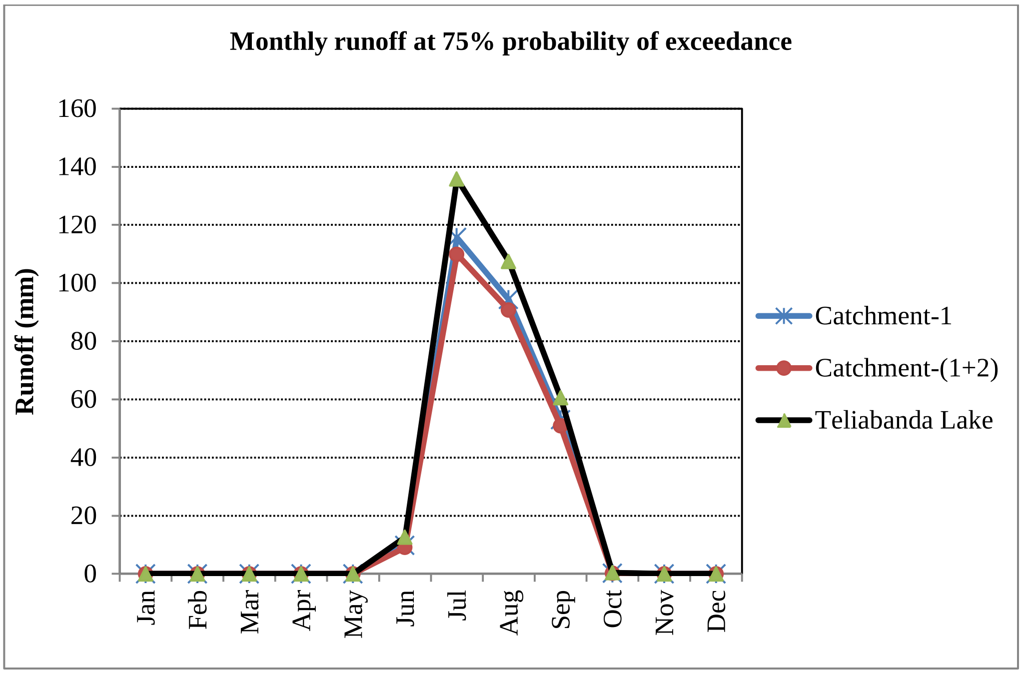


Figure 36 Month-wise variation of surface runoffs at 75% probability of exceedance for the Teliabanda Lake area and the Teliabanda catchment 1 and catchment (1+2).

To determine the annual rainfall corresponding to the 75% dependability of surface runoffs, a relation between the annual rainfall versus annual surface runoff has been developed (Figure 37) by analyzing the 10 years (2001-2010) rainfall data and the corresponding surface runoff. The rainfall-runoff shows a nonlinear relationship. It is clearly evident from Table 14 that different catchments depict different probability of exceedance of rainfall for 75% dependability of surface runoff; e.g., Teliabanda Lake area would require certainty of 1048 mm of annual rainfall to generate 75% dependable runoffs of 507.9 mm in a year, while Teliabanda area catchments would require certainty of about 930 - 956 mm of annual rainfall to generate 75% dependable runoffs of 430 - 447 mm in a year.

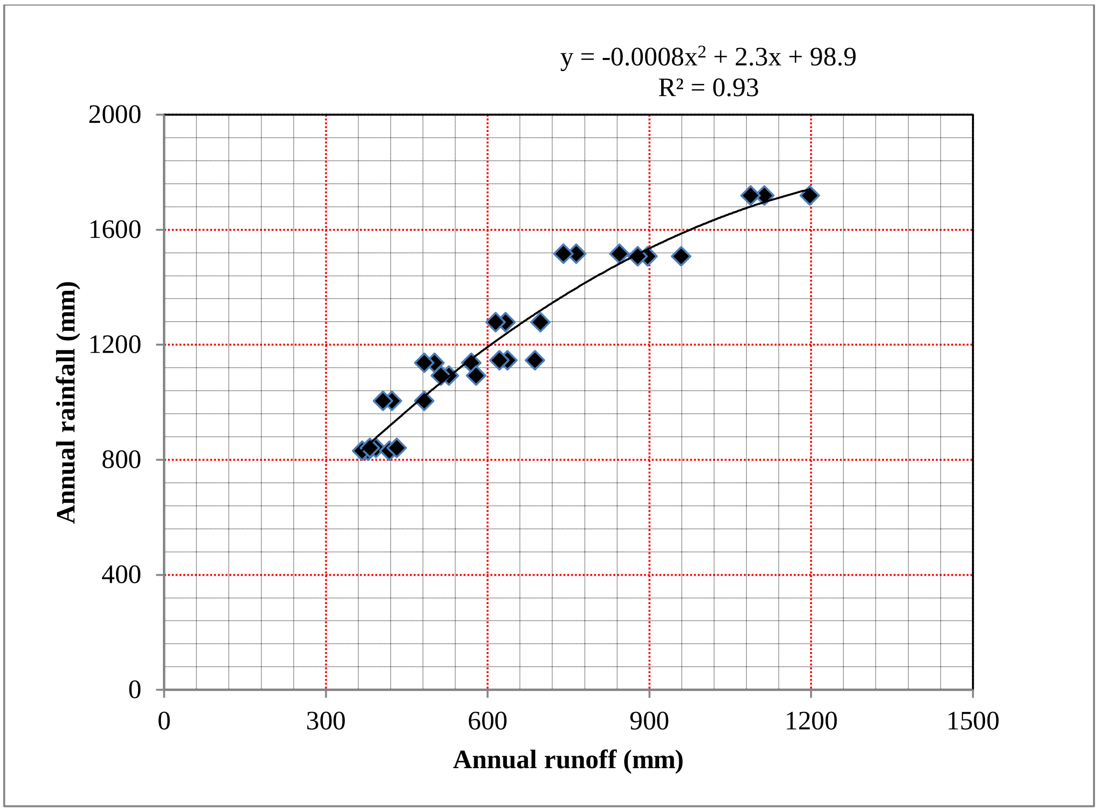


Figure 37 Plot of annual rainfall versus annual runoff for the Teliabanda area and Teliabanda Lake area.

Table 14 Annual rainfall corresponding to the 75% dependable surface runoff for the Teliabanda area and Teliabanada Lake area.

Catchment name	Annual runoff at 75% probability of exceedance (mm)	Predicted annual rainfall corresponding to 75% probability of runoff (mm)
Catchment-1	447	956
Catchment-(1+2)	430	930
Teliabanda lake	508	1048

5.3.2 Groundwater table maps

Groundwater flow direction in the respective area will help to select the suitable location of abstraction wells for withdrawal of groundwater. In order -to analyze the groundwater flow, monthly groundwater levels were measured by the CGWB- Raipur for one year (2011) from 50 dug- and bore wells used in Raipur area Raipur. Dug wells are shallow depth wells and groundwater levels indicate the level of phreatic aquifer; while bore wells are deep wells which may represent both phreatic as well as piezometric surface. The groundwater levels were given as depth below ground surface. Therefore, by collecting the ground surface level of the respective well location, this data was converted to groundwater level above msl (mean sea level) and then geo-referenced. The pre- and post-monsoon groundwater contour maps depicting the direction of groundwater flow for both dug- and bore wells observations are generated separately (Figure 38 - Figure 41). The calculations from the observations of the dug well data (Figure 38 - Figure 39) shows that the groundwater levels vary between 263 m and 293 m above msl (i.e., 2 m to 13 m bgl) during pre-monsoon and 265 m to 295 m above msl (i.e., 1m to 11 m bgl) during post-monsoon. The plot of bore wells data (Figure 40 - Figure 41) shows that the groundwater levels vary between 210 m and 290 m above msl (4 m to 60 m bgl) during pre-monsoon and 252 m to 294 m above msl (2 to 19 m bgl) during post-monsoon. The directions of the groundwater flow during pre- and post-monsoon period are found to be similar for both dug wells as well as bore wells.. The direction of groundwater flow is largely towards north.

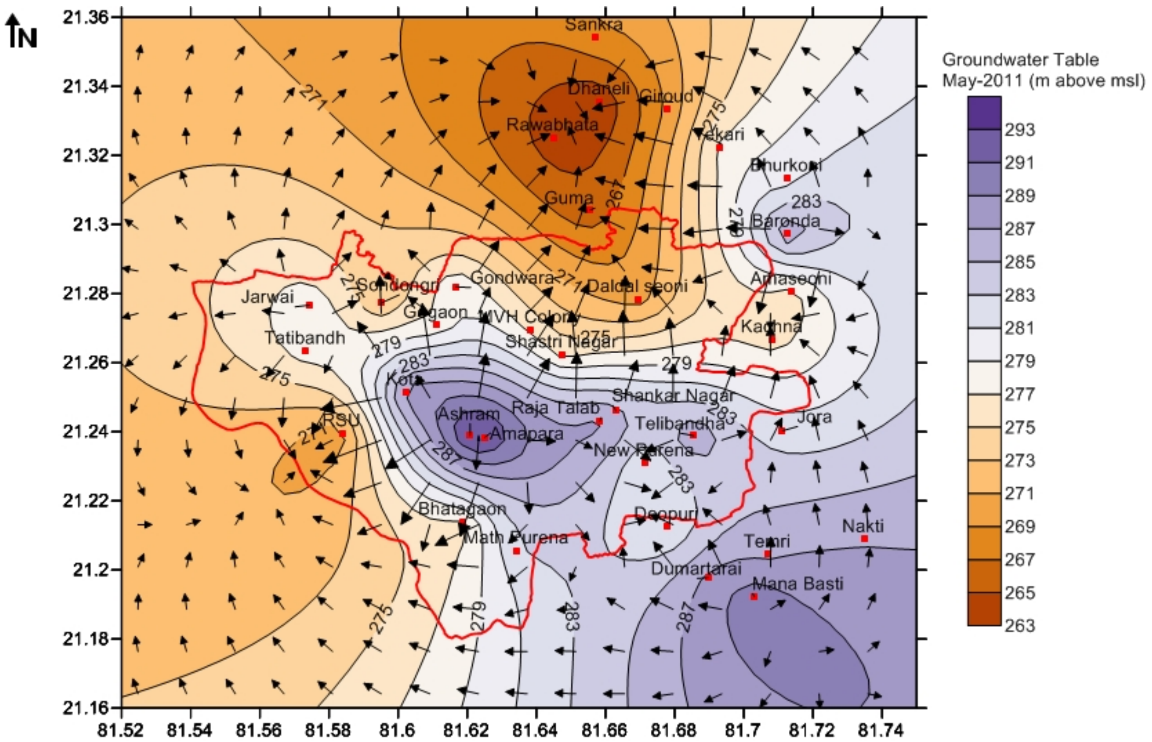


Figure 38 Groundwater table contour map of the Raipur Municipal area (red boundary) for the pre-monsoon period based on the dug well data.

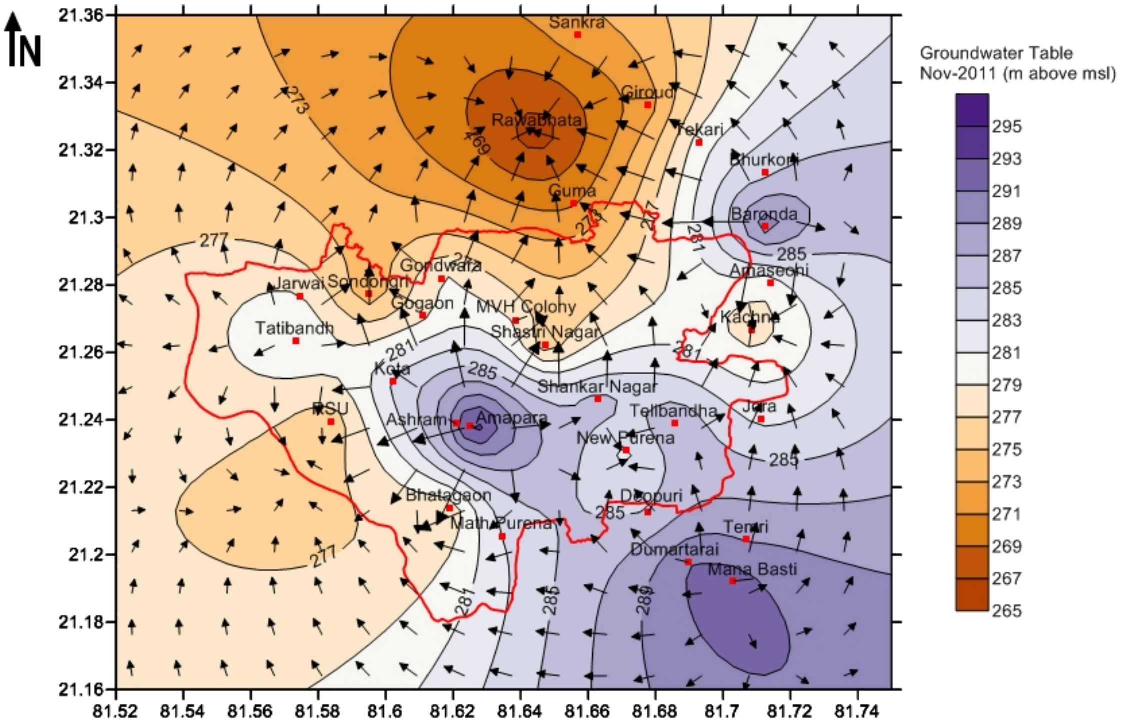


Figure 39 Groundwater table contour map of the Raipur Municipal area (red boundary) for the post-monsoon period based on the dug well data.

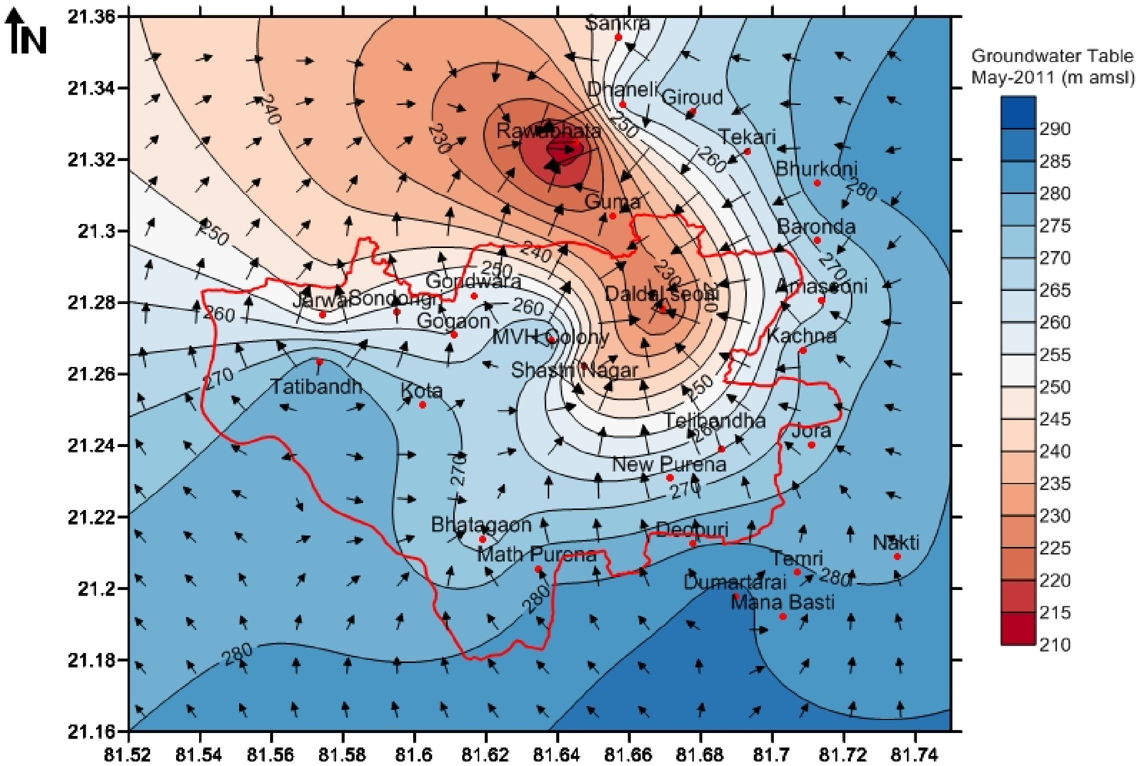


Figure 40 Groundwater table contour map of the Raipur Municipal area (red boundary) for the pre-monsoon period based on the bore wells data.

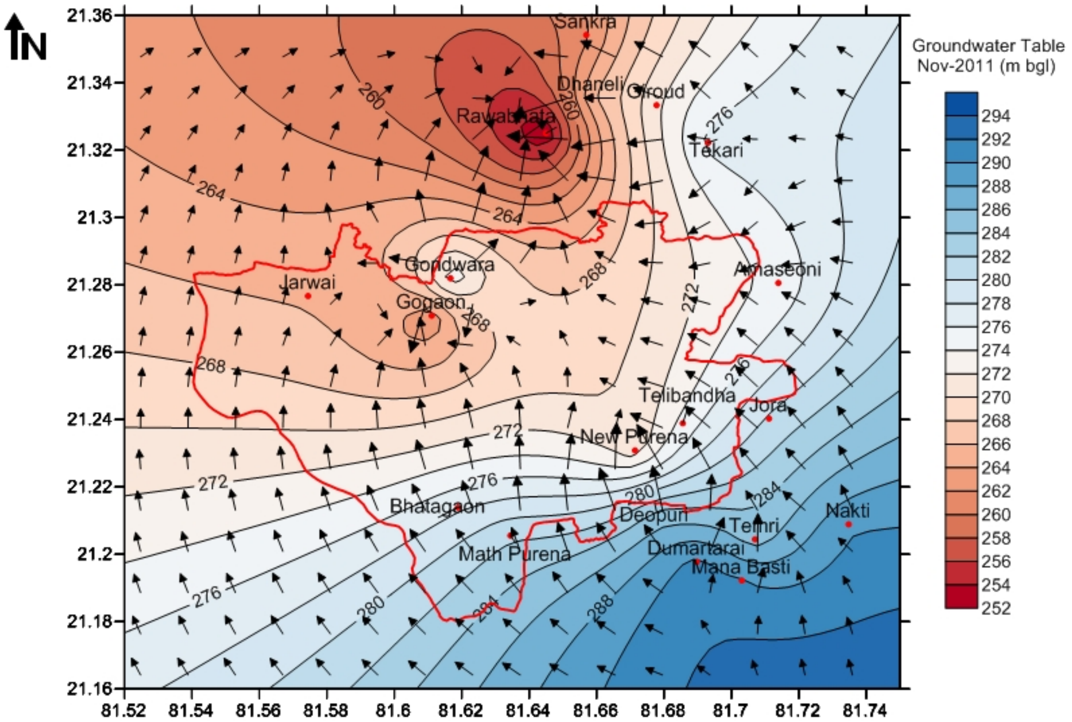


Figure 41 Groundwater table contour map of the Raipur Municipal area (red boundary) for the post-monsoon period based on the bore well data.

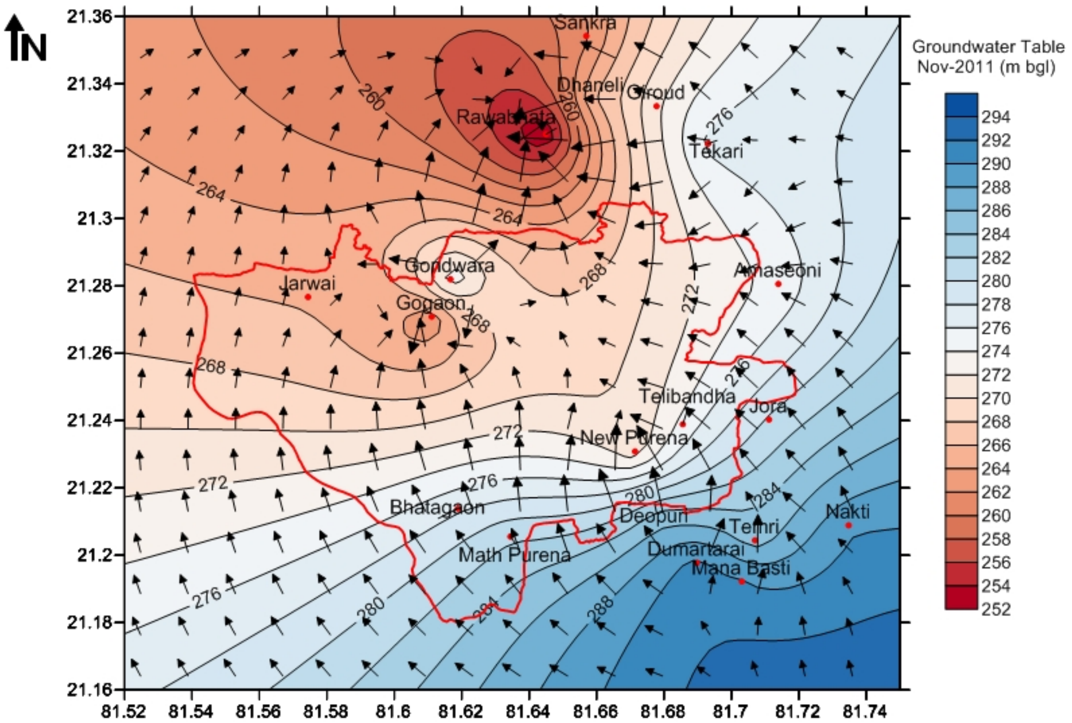


Figure 42 Groundwater table contour map (drawn from bore well data) of Raipur Municipal area (red boundary) indicating the flow direction during post-monsoon.

5.3.3 Electrical resistivity tomography (ERT) profiles

Electrical resistivity or electrical conductivity is widely used for characterizing the geological formation by electrical methods. The depth of measurement of ground resistivity is related to the spacing of the electrodes and may vary depending on the subsurface conditions. In general, it is possible to map the different stratigraphic units in a geologic section as long as the units have a resistivity contrast. Often this is connected to rock porosity and water saturation status of the pore spaces. Resistivity method is successfully used to determine aquifer water table and its depth of occurrence, conductive ore mineral bodies, ground water quality, brine plumes, seawater intrusion, well siting, aquifer exploration and general stratigraphic mapping.

Electrical Resistivity Tomography requires the same four electrode resistance measurement used by the Schlumberger brothers (two electrodes to inject current and two other electrodes to measure the resulting potential).

Resistivity measurements were carried out with the resistivity meter Syscal R1 Junior (IRIS Instruments, Orléans, France) equipped with 48 electrodes. The electrodes are high-quality stainless steel plates of 12” length moulded onto multi-core cables, with 12 electrodes per cable. The electrodes were placed in a small hole, 20 cm below the ground cover, to ensure good ground contact during the experiment. The 4 multicore cables run through the profile, at different sites, where they connect the electrodes to a multi-channel resistivity meter, switchbox and a computer which regulates the acquisition of data.

The electrodes remained on the soil surface throughout the experiment to avoid any electrode polarization changes and to ensure a best quality of measurements.

The experimental set up include a row of 48 electrodes, lined up on the soil surface, which were separated by 4 m, 6 m and 10 m, depending on the availability of area. We obtained the resistivity values and inverted them for the pseudo section.

The resistivity data has been processed and interpreted with the help of RES2DINV software developed by Loke and Barker (1996). It is based on the smoothness constrained least square method and 2D subsurface model is obtained from the resistivity section. Electrical resistivity imaging was carried out at five selected areas in and around Teliabanda Lake region (Figure 43).

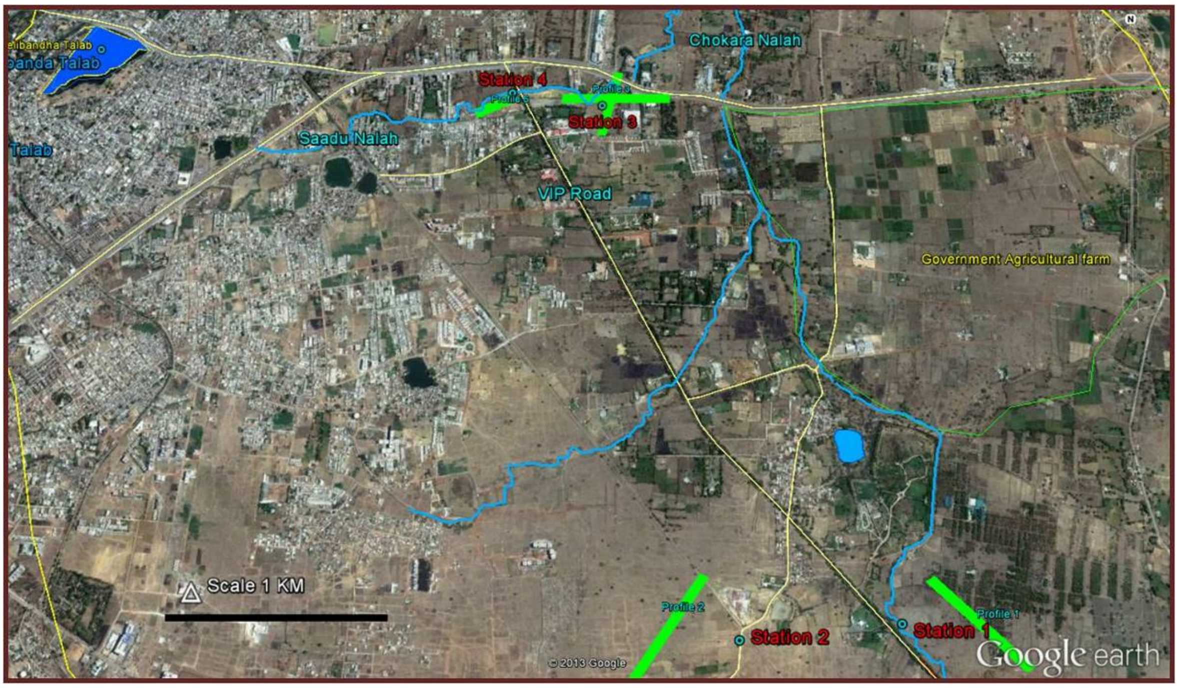


Figure 43 Showing location of ERT profiles near Telibandha lake region and the drainage pattern.

The result from one profile is shown exemplary here and all other profiles can be found in the annex (Figure 59 - Figure 62).

Station 1: AMLIDHI (Location: N 21° 12’ 49.9”, E 81°41’ 50.5”)

Profile (Station 1) was laid down in NNW-SSE direction for the ERT data acquisition. The experimental field setup was laid along a profile of 480 m with the electrode spacing of 10 m. The Wenner-Schlumberger array was used to survey the profile. A total number of 529 datum points were measured at 23 data levels, which is used for plotting the pseudo section (Figure 44) by the observed data sets. There is a single railway track parallel to the profile about 150-200 m away from the central electrode. There is also cemented road approximately 100 m away from the 1st electrode and also a pond approximately 10 m away. All the electrodes were well connected to the ground thus giving almost nil earth resistance. There is a nearby bore well which has a water depth of 20-40 ft (according to information gathered from local sources). Some limestone was transported and dumped near the site.

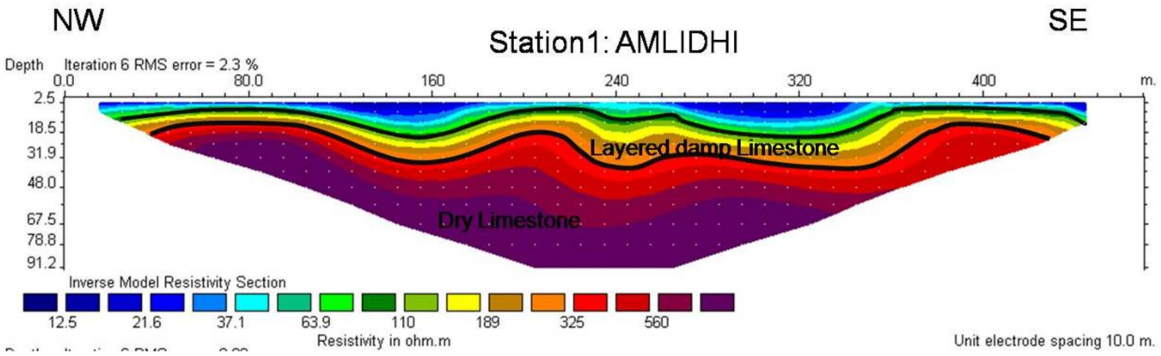


Figure 44 Electrical Resistivity Tomogram at station 1 at Amlidhi.

The pseudo section shown in Figure 44 clearly brings out the layered structure of limestone exactly from the subsurface. At the depth of 5 m there is a thick layer of 15-20 m thickness of damp limestone with resistivity varying between 50-150 ohm-m and below there is a dry limestone up to 90 m with high resistivity of more than 300 ohm-m.

5.4 Preliminary conclusions

- Transition zone of shaly limestone and compact limestone is clearly demarcated
- Resistivity mapping below the sub-surface up to 60-70 m correlates well along all the pseudo sections and is consistent with the vertical electrical soundings carried out in the first phase of geo-electrical investigations of the area

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Annex – Data tables, additional figures

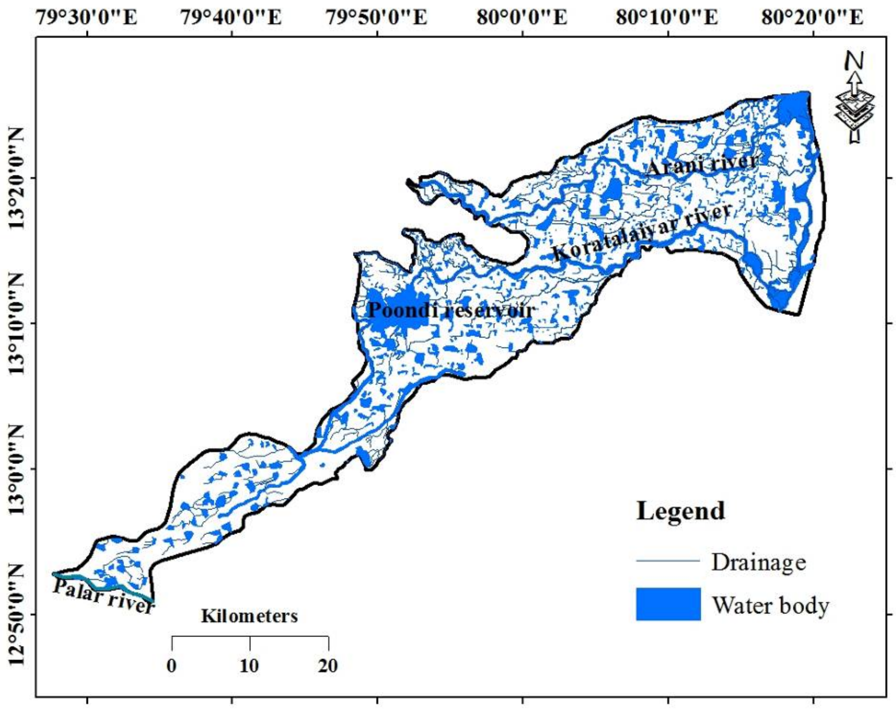

Figure 45 Drainage pattern in the study area.

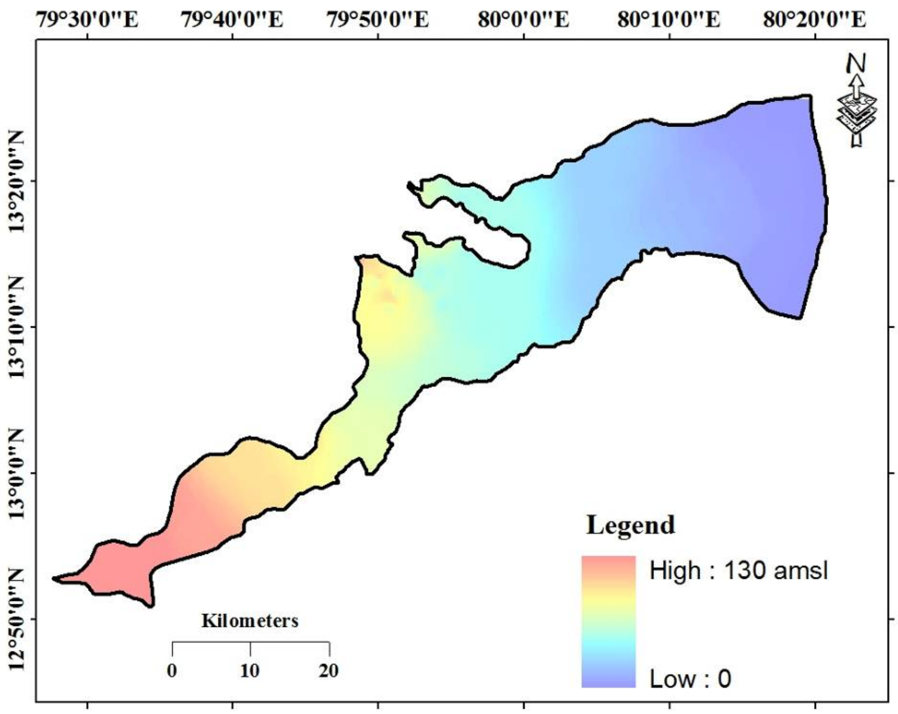

Figure 46 Topographical elevation (m) of the study area.

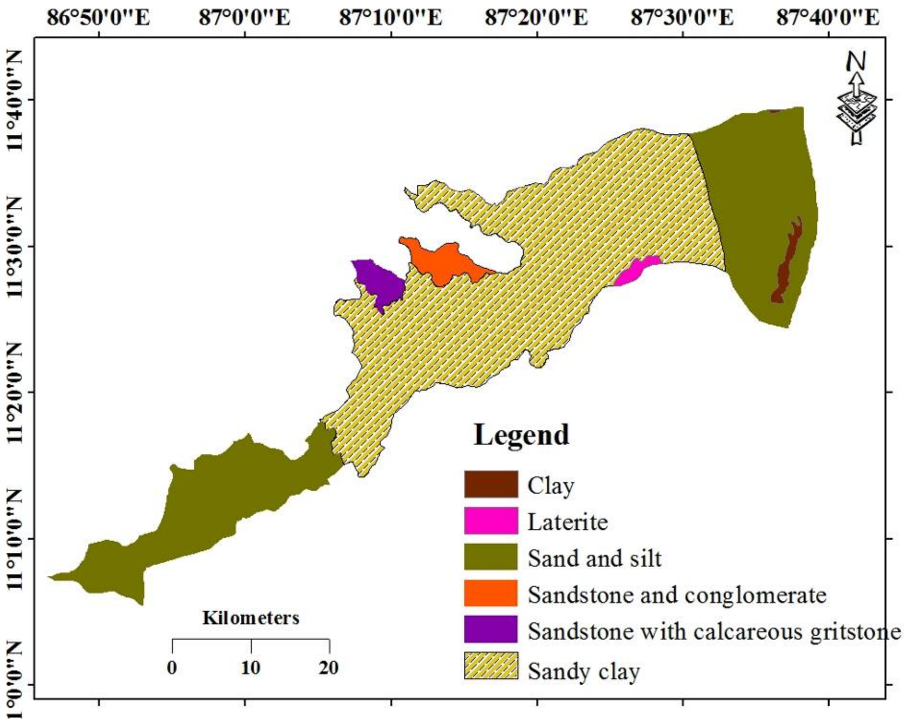

Figure 47 Geology of the study area.

Table 15 List of parameters for which analysis was done, detection limits and Indian drinking water standards from 1993 and 2012.

Item. No.	Test for	Detection limit (mg/l)	as per IS 10500 - 1991 Reaff.1993		as per IS 10500 - changes - 2012	
			Desirable	Permissible	Desirable	Permissible
1	ALUMINIUM as Al	0.001	0.03 mg/l	0.2 mg/l		
2	IRON (as Fe)	0.001	0.3 mg/l	1.0 mg/l	0.3 mg/l	No relaxation *
3	MAGNESIUM as Mg	0.001	30 mg/l	100 mg/l		
4	COPPER as Cu	0.01	0.05 mg/l	1.5 mg/l		
5	MANGANESE as Mn	0.001	0.1 mg/l	0.3 mg/l		*
6	ZINC (as Zn)	0.001	5 mg/l	15 mg/l		
7	BORON as B	0.005	1 mg/l	5 mg/l	0.5 mg/l	1.0 mg/l
8	MERCURY as Hg	0.001	0.001 mg/l	No relax		
9	CADMIUM as Cd	0.001	0.01 mg/l	No relax	0.003 mg/l	No relaxation
10	SELENIUM (as Se)	0.001	0.01 mg/l	No relax		
11	ARSENIC as As	0.001	0.05 mg/l	No relax	0.01 mg/l	0.05 mg/l
12	CYANIDE as CN	0.01	0.05 mg/l	No relax		
13	LEAD (as Pb)	0.001	0.05 mg/l	No relax	0.01 mg/l	No relaxation
14	CHROMIUM (as Cr^{6+})	0.01	0.05 mg/l	No relax		
15	TOTAL HARDNESS as $CaCo_3$	1.00	300 mg/l	600 mg/l	200 mg/l	600 mg/l
16	TOTAL DISSOLVED SOLIDS	1.00	500 mg/l	2000 mg/l		
17	ALKALINITY as $CaCO_3$	0.50	200 mg/l	600 mg/l		
18	CHLORIDES as Cl		250 mg/l	1000 mg/l		
19	CALCIUM as Ca	2.00	75 mg/l	200 mg/l		
20	SULPHATE	0.05	200 mg/l	400 mg/l		**

Table 15 - continued

Item. No.	Test for	Detection limit (mg/l)	as per IS 10500 - 1991 Reaff.1993		as per IS 10500 - changes - 2012	
			Desirable	Permissible	Desirable	Permissible
22	FLUORIDE (as F)	1.00	1.0 mg/l	1.5 mg/l		
23	COLOUR (HAZEN UNITS)	0.10	5 HU	25 H.U	5 HU	15 HU
24	B.O.D @ 27°C for 3 days	1 .00	-	30 mg/l		
25	ODOUR	1 HU	Unobjectionable		Agreeable	Agreeable
26	COD					
27	TASTE		Agreeable	-	Agreeable	Agreeable
28	TURBIDITY		5 NTU	10 NTU	1 NTU	5 NTU
29	pH Value		6.5-8.5	No relax		
30	RESIDUAL FREE CHLORINE	0.05 NTU	0.2mg/l	-	0.2 mg/l	1.0 mg/l ***
31	PHENOLIC COMPOUNDS (AS C6H50H)	1.00	0.001 mg/l	0.002 mg/l		
32	ANIONIC SURFACE ACTIVE AGENTS as (MBAS)	0.05	0.2 mg/l	1.0mg/l		
33	MINERAL OIL	0.01	0.01 mg/l	0.03 mg/l	0.5mg/l	No relaxation
34	COLIFORMS		None in 100 ml			

* Total concentration of Manganese as Mn and Iron as Fe shall not exceed 0.3 mg/l

** may be extended to 400 provided that Manganese does not exceed 30

*** Tested at consumer end

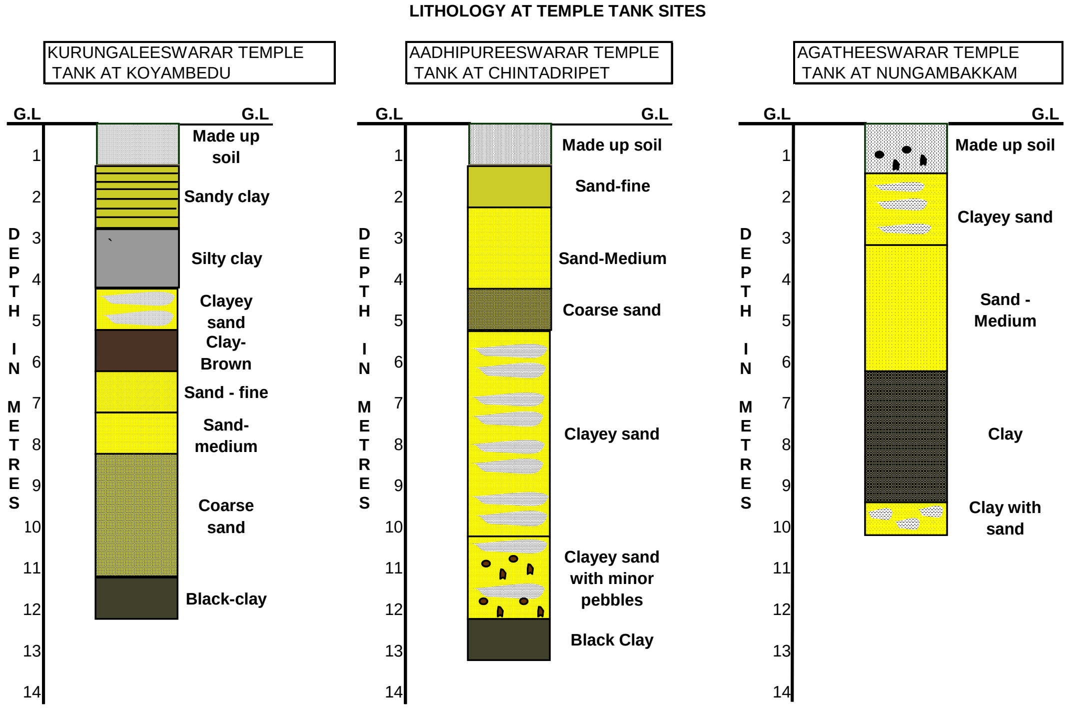

Figure 1.4.2 Lithology at Temple tank sites

Figure 48 Lithological logs from hand auger drilling.

Table 16 Analytical results for the Aadhipureswarar Temple Tank (BDL = below detection limit).

Parameter	Sampling date 05.01.2012	Sampling date 03.04.2012	Sampling date 20.07.2012	Sampling date 06.11.2012*
ALUMINIUM as Al	0.032mg/l	0.108 mg/l	BDL(DL 0.001mg/l)	
COLOUR (HAZEN UNITS)	10 Hazen (True colour)	20 Hazen (True Colour)	10 HU	10 HU
B.O.D @ 27°C for 3 days	less than 2 mg/l			
ODOUR	Unobjectionable	Objectionable	Disagreeable	Agreeable
COD	52 mg/l			
TASTE	Disagreeable	Disagreeable	Disagreeable	Agreeable
TURBIDITY	0.7 NTU	12.6 NTU	30 NTU	9.5 NTU
Ph Value	7.04	7.57	9.52	8.93
TOTAL HARDNESS as $CaCo_3$	204 mg/l	64 mg/l	72 mg/l	54 mg/l
IRON (as Fe)	BDL(DL:0.001 mg/l)	0.17 mg/l	1.7mg/l	0.23mg/l
CHLORIDES as Cl	65 mg/l	54 mg/l	88 mg/l	21 mg/l
RESIDUAL FREE CHLORINE	BDL(DL:0.1 mg/l)	BDL(DL:0.1 mg/l)	BDL(DL 0.1mg/l)	
TOTAL DISSOLVED SOLIDS	380 mg/l	190 mg/l	288 mg/l	116 mg/l
CALCIUM as Ca	53 mg/l	18 mg/l	20 mg/l	17 mg/l
MAGNESIUM as Mg	18 mg/l	4.4 mg/l	5.20 mg/l	2.5 mg/l
COPPER as Cu	BDL(DL:0.001 mg/l)	0.002 mg/l	BDL(DL 0.001mg/l)	
MANGANESE as Mn	0.002mg/l	0.046 mg/l	0.01 mg/l	
SULPHATE as SO4	28 mg/l	11 mg/l	21 mg/l	5.6 mg/l
NITRATE (as NO3)	3.7mg/l	0.9 mg/l	3.8mg/l	
FLUORIDE (as F)	0.21 mg/l	BDL(DL:0.1 mg/l)	BDL(DL 0.1mg/l)	
PHENOLIC COMPOUNDS (AS C6H50H)	Absent	Absent	Absent	
MERCURY as Hg	BDL(DL:0.001 mg/l)	0.002 mg/l	BDL(DL 0.001mg/l)	
CADMIUM as Cd	BDL(DL:0.001 mg/l)	BDL(DL:0.001 mg/l)	BDL(DL 0.001mg/l)	
SELENIUM (as Se)	BDL(DL:0.001 mg/l)	BDL(DL:0.001 mg/l)	BDL(DL 0.001mg/l)	
ARSENIC as As	0.001 mg/l	BDL(DL:0.001 mg/l)	BDL(DL 0.001mg/l)	
CYANIDE as CN	Absent	Absent	Absent	
LEAD (as Pb)	BDL(DL:0.001 mg/l)	0.004 mg/l	BDL(DL 0.001mg/l)	
ZINC (as Zn)	0.002 mg/l	0.018 mg/l	BDL(DL 0.001mg/l)	

Table 16 - continued

Parameter	Sampling date	Sampling date	Sampling date	Sampling date
	05.01.2012	03.04.2012	20.07.2012	06.11.2012*
CHROMIUM (as Cr6+)	BDL(DL:0.001 mg/l)	BDL(DL:0.01 mg/l)	BDL(DL 0.1mg/l)	
POLYNUCLEAR AROMATIC HYDROCARBONS	BDL(DL:0.05 µg/l)		BDL(0.05 µg/l)	
MINERAL OIL	Absent	Absent	Absent	
ALKALINITY as CaCo3	186 mg/l	82 mg/l	82 mg/l	54 mg/l
BORON as B	0.035 mg/l	0.014 mg/l	0.036mg/l	
E.coli	Absent/100 ml	Absent/100 ml	Absent/100ml	Absent/100 ml
Coliform	Present:92 MPN/100 ml	Present: 54 MPN/100 Ml	Present:28MPN /100ml	Present: 92MPN/
Faecal coliforms	Absent/100 ml	Absent/100 ml	Absent/100ml	Absent/100 ml

*Sample dated 06.11.2012 was analysed for limits as per IS 10500 -2012 revision for limited parameters only for which results are shown

Table 17 Analytical results for the Aadhipureswarar Temple groundwater.

Parameter	Sampling date 5.01.2012	Sampling date 03.04.2012	Sampling date 20.07.2012	Sampling date 06.11.2012*
ALUMINIUM as Al	0.035 mg/l	BDL (DL : 0.001mg/l)	0.008mg/l	
COLOUR (HAZEN UNITS)	10 Hazen (True Colour)	10 Hazen	25HU	10 HU
B.O.D @ 27°C for 3 days	Less than 2 mg/l			
ODOUR	Unobjectionable	Unobjectionable	Unobjectionabl e	Agreeable
COD	32 mg/l			
TASTE	Agreeable	Agreeable	Agreeable	Agreeable
TURBIDITY	8.2 NTU	0.1 NTU	1.6 NTU	0.1 NTU
Ph Value	7.33	7.01	7.39	7.82
TOTAL HARDNESS as $CaCo_3$	108 mg/l	244 mg/l	217 mg/l	249 mg/l
IRON (as Fe)	0.055 mg/l	BDL(DL:0.001 mg/l	0.27mg/l	BDL(DL:0.02 mg/l
CHLORIDES as Cl	38 mg/l	100 mg/l	77 mg/l	77 mg/l
RESIDUAL FREE CHLORINE	BDL(DL:0.1 mg/l	BDL(DL:0.1 mg/l	BDL(DL 0.1mg/l)	
TOTAL DISSOLVED SOLIDS	204 mg/l	520 mg/l	442 mg/l	497 mg/l
CALCIUM as Ca	34 mg/l	82 mg/l	56 mg/l	83 mg/l
MAGNESIUM as Mg	6 mg/l	9.7 mg/l	9.40 mg/l	10 mg/l
COPPER as Cu	BDL(DL:0.001 mg/l	BDL(DL:0.001 mg/l	BDL(DL 0.001mg/l)	
MANGANESE as Mn	0.026 mg/l	BDL(DL:0.001 mg/l	0.002 mg/l	
SULPHATE as SO4	17 mg/l	55 mg/l	48 mg/l	43 mg/l
NITRATE (as NO3)	3 mg/l	35 mg/l	29 mg/l	
FLUORIDE (as F)	0.17 mg/l	BDL(DL:0.1 mg/l	0.16mg/l	
PHENOLIC COMPOUNDS (AS C6H50H)	Absent	Absent	Absent	
MERCURY as Hg	BDL(DL:0.001 mg/l	BDL(DL:0.001 mg/l	BDL(DL 0.001mg/l)	
CADMIUM as Cd	BDL(DL:0.001 mg/l	BDL(DL:0.001 mg/l	BDL(DL 0.001mg/l)	
SELENIUM (as Se)	BDL(DL:0.001 mg/l	BDL(DL:0.001 mg/l	BDL(DL 0.001mg/l)	
ARSENIC as As	0.003 mg/l	BDL(DL:0.001 mg/l	BDL(DL 0.001mg/l)	
CYANIDE as CN	Absent	Absent	Absent	
LEAD (as Pb)	BDL(DL:0.001 mg/l	BDL(DL:0.001 mg/l	BDL(DL 0.001mg/l)	

Table 17 - continued

Parameter	Sampling date	Sampling date	Sampling date	Sampling date
	5.01.2012	**03.04.2012**	**20.07.2012**	**06.11.2012***
ANIONIC SURFACE ACTIVE AGENTS as (MBAS)	BDL(DL:0.05 mg/l	BDL(DL:0.05 mg/l	BDL(DL 0.05mg/l)	
CHROMIUM (as Cr6+)	BDL(DL:0.001 mg/l	BDL(DL:0.01 mg/l	BDL(DL 0.1mg/l)	
POLYNUCLEAR AROMATIC HYDROCARBONS	BDL(DL:0.05 µg/l	BDL(DL:0.05 µg/l	BDL(0.05 µg/l)	
MINERAL OIL	Absent	Absent	Absent	
ALKALINITY as CaCo3	104 mg/l	239 mg/l	229 mg/l	229 mg/l
BORON as B	0.008 mg/l	BDL(DL:0.005 mg/l	0.03mg/l	
E.coli	Absent/100 ml	Absent/100 ml	Absent/100ml	Absent/100ml
Coliform	Present: 52 MPN/100 ml	Present: 24 MPN/100 ml	Present:161MPN/100ml	Present:161MPN/100ml
Faecal coliforms	Absent/100 ml	Absent/100 ml	Present:13MPN/100ml	Absent/100 ml

*Sample dated 06.11.2012 was analysed for limits as per IS 10500 -2012 revision for limited parameters only for which results are shown

Table 18 Analytical results Suriyamman Temple groundwater.

Parameter	Sampling date 24.12.2011	Sampling date 09.04.2012	Sampling date 20.07.2012	Sampling date 06.11.2012*
ALUMINIUM as Al	BDL(DL0.001 mg/l)	BDL(DL0.001mg/l)	BDL(DL0.001mg/l)	
COLOUR (HAZEN UNITS)	10 Hazen	10 Hazen	10 Hazen	10 Hazen
B.O.D @ 27°C for 3 days	Less than 2 mg/l			
ODOUR	Unobjectionable	Unobjectionable	Unobjectionable	Agreeable
COD	8 mg/l			
TASTE	Agreeable	Agreeable	Disagreeable	
TURBIDITY	0.2NTU	0.6 NTU	1.1 NTU	0.7 NTU
Ph Value	7.03	6.95	7.17	7.97
TOTAL HARDNESS as $CaCo_3$	551mg/l	360 mg/l	453 mg/l	461 mg/l
IRON (as Fe)	BDL(DL0.001 mg/l)	0.08 mg/l	0.003 mg/l	0.07 mg/l
CHLORIDES as Cl	270mg/l	177 mg/l	182 mg/l	185 mg/l
RESIDUAL FREE CHLORINE	BDL(Dl:0.1 mg/l)	BDL(Dl:0.1 mg/l)	BDL(Dl:0.1 mg/l)	
TOTAL DISSOLVED SOLIDS	1148 mg /l	720 mg /l	724 mg /l	746 mg /l
CALCIUM as Ca	184mg/l	111 mg/l	116 mg/l	134 mg/l
MAGNESIUM as Mg	23mg/l	20 mg/l	40 mg/l	31 mg/l
COPPER as Cu	BDL(DL:0.001 mg/l)	BDL(DL:0.001 mg/l)	BDL(DL:0.001 mg/l)	
MANGANESE as Mn	0.445 mg/l	0.66 mg/l	0.59 mg/l	
SULPHATE as SO4	119 mg/l	64 mg/l	58 mg/l	45 mg/l
NITRATE (as NO3)	39 mg/l	17.8 mg/l	10 mg/l	
FLUORIDE (as F)	0.19 mg/l	0.16 mg/l	0.52 mg/l	
PHENOLIC COMPOUNDS (AS C6H50H)	Absent	Absent	Absent	
MERCURY as Hg	BDL (DL:0.001 mg/l)	BDL (DL:0.001 mg/l)	BDL (DL:0.001 mg/l)	
CADMIUM as Cd	BDL (DL:0.001 mg/l)	BDL (DL:0.001 mg/l)	BDL (DL:0.001 mg/l)	
SELENIUM (as Se)	BDL (DL:0.001 mg/l)	BDL (DL:0.001 mg/l)	BDL (DL:0.001 mg/l)	
ARSENIC as As	BDL (DL:0.001 mg/l)	BDL (DL:0.001 mg/l)	BDL (DL:0.001 mg/l)	
CYANIDE as CN	Absent	Absent	Absent	
LEAD (as Pb)	BDL(DL:0.001 mg/l)	BDL(DL:0.001 mg/l	BDL(DL:0.001 mg/l	

Table 18 - continued

Parameter	Sampling date	Sampling date	Sampling date	Sampling date
	24.12.2011	**09.04.2012**	**20.07.2012**	**06.11.2012***
ZINC (as Zn)	BDL(DL:0.001 mg/l)	BDL(DL:0.001 mg/l	BDL(DL:0.001 mg/l	
ANIONIC SURFACE ACTIVE AGENTS as (MBAS)	BDL(DL:0.05 mg/l)	BDL(DL:0.5 mg/l	BDL(DL:0.5 mg/l	
CHROMIUM (as Cr6+)	BDL(DL:0.01 mg/l)	BDL(DL:0.01 mg/l	BDL(DL:0.01 mg/l	
POLYNUCLEAR AROMATIC HYDROCARBONS	BDL(DL:0.05 mg/l)	BDL(DL:0.5 µg/l)	BDL(DL:0.5 µg/l)	
MINERAL OIL	Absent	Absent	Absent	
ALKALINITY as CaCo3	445 mg/l	309 mg/l	281 mg/l	335 mg/l
BORON as B	0.032 mg/l	0.07 mg/l	0.036 mg/l	
E.coli	Absent/100ml	Absent/100ml	Absent/100ml	Absent/100 ml
Coliform	Present;54 MPN/ 100 ml	Present: 54 MPN/100 ml	Present: 161MPN/	Present: 161MPN/
Faecal coliforms	Absent /100 ml	Absent /100 ml	Present; 8 MPN/100 ml	Absent /100 ml

*Sample dated 06.11.2012 was analysed for limits as per IS 10500 -2012 revision for limited parameters only for which results are shown

Table 19 Analytical results Suriyamman Temple Tank surface water.

Parameter Test for	Sampling date 24.12.11	Sampling date 09.04.2012	Sampling date 20.07.2012	Sampling date 06.11.2012*
ALUMINIUM as Al	BDL(DL0.001mg/l)	0.003mg/l	0.014mg/l	
COLOUR (HAZEN UNITS)	10 Hazen	5 Hazen (True Colour)	10 Hazen (True Colour)	10 Hazen (True C)
B.O.D @ 27°C for 3 days				
ODOUR	Unobjectionable	Unobjectionable	Unobjectionable	Agreeable
COD				
TASTE	Agreeable	Agreeable	Agreeable	DISAgreeable
TURBIDITY	0.2NTU	3.4 NTU	6.8 NTU	6.1 NTU
Ph Value	7.66	7.76	7.63	7.87
TOTAL HARDNESS as $CaCo_3$	301mg/l	200 mg/l	267 mg/l	334 mg/l
IRON (as Fe)	BDL(DL0.001mg/l)	0.05mg/l	0.033mg/l	0.09mg/l
CHLORIDES as Cl	96mg/l	126 mg/l	182 mg/l	95 mg/l
RESIDUAL FREE CHLORINE	BDL(Dl:0.1 mg/l)	BDL(Dl:0.1 mg/l)	BDL(Dl:0.1 mg/l)	
TOTAL DISSOLVED SOLIDS	570 mg /l	484 mg /l	580 mg /l	544 mg /l
CALCIUM as Ca	83 mg/l	56 mg/l	51 mg/l	90 mg/l
MAGNESIUM as Mg	23mg/l	15 mg/l	34 mg/l	27 mg/l
COPPER as Cu	BDL(DL:0.001 mg/l)	BDL(DL:0.001 mg/l)	BDL(DL:0.001 mg/l)	
MANGANESE as Mn	0.023 mg/l	0.017 mg/l	0.045 mg/l	
SULPHATE as SO4	93 mg/l	63 mg/l	86 mg/l	166 mg/l
NITRATE (as NO3)	BDL(DL:0:0.1 mg/l)	2.2 mg/l	1.7 mg/l	
FLUORIDE (as F)	0.26 mg/l	BDL(DL:0.1 mg/l)	0.41 mg/l	
PHENOLIC COMPOUNDS (AS C6H50H)	Absent	Absent	Absent	
MERCURY as Hg	BDL (DL:0.001 mg/l)	BDL (DL:0.001 mg/l)	BDL (DL:0.001 mg/l)	
CADMIUM as Cd	BDL (DL:0.001 mg/l)	BDL (DL:0.001 mg/l)	BDL (DL:0.001 mg/l)	
SELENIUM (as Se)	BDL (DL:0.001 mg/l)	BDL (DL:0.001 mg/l)	BDL (DL:0.001 mg/l)	
ARSENIC as As	BDL (DL:0.001 mg/l)	BDL (DL:0.001 mg/l)	BDL (DL:0.001 mg/l)	
CYANIDE as CN	Absent	Absent	Absent	
LEAD (as Pb)	BDL(DL:0.001 mg/l)	BDL (DL:0.001 mg/l)	BDL (DL:0.001 mg/l)	
ZINC (as Zn)	BDL(DL:0.001 mg/l)	BDL (DL:0.001 mg/l)	BDL (DL:0.001 mg/l)	

Table 19 continued

Parameter Test for	Sampling date 24.12.11	Sampling date 09.04.2012	Sampling date 20.07.2012	Sampling date 06.11.2012*
CHROMIUM (as Cr6+)	BDL(DL:0.01 mg/l)	BDL(DL:0.01 mg/l	BDL(DL:0.01 mg/l	
POLYNUCLEAR AROMATIC HYDROCARBONS	BDL(DL:0.05 mg/l)	BDL(DL:0.5 µg/l	BDL(DL:0.5 µg/l	
MINERAL OIL	Absent	Absent	Absent	
ALKALINITY as CaCo3	232 mg/l	190 mg/l	121 mg/l	155 mg/l
BORON as B	0.017 mg/l	0.06 mg/l	0.033 mg/l	
E.coli	Absent/100ml	Absent/100ml	Absent/100ml	Absent/100 ml
Coliform	Present;92 MPN/100 ml	Present; 24 MPN/100 ml	Present; 8 MPN/100 ml	Present; 54 MPN/
Faecal coliforms	Absent /100 ml	Absent /100 ml	Absent /100 ml	Absent /100 ml

*Sample dated 06.11.2012 was analysed for limits as per IS 10500 -2012 revision for limited parameters only for which results are shown

Table 20 Analytical results Agastheswarar Temple groundwater.

Parameter Test for	Sampling date 21.11.2011	Sampling date 05.04.2012	Sampling date 20.07.2012	Sampling date 06.11.2012*
ALUMINIUM as Al	BDL(DL:0.001 mg/l)	BDL(DL:0.001 mg/l)	BDL(DL:0.001 mg/l)	
COLOUR (HAZEN UNITS)	10 Hazen (True Colour)	10 Hazen (True Colour)	25 Hazen (True Colour)	10 Hazen (True Col)
B.O.D @ 27°C for 3 days	Less than 2 mg/l			
ODOUR	Unobjectionable	Unobjectionable	Unobjectionable	Agreeable
COD	Less than 4 mg/l			
TASTE	Disagrieeable	Agreeable	Agreeable	Agreeable
TURBIDITY	5.6 NTU	3.0 NTU	1.3 NTU	4.1 NTU
Ph Value	6.82	7.49	7.04	7.46
TOTAL HARDNESS as $CaCo_3$	477 mg/l	224 mg/l	169 mg/l	305 mg/l
IRON (as Fe)	0.029 mg/l	0.037 mg/l	1.5 mg/l	0.4 mg/l
CHLORIDES as Cl	346 mg/l	111 mg/l	154 mg/l	150 mg/l
RESIDUAL FREE CHLORINE	BDL(DL:0.1 mg/l	BDL(DL:0.1 mg/l	BDL(DL:0.1 mg/l	
TOTAL DISSOLVED SOLIDS	1210 mg/l	528 mg/l	496mg/l	678mg/l
CALCIUM as Ca	155 mg/l	58 mg/l	54 mg/l	92 mg/l
MAGNESIUM as Mg	22 mg/l	19 mg/l	8.5 mg/l	18 mg/l
COPPER as Cu	BDL(DL:0.001 mg/l	BDL(DL:0.001 mg/l	BDL(DL:0.001 mg/l	
MANGANESE as Mn	2.094 mg/l	0.088 mg/l	0.77 mg/l	
SULPHATE as SO4	97 mg/l	128 mg/l	46 mg/l	36 mg/l
NITRATE (as NO3)	0.6 mg/l	0.85 mg/l	2.6 mg/l	
FLUORIDE (as F)	0.22 mg/l	0.35 mg/l	o.73 mg/l	
PHENOLIC COMPOUNDS (AS C6H50H)	Absent	Absent	Absent	
MERCURY as Hg	BDL(DL:0.001 mg/l	BDL(DL:0.001 mg/l	BDL(DL:0.001 mg/l	
CADMIUM as Cd	BDL(DL:0.001 mg/l	BDL(DL:0.001 mg/l	BDL(DL:0.001 mg/l	
SELENIUM (as Se)	BDL(DL:0.001 mg/l	BDL(DL:0.001 mg/l	BDL(DL:0.001 mg/l	
ARSENIC as As	0.003 mg/l	BDL(DL:0.001 mg/l	0.007 mg/l	
CYANIDE as CN	Absent	Absent	Absent	
LEAD (as Pb)	BDL(DL:0.001 mg/l	BDL(DL:0.001 mg/l	BDL(DL:0.001 mg/l	
ZINC (as Zn)	BDL(DL:0.001 mg/l	BDL(DL:0.001 mg/l	0.008 mg/l	

Table 20 continued

Parameter Test for	Sampling date 21.11.2011	Sampling date 05.04.2012	Sampling date 20.07.2012	Sampling date 06.11.2012*
CHROMIUM (as Cr6+)	BDL(DL:0.001 mg/l	BDL(DL:0.01 mg/l	BDL(DL:0.01 mg/l	
POLYNUCLEAR AROMATIC HYDROCARBONS	BDL(DL:0.05 µg/l	BDL(DL:0.05 µg/l	BDL(DL:0.05 µg/l	
MINERAL OIL	Absent	Absent	Absent	
ALKALINITY as CaCo3	398 mg/l	276 mg/l	175 mg/l	284 mg/l
BORON as B	0.092 mg/l	BDL(DL:0.05 mg/l	0.13 mg/l	
E.coli	Absent/100 ml	Absent/100 ml	Absent/100 ml	Absent/100 ml
Coliform	Present: 161 MPN/100 ml	Present: 54 MPN/100 ml	Present: 161MPN/100 ml	Present: 92MPN/
Faecal coliforms	Present: 8 MPN/100 ml	Absent/100 ml	Present: 8MPN/100 ml	Absent/100 ml

*Sample dated 06.11.2012 was analysed for limits as per IS 10500 -2012 revision for limited parameters only for which results are shown

Table 21 Analytical results Agastheswarar Temple Tank.

Parameter	Sampling date 19/11/2011	Sampling date 05.04.2012	Sampling date 20.07.2012	Sampling date 06.11.2012*
ALUMINIUM as Al	0.009mg/l	BDL(DL:0.001 mg/l	0.007 mg/l	
COLOUR (HAZEN UNITS)	20 Hazen(True colour)	40 Hazen (True colour)	10 Hazen (True Colour)	10 Hazen (True Colr)
B.O.D @ 27°C for 3 days	10 mg/l	_		
ODOUR	Unobjectionable	Unobjectionabl e	Disagreeable	Agreeable
COD	55 mg/l	_		
TASTE	Disagreeable	Disagreeable	Disagreeable	Disagreeable
TURBIDITY	5.6 NTU	21.3 NTU	34 NTU	0.7 NTU
Ph Value	7.38	7.98	7.91	7.62
TOTAL HARDNESS as $CaCo_3$	123 mg/l	101 mg/l	130 mg/l	134 mg/l
IRON (as Fe)	0.20 mg/l	0.016 mg/l	1.7 mg/l	0.3 mg/l
CHLORIDES as Cl	50 mg/l	70 mg/l	130 mg/l	27 mg/l
RESIDUAL FREE CHLORINE	BDL(DL:0.1 mg/l)	BDL(DL:0.1 mg/l)	BDL(DL:0.1 mg/l	
TOTAL DISSOLVED SOLIDS	296 mg/l	308 mg/l	432 mg/l	297 mg/l
CALCIUM as Ca	35 mg/l	22 mg/l	32 mg/l	36 mg/l
MAGNESIUM as Mg	8.8 mg/l	11 mg/l	12 mg/l	11 mg/l
COPPER as Cu	0.002 mg/l	BDL(DL:0.001 mg/l)	BDL(DL:0.001 mg/l	
MANGANESE as Mn	0.007 mg/l	0.021 mg/l	0.008 mg/l	
SULPHATE as SO4	39 mg/l	19 mg/l	40 mg/l	25 mg/l
NITRATE (as NO3)	1.8 mg/l	0.28 mg/l	1.7 mg/l	
FLUORIDE (as F)	0.14 mg/l	0.24 mg/l	BDL(DL:0.1 mg/l	
PHENOLIC COMPOUNDS (AS C6H50H)	Absent	Absent	Absent	
MERCURY as Hg	BDL(DL:0.001 mg/l)	BDL(DL:0.001 mg/l)	BDL(DL:0.001 mg/l	
CADMIUM as Cd	BDL(DL:0.001 mg/l)	BDL(DL:0.001 mg/l)	BDL(DL:0.001 mg/l	
SELENIUM (as Se)	BDL(DL:0.001 mg/l)	BDL(DL:0.001 mg/l)	BDL(DL:0.001 mg/l	
ARSENIC as As	0.001 mg/l	BDL(DL:0.001 mg/l)	0.002 mg/l	
CYANIDE as CN	Absent	Absent	Absent	
LEAD (as Pb)	BDL(DL:0.001 mg/l)	BDL(DL:0.001 mg/l)	BDL(DL:0.001 mg/l	
ZINC (as Zn)	0.002 mg/l	BDL(DL:0.001 mg/l)	BDL(DL:0.001 mg/l	

Table 21 continued

Parameter	Sampling date 19/11/2011	Sampling date 05.04.2012	Sampling date 20.07.2012	Sampling date 06.11.2012*
CHROMIUM (as Cr6+)	BDL(DL:0.001 mg/l)	BDL(DL:0.01 mg/l)	BDL(DL:0.01 mg/l	
POLYNUCLEAR AROMATIC HYDROCARBONS	BDL(DL:0.05 µg/l)	BDL(DL:0.05 µg/l)	BDL(DL:0.05 µg/l	
MINERAL OIL	Absent	Absent	Absent	
ALKALINITY as CaCo3	135 mg/l	126 mg/l	158 mg/l	129 mg/l
BORON as B	0.083 mg/l	BDL(DL:0.005 mg/l)	0.12 mg/l	
E.coli	Absent/100 ml	Absent/100 ml	Absent/100 ml	Absent/100 ml
Coliform	Present:161 MPN/100 ml	Present:92 MPN/100 Ml	Present: 161MPN/100 ml	Present:92 MPN/
Faecal coliforms	Present:11 MPN/100 ml	Absent/100 ml	Absent/100 ml	Absent/100 ml

*Sample dated 06.11.2012 was analysed for limits as per IS 10500 -2012 revision for limited parameters only for which results are shown.

Table 22 Analytical results Kurrungaleswarar Temple Tank surface water.

Parameter	Sampling date 19.11.2011	Sampling date 03.04.2012	Sampling date 20.07.2012	Sampling date 06.11.2012*
ALUMINIUM as Al	0.017 mg/l	0.452 mg/l	0.02 mg/l	
COLOUR (HAZEN UNITS)	20 Hazen (True colour)	20 Hazen (True colour)	25 Hazen (True colour)	10 Hazen (True c colour)
B.O.D @ 27°C for 3 days	8 mg/l			
ODOUR	Objectionable	Objectionable	UnObjectionabl e	Agreeable
COD	47 mg/l			
TASTE	Disagreeable	Disagreeable	Agreeable	
TURBIDITY	7.3 NTU	60.0 NTU	3.0 NTU	2.8 NTU
pH Value	6.99	7.56	7.36	7.44
TOTAL HARDNESS as $CaCo_3$	107 mg/l	90 mg/l	173 mg/l	132 mg/l
IRON (as Fe)	0.2 mg/l	0.66 mg/l	0.2 mg/l	0.1 mg/l
CHLORIDES as Cl	45 mg/l	62 mg/l	40 mg/l	37 mg/l
RESIDUAL FREE CHLORINE	BDL(DL:0.1 mg/l)	BDL(DL:0.1 mg/l)	BDL(DL:0.1 mg/l)	
TOTAL DISSOLVED SOLIDS	249 mg/l	340 mg/l	312 mg/l	242 mg/l
CALCIUM as Ca	33 mg/l	25 mg/l	58 mg/l	41 mg/l
MAGNESIUM as Mg	5.9 mg/l	6.8 mg/l	6.6 mg/l	7.3 mg/l
COPPER as Cu	0.002 mg/l	0.013 mg/l	BDL(DL:0.001 mg/l)	
MANGANESE as Mn	0.156 mg/l	0.145 mg/l	0.06 mg/l	
SULPHATE as SO4	12 mg/l	16 mg/l	111 mg/l	23 mg/l
NITRATE (as NO3)	0.9 mg/l	2.9 mg/l	1.1 mg/l	
FLUORIDE (as F)	0.14 mg/l	BDL(DL:0.1 mg/l)	0.4 mg/l	
PHENOLIC COMPOUNDS (AS C6H50H)	Absent	Absent	Absent	
MERCURY as Hg	BDL(DL:0.001 mg/l)	0.004 mg/l	BDL(DL:0.001 mg/l)	
CADMIUM as Cd	BDL(DL:0.001 mg/l)	BDL(DL:0.001 mg/l)	BDL(DL:0.001 mg/l)	
SELENIUM (as Se)	BDL(DL:0.001 mg/l)	BDL(DL:0.001 mg/l)	BDL(DL:0.001 mg/l)	
ARSENIC as As	BDL(DL:0.001 mg/l)	0.001 mg/l	0.003 mg/l	
CYANIDE as CN	Absent	Absent	Absent	
LEAD (as Pb)	BDL(DL:0.001 mg/l)	0.007 mg/l	BDL(DL:0.001 mg/l)	
ZINC (as Zn)	0.001 mg/l	0.056 mg/l	0.003 mg/l	
ANIONIC SURFACE ACTIVE AGENTS as (MBAS)	BDL(DL:0.05 mg/l)	BDL(DL:0.05 mg/l)	BDL(DL:0.05 mg/l)	

Table 22 continued

Parameter	Sampling date	Sampling date	Sampling date	Sampling date
POLYNUCLEAR AROMATIC HYDROCARBONS	BDL(DL:0.05 µg/l)		BDL(DL:0.05 µg/l	
MINERAL OIL	Absent	Absent	Absent	
ALKALINITY as CaCo3	126 mg/l	225 mg/l	102 mg/l	41 mg/l
BORON as B	BDL(DL:0.005 mg/l)	BDL(DL:0.005 mg/l)	0.015 mg/l	
E.coli	Absent/100 ml	Absent/100 ml	Absent/100 ml	Absent/100 ml
Coliform	161 MPN/100 Ml	92 MPN/100 Ml	28 MPN/100 ml	161 MPN/100 ml
Faecal coliforms	13 MPN/100 Ml	Absent/100 ml	Absent/100 ml	Absent/100 ml

*Sample dated 06.11.2012 was analysed for limits as per IS 10500 -2012 revision for limited parameters only for which results are shown

Table 23 Analytical results Kurrungaleswarar Temple groundwater.

Parameter	Sampling date 19.11.2011	Sampling date 09.04.2012	Sampling date 20.07.2012	Sampling date 06.11 .2012*
ALUMINIUM as Al	0.003 mg/l	0.073mg/l	BDL(DL:0.001 mg/l	
COLOUR (HAZEN UNITS)	10 Hazen (True Colour)	20 Hazen (True Colour)	10 Hazen (True Colour)	10 HU(True Col
B.O.D @ 27°C for 3 days	Less than 2 mg/l			
ODOUR	Unobjectionable	Unobjectionable	Unobjectionable	agreeable
COD	Less than 4 mg/l			
TASTE	Disagreeable	Disagreeable	Agreeable	Agreeable
TURBIDITY	3.2 NTU	0.5 NTU	2.2 NTU	1.2NTU
Ph Value	7.33	7.52	6.96	7.96
TOTAL HARDNESS as $CaCo_3$	309 mg/l	334 mg/l	435 mg/l	420 mg/l
IRON (as Fe)	0.46 mg/l	0.105mg/l	0.068 mg/l	0.04 mg/l
CHLORIDES as Cl	171 mg/l	209 mg/l	194 mg/l	177 mg/l
RESIDUAL FREE CHLORINE	BDL(DL:0.1 mg/l	BDL(DL:0.1 mg/l	BDL(DL:0.1 mg/l	
TOTAL DISSOLVED SOLIDS	902 mg/l	902mg/l	888 mg/l	864 mg/l
CALCIUM as Ca	70 mg/l	90 mg/l	109 mg/l	99 mg/l
MAGNESIUM as Mg	32 mg/l	27 mg/l	40 mg/l	42 mg/l
COPPER as Cu	BDL(DL:0.001 mg/l	0.005 mg/l	*BDL(DL:0.001 mg/l)*	
MANGANESE as Mn	1.9 mg/l	2.68mg/l	0.161 mg/l	
SULPHATE as SO4	86 mg/l	26mg/l	107 mg/l	94 mg/l
NITRATE (as NO3)	0.5 mg/l	0.5mg/l	26.7 mg/l	
FLUORIDE (as F)	0.13 mg/l	BDL(DL:0.1 mg/l	0.25 mg/l	
PHENOLIC COMPOUNDS (AS C6H50H)	Absent	Absent	Absent	
MERCURY as Hg	BDL (DL:0.001 mg/l)	BDL(DL:0.001 mg/l	BDL(DL:0.001 mg/l	
CADMIUM as Cd	BDL (DL:0.001 mg/l)	BDL(DL:0.001 mg/l	BDL(DL:0.001 mg/l	
SELENIUM (as Se)	BDL (DL:0.001 mg/l)	BDL(DL:0.001 mg/l	BDL(DL:0.001 mg/l	
ARSENIC as As	0.002 mg/l	BDL(DL:0.001 mg/l	BDL(DL:0.001 mg/l	
CYANIDE as CN	Absent	Absent	Absent	
LEAD (as Pb)	BDL(DL:0.001 mg/l	0.003 mg/l	BDL(DL:0.001 mg/l	

Table 23 - continued

Parameter	Sampling date	Sampling date	Sampling date	Sampling date
ANIONIC SURFACE ACTIVE AGENTS as (MBAS)	BDL(DL:0.05 mg/l	BDL(DL:0.05 mg/l	BDL(DL:0.05 mg/l	
CHROMIUM (as Cr6+)	BDL(DL:0.001 mg/l	BDL(DL:0.01 mg/l	BDL(DL:0.01 mg/l	
POLYNUCLEAR AROMATIC HYDROCARBONS	BDL(DL:0.05 µg/l	BDL(DL:0.05 µg/l	BDL(DL:0.05 µg/l	
MINERAL OIL	Absent	Absent	Absent	
ALKALINITY as CaCo3	438 mg/l	473mg/l	324 mg/l	322 mg/l
BORON as B	0.171 mg/l	0.019 mg/l	0.085 mg/l	
E.coli	Absent/100 ml	Absent/100 ml	Absent/100 ml	Absent/100 ml
Coliform	Present: 92 MPN/100 ml	Present: 54 MPN/100 ml	Present: 161 MPN/100 ml	Present: 92 MPN/100 ml
Faecal coliforms	Present: 8 MPN/100 ml	Absent/100 ml	Present: 13 MPN/100 ml	Absent/100 ml

*Sample dated 06.11.2012 was analysed for limits as per IS 10500 -2012 revision for limited parameters only for which results are shown

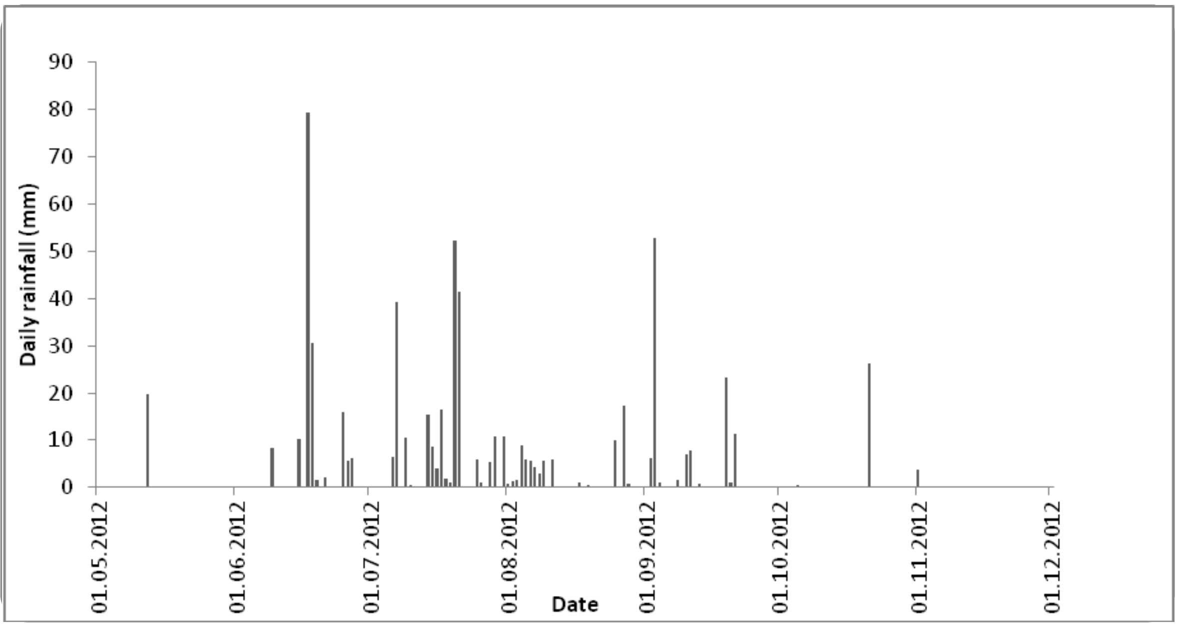

Figure 49 Daily rainfall in 2012 in the Maheshwaram watershed.

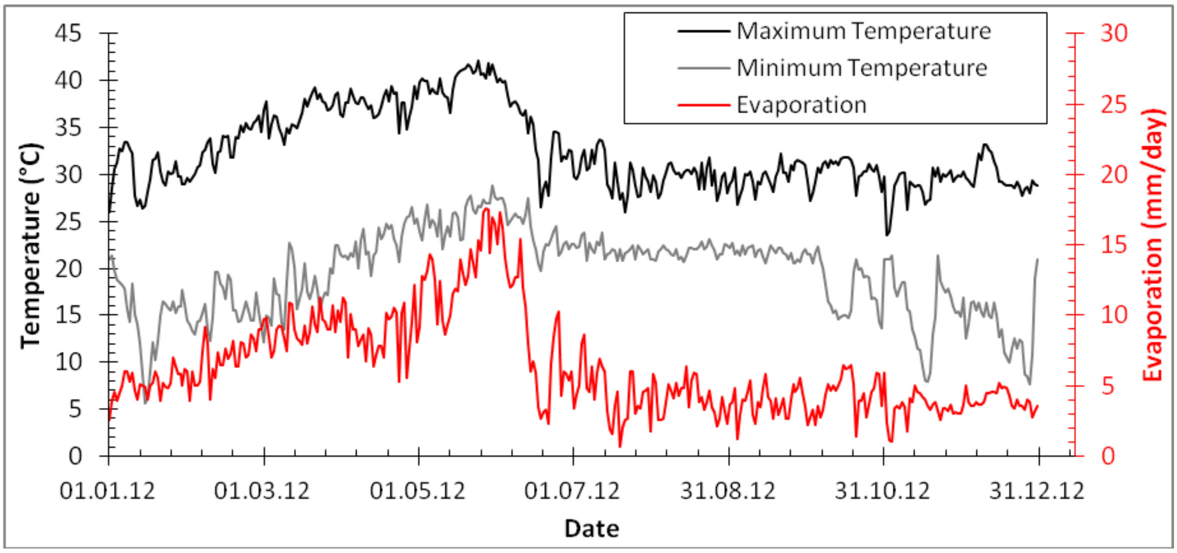

Figure 50 Evaporation and temperature (ICRISAT meteorological station - Hyderabad).

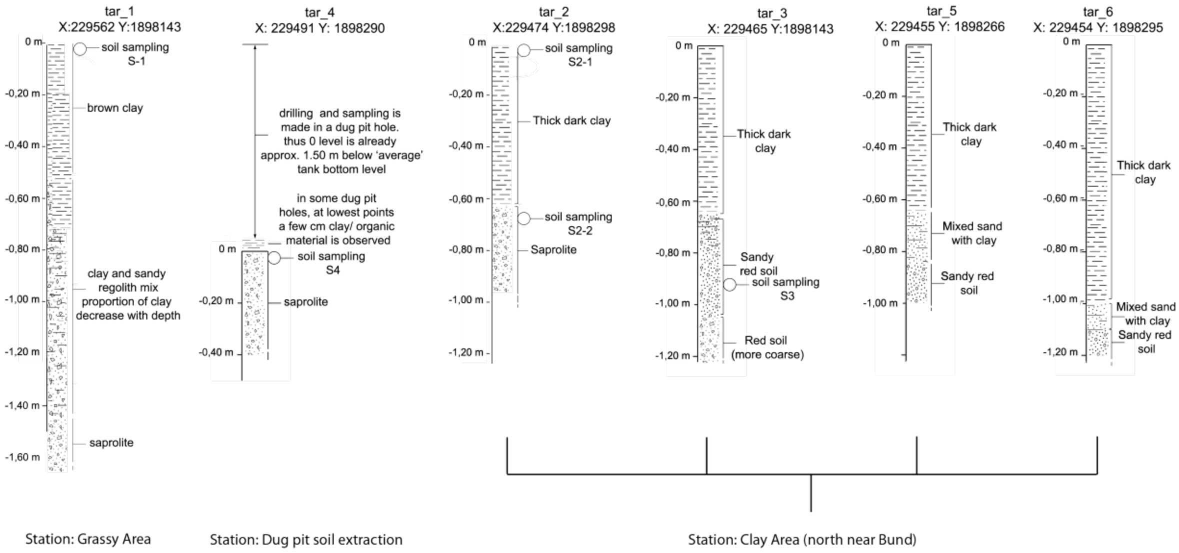

Figure 51 Soil profiles obtained from auger drillings, circles indicate samples where grain size distribution was determined.

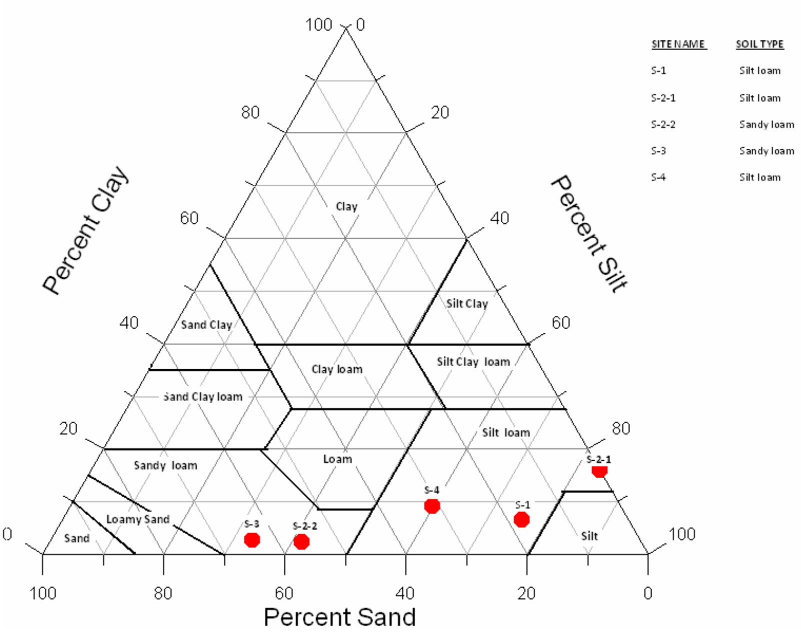

Figure 52 Soil composition.

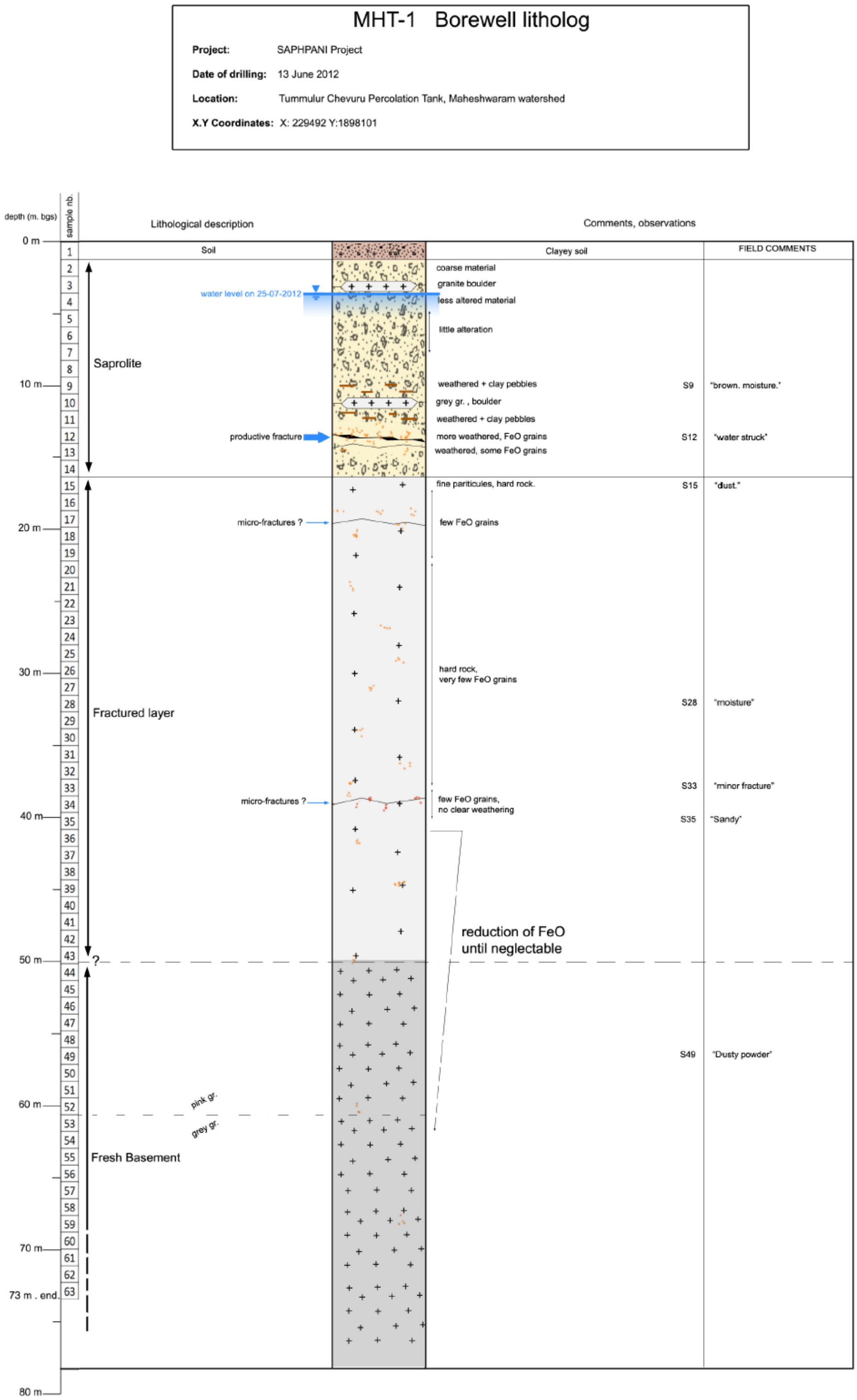

Figure 53 Litho log MHT 1 Maheshwaram.

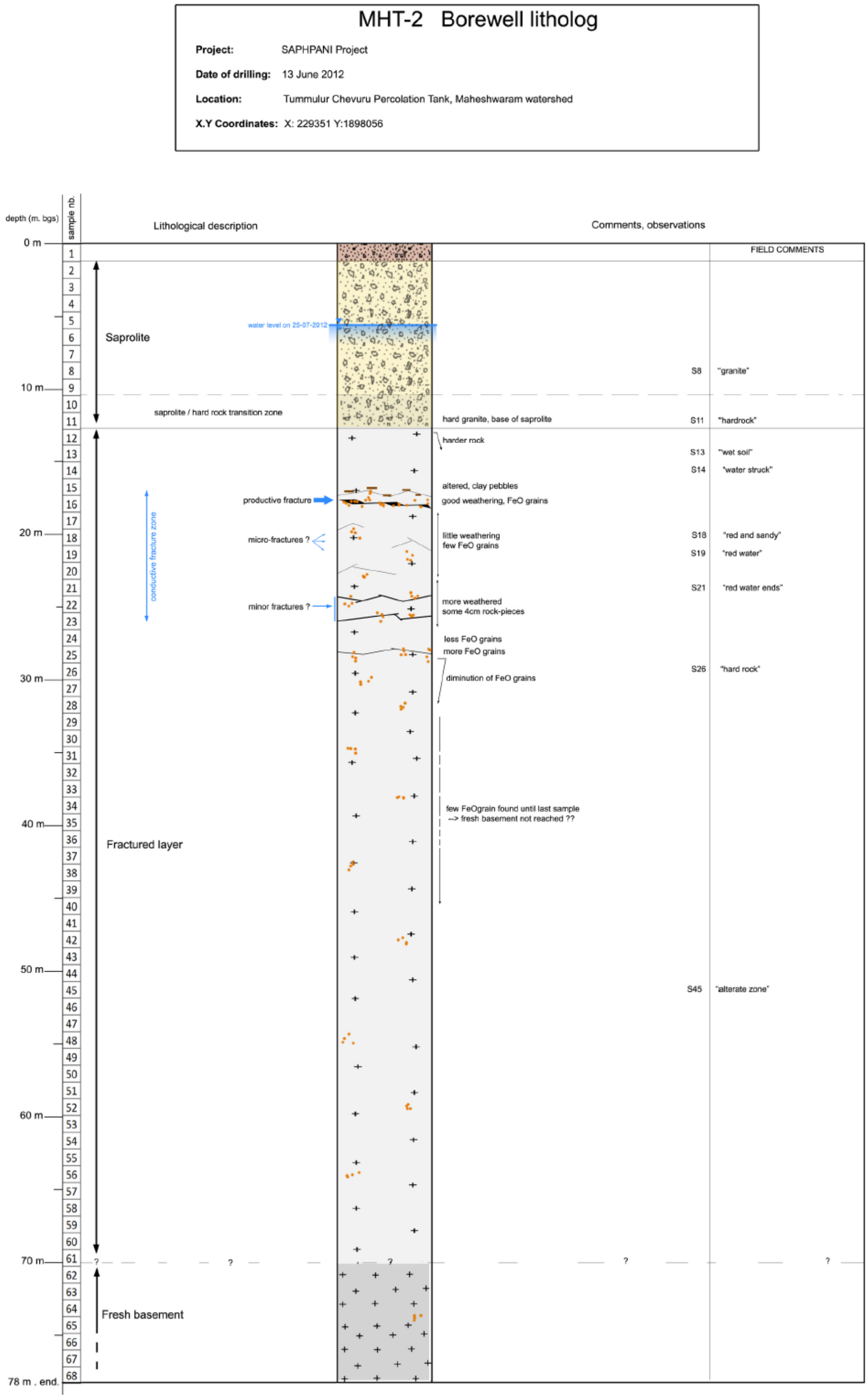

Figure 54 Litho log MHT 2 Maheshwaram.

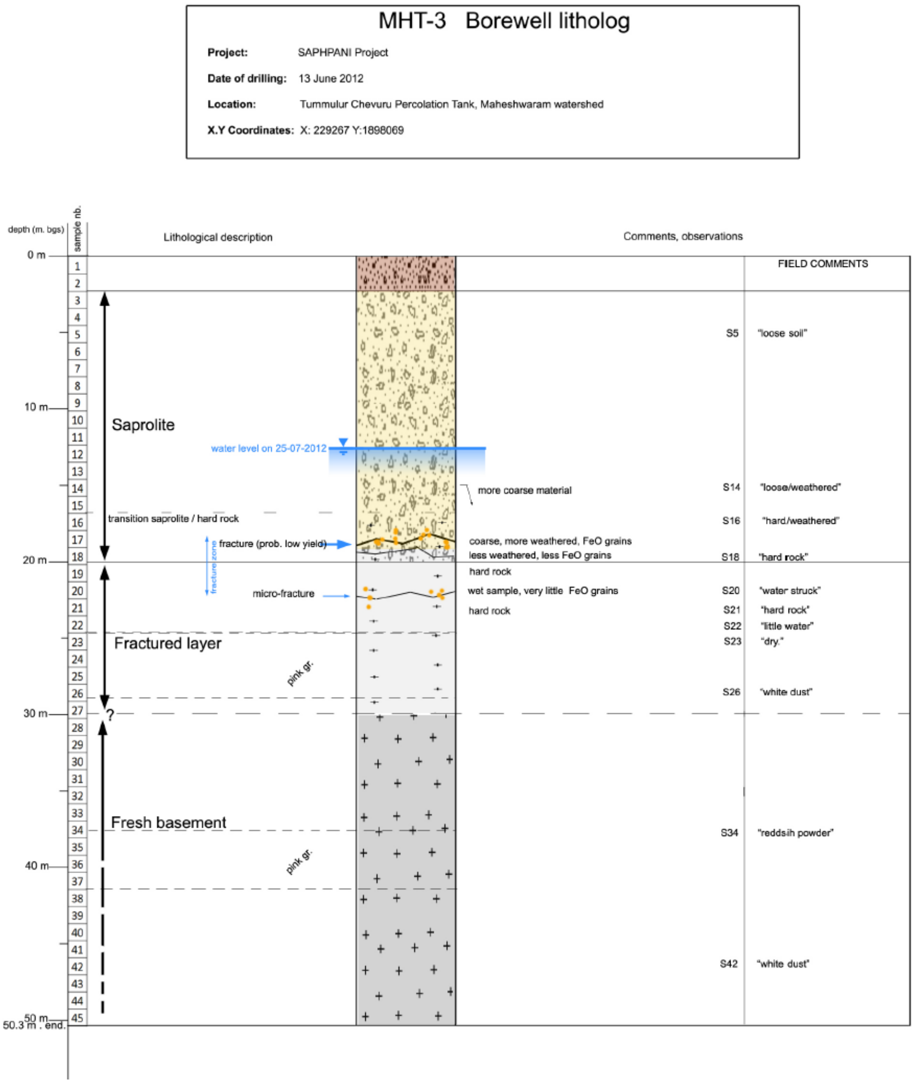

Figure 55 Litho log MHT 3 Maheshwaram.

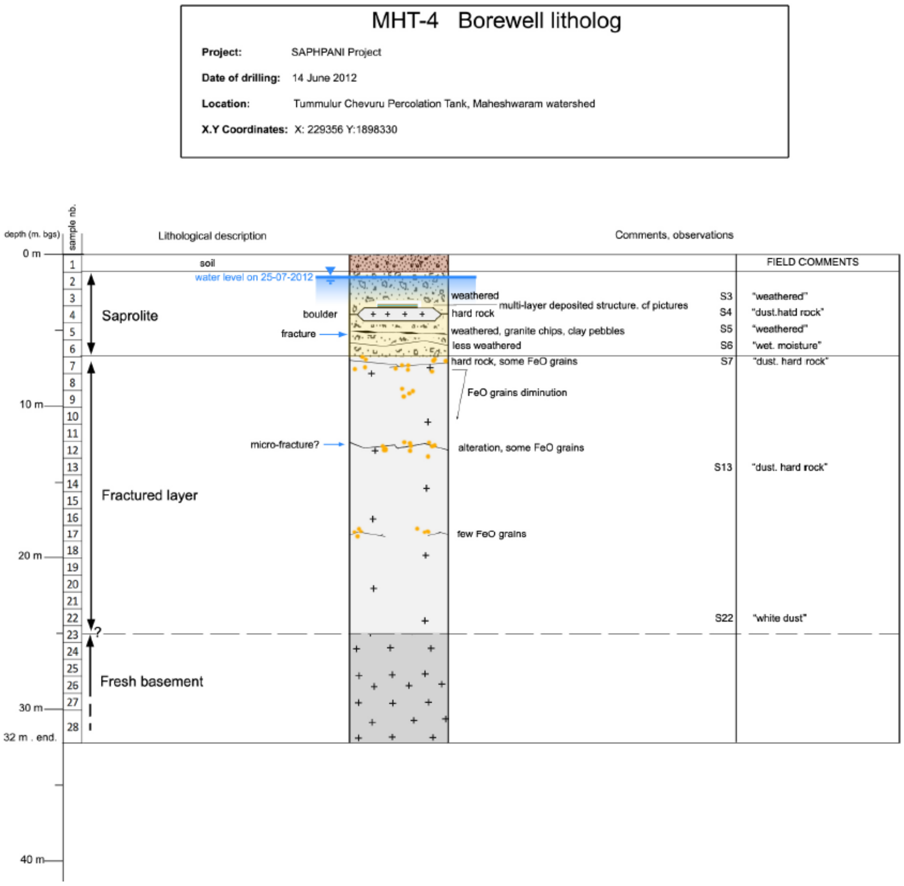

Figure 56 Litho log MHT 4 Maheshwaram.

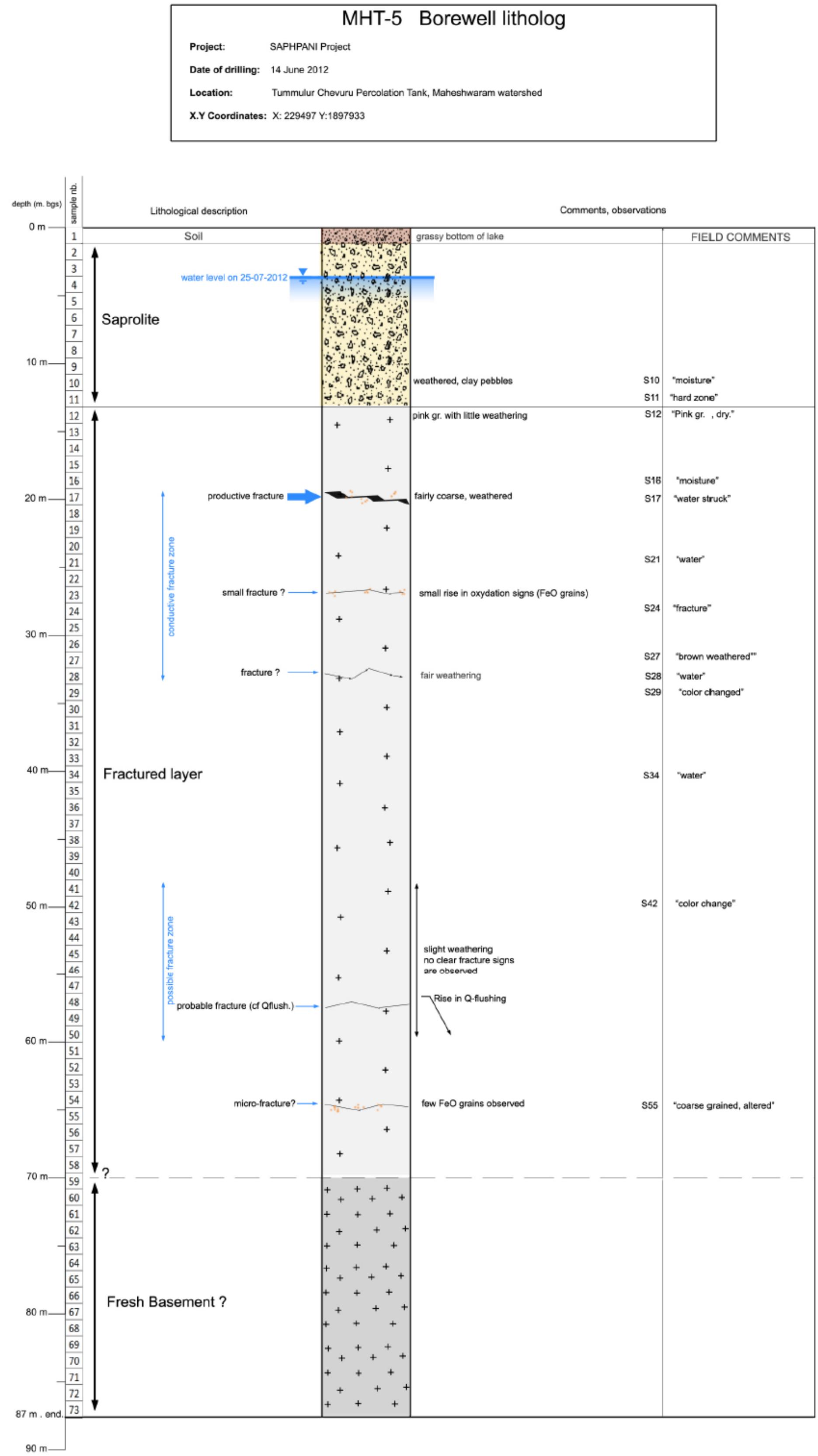

Figure 57 Litho log MHT 5 Maheshwaram.

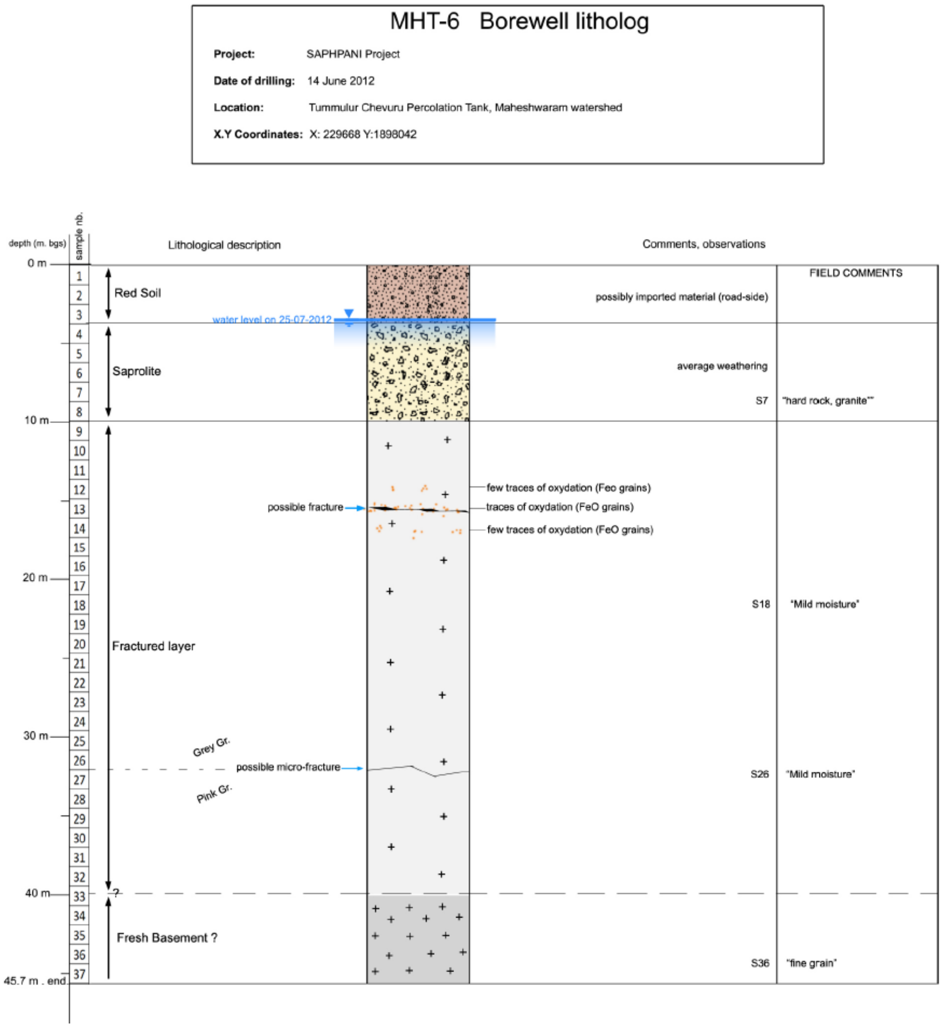

Figure 58 Litho log MHT 6 Maheshwaram.

Table 24 Mean monthly data of the meteorological parameters of the Raipur city area estimated based on daily data series for the period 2001-2010 (Data: IGKV, Raipur).

Month	Maximum temperature (°C)	Minimum temperature (°C)	Relative humidity (%)	Wind speed (Km/hr)	Evaporation (mm/day)
January	28	11	60	2	3
February	31	14	56	3	4
March	35	19	47	4	6
April	40	23	35	6	10
May	42	27	33	8	12
June	37	27	57	10	9
July	31	25	81	9	4
August	30	25	85	8	4
September	31	24	81	5	4
October	31	21	72	3	4
November	30	16	65	2	3
December	28	12	63	2	3

Table 25 Month-wise distribution of average annual rainfall in the Raipur city area.

Month	Average monthly rainfall (mm)	Month	Average monthly rainfall (mm)
January	17.73	July	354.92
February	14.63	August	287.52
March	13.85	September	206.74
April	10.31	October	49.68
May	19.86	November	11.16
June	209.4	December	10.98
	Total		**1206.78 mm**

Table 26 Runoff at different probability of exceedance for the Teliabanda Lake area.

Month	Av. monthly runoff (mm)	Runoff at 50% probability	Runoff at 75% probability	Runoff at 90% probability	Runoff at 100% probability
Jan	5.03	0.000	0.000	0.000	0.000
Feb	3.74	0.000	0.000	0.000	0.000
Mar	1.37	0.000	0.000	0.000	0.000
Apr	0.09	0.000	0.000	0.000	0.000
May	3.45	0.000	0.000	0.000	0.000
Jun	134.31	132.983	12.591	0.670	0.000
Jul	223.95	180.385	135.857	73.914	21.846
Aug	160.13	126.042	107.487	97.150	83.625
Sep	119.92	144.508	60.612	32.651	10.370
Oct	25.03	16.709	0.419	0.000	0.000
Nov	4.52	0.000	0.000	0.000	0.000
Dec	5.18	0.000	0.000	0.000	0.000

Table 27 Runoff at different probability of exceedance for the catchment 1 of the Teliabanda area.

Month	Av. monthly runoff (mm)	Runoff at 50% probability	Runoff at 75% probability	Runoff at 90% probability	Runoff at 100% probability
Jan	4.13	0.000	0.000	0.000	0.000
Feb	3.08	0.000	0.000	0.000	0.000
Mar	1.01	0.000	0.000	0.000	0.000
Apr	0.05	0.000	0.000	0.000	0.000
May	3.11	0.000	0.000	0.000	0.000
Jun	126.50	123.153	9.736	0.336	0.000
Jul	205.00	161.394	115.651	67.271	17.607
Aug	143.57	111.955	94.349	78.260	71.813
Sep	110.00	135.090	52.980	28.027	8.072
Oct	21.90	13.612	0.255	0.000	0.000
Nov	3.70	0.000	0.000	0.000	0.000
Dec	4.87	0.00	0.00	0.00	0.00

Table 28 Runoff at different probability of exceedance for the catchment (1+2) of the Teliabanda area.

Month	Av. monthly runoff (mm)	Runoff at 50% probability	Runoff at 75% probability	Runoff at 90% probability	Runoff at 100% probability
Jan	3.90	0.000	0.000	0.000	0.000
Feb	2.91	0.000	0.000	0.000	0.000
Mar	0.94	0.000	0.000	0.000	0.000
Apr	0.04	0.000	0.000	0.000	0.000
May	3.01	0.000	0.000	0.000	0.000
Jun	124.21	120.147	9.071	0.275	0.000
Jul	199.34	155.603	109.896	65.239	16.651
Aug	138.82	107.943	90.748	73.082	68.707
Sep	107.02	132.169	50.899	26.678	7.556
Oct	21.07	12.896	0.222	0.000	0.000
Nov	3.50	0.000	0.000	0.000	0.000
Dec	4.77	0.000	0.000	0.000	0.000

Station 2: DEVPURI

Locations: N 21°12’ 47.6”, E 81°41’ 24.9”

ERT Data Acquisition

Profile at station 2 (Devpuri) is laid down in NNE-SSW direction for the ERT data acquisition. This site is in open field near the railway track. It allowed us to map the layers with maximum spacing of 10 m between the electrodes. Thus experimental field setup was laid along 480 m. The Wenner-Schlumberger array was used for resistivity measurements. A total number of 529 datum points were measured at 23 data levels, which lead to the plotting of a pseudo section (Figure 59), by the observed data sets. The ground resistance was again negligible. There was some transported shaly limestone near the centre of the profile.

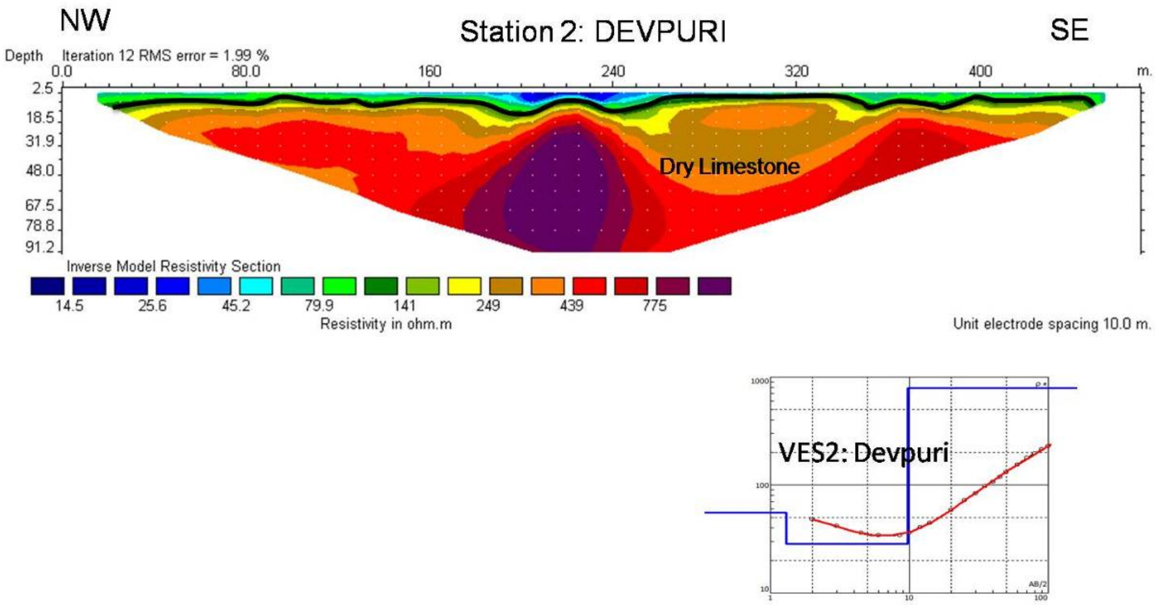

Figure 59 ERT profile along station 2 at Devpuri with VES curve carried out during first field survey.

The Vertical Electrical Soundings carried out by Dar et al. 2012 shows the three layered structure with top soil up to 2 m and second layer of thickness 8-10 m. In the acquired pseudo section (Figure 59) it also brings out clearly that there is a weathered limestone or shaly limestone of nearly 50 ohm-m resistivity up to a depth of 10 m below the surface. Next to it is a hard/dry limestone up to a depth of 90 m with high resistivity more than 150 ohm-m. There is also an intrusive body of comparatively high resistivity.

Site 3: QUEENS CLUB OF INDIA (Landmark)

Locations: N 21°14’ 13.1”, E 81°41’ 03.8”

Electrical resistivity tomography (ERT) Data Acquisition

Electrodes are laid down in NE-SW direction along the profile with electrode spacing of 4 m thus covering total 188 m long profile (Figure 60). Data was acquired with Wenner-Schlumberger configurations with 1st electrode in S-W direction and last 48th electrode in N-E direction. The raw data was inverted with RES2DINV and pseudo section was acquired as shown below in Figure 60. There is one nalah flowing parallel to the profile in SW-NE direction approximately 10-15m away from electrodes. One well towards east of the profile has 50 feet of water level. Also there are 4 bore well dug in this area having 50-80 feet water level. Ground resistance is again negligible at this station also.

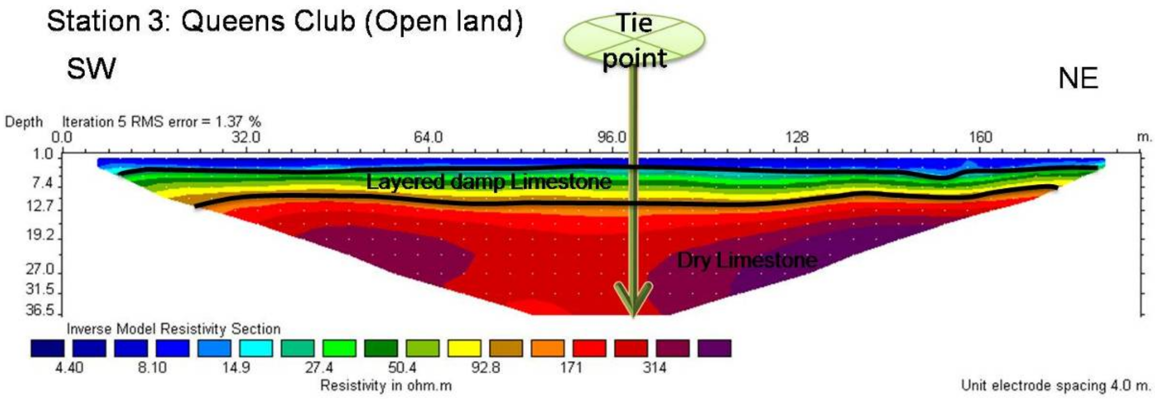

Figure 60 ERT profile along station 3 at Queens club site.

Top layer of 4-6 m is very conducting with resistivity less than 15 ohm-m. The flow of Saddu nalah (refer Figure 43) which is parallel to the profile is from SW to NE, and meet the Chhokhara nalah at the end. Weathered limestone/shale is interpreted from 6 m till 15 m below the surface and below which is the dry limestone with high resistivity between 100 ohm-m and 400 ohm-m. At this station data along two cross-profiles was acquired. Figure 60 and Figure 61 shows the cross profiles which intersects each other at the “tie-point” being marked in respective pseudo sections.

The cross profile of Figure 60 is shown in Figure 61. Electrodes are laid down in E-W direction with 1st electrode in east direction and 48th electrode in west direction with electrode spacing of 6 m. Resistivity data was acquired with both wenner-schlumberger and dipole dipole configuration (Figure 61a and b). Both configuration give consistent result. The two profiles intersect at 26th-27th and 24th-25th of first and crossed profile respectively.

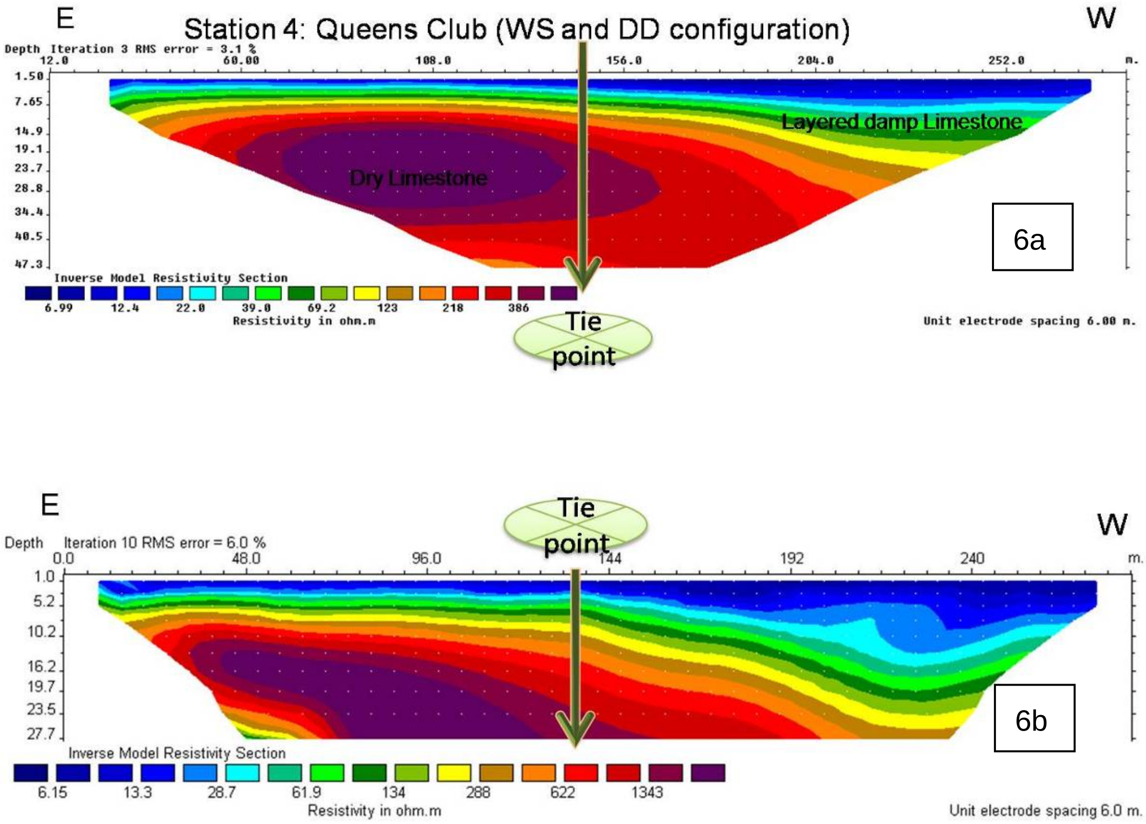

Figure 61 ERT cross-profile along station 3 at Queens club site. 6a shows the tomogram with wenner schlumberger configuration and 6b shows acquisition with dipole-dipole configurations.

The resistivity values exactly correlates along the “tie-point”. The overall resistivity variations give the same lithology of damp limestone up to a depth of 10 m on eastern flank and 15 m on the western side of the profile. The resistivity varies less than 100 ohm-m up to 20 on the western end. Below which hard limestone is located up to 45 m depth with high resistivity up to 400 ohm-m. Dipole dipole configuration gives pseudo section up to a shallower level whereas with Wenner-Schlumberger we can map almost one and half the depth of dipole dipole configuration.

Site 4: SHRI RAM MANDIR

Locations: N 21°14’ 15.4”, E 81°40’ 47.8”

ERT Data Acquisition

The profile is in NE-SW direction (Figure 62) with 1st electrode towards NE and 48th electrode in SW directions respectively. The profile is 188 m long with electrode separation of 4 m. Total 23 data levels were mapped with 529 datum points. Raw resistivity values were inverted using RES2DINV and then pseudo section was prepared.

There is flowing Nalah in SW-NE direction approximately 10-12m away from 48th electrode and 30-35m away from central electrode and 1-2m away from 1st electrode. As information gathered from local sources there are four bore well dug previously where water struck at 150 feet approximately.

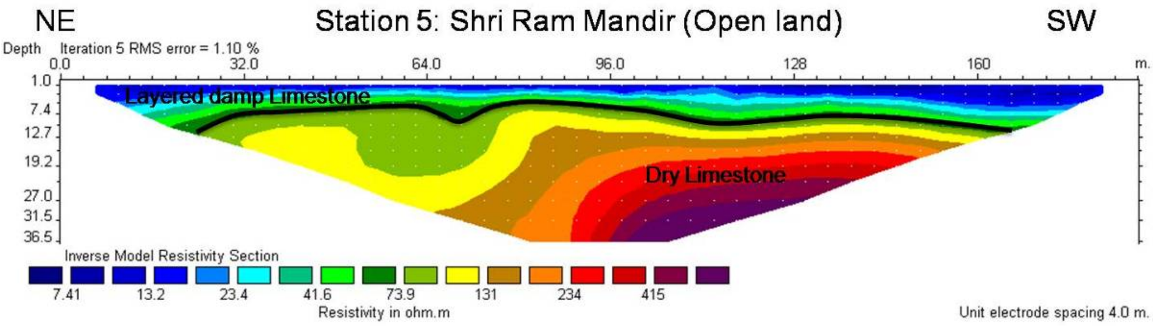

Figure 62 ERT profile along station 4 at Shri Ram Mandir site.

The top layer with thickness of 8-10 m is conducting with resistivity values of less than 80-100 ohm-m. The structure is not so clearly layered as in previous pseudo section as there is a kink observed at a distance of 60 -70 m from the first electrode position. This carries up to a depth of 20 m below from 50 m till 80 m along the profile. Though the resistivity values varies from 80 -100 ohm-m at this location, below which there is hard and dry limestone with high resistivity from 150 ohm and 400 ohm-m

Table 29 Site ID, coordinates and stable isotopes for samples from AK-aquifer .

Site ID	UTM X	UTM Y	^{18}O	σ ^{18}O	D	σ D
sw1	396404.5	1472334.5	-1.42	0.06	-9.33	0.94
sw1			-1.15	0.06	-6.22	1.32
sw1			-0.19	0.07	-1.25	0.48
sw1			-1.90	0.28	-10.66	2.47
sw2			-1.90	0.28	-10.66	2.47
sw2			-4.65	0.02	-22.42	0.94
dw2	423485.8	1481652.3	-3.30	0.09	-17.88	0.66
dw3	423506.3	1481670.9	-4.87	0.09	-28.88	0.70
			-0.69	0.06	-4.64	0.38
dw4	428109.1	1476571.3	-5.20	0.03	-29.16	0.39
tw1	418323.3	1481329.4	-3.53	0.06	-21.81	0.49
dw27	396877.2	1472606.1	-2.64	0.06	-17.55	0.34
dw1.1	396398.3	1472320.9	-3.16	0.10	-18.85	0.72
dw1.1			-3.43	0.12	-20.71	0.59
dw1.1			-3.27	0.08	-19.69	0.36
dw1.2	396364.5	1472318.4	-3.78	0.08	-22.29	0.54
bw14a	416981.3	1468872.0	-3.16	0.05	-21.47	0.35
bw15	414817.2	1471834.6	-3.03	0.11	-20.54	0.93
dw16	421936.4	1473943.1	-5.39	0.09	-34.76	0.36
dw16			-3.74	0.07	-22.99	0.57
bw Salt Pan	425067.8	1476729.6	-2.66	0.09	-20.74	0.28
sp			-1.35	0.08	-9.83	0.42
sp2			-1.53	0.05	-10.13	0.40
dw29	398094.5	1471849.2	-4.31	0.05	-25.47	0.38
tw11	396324.6	1471722.5	-4.08	0.07	-23.90	0.53
tw77	395917.5	1473960.3	-3.95	0.09	-25.57	0.83
dw31	395923.3	1473941.5	-3.62	0.10	-23.05	1.04
dw18	397004.7	1473495.0	-3.93	0.08	-26.15	0.84
seawater1	423967.8	1448569.4	-0.17	0.07	2.56	0.24
seawater2	423967.8	1448569.4	-0.21	0.07	2.56	0.55
pulikat lake	423133.0	1482587.0	-0.13	0.08	2.90	0.41
bw18	418749.0	1466307.0	-2.87	0.03	-16.60	0.29
bw19	410500.0	1465993.0	-2.94	0.10	-17.88	0.78
bw20	413523.0	1468592.0	-2.66	0.09	-14.72	0.43
bw21	414004.0	1469020.0	-1.97	0.12	-11.49	0.53

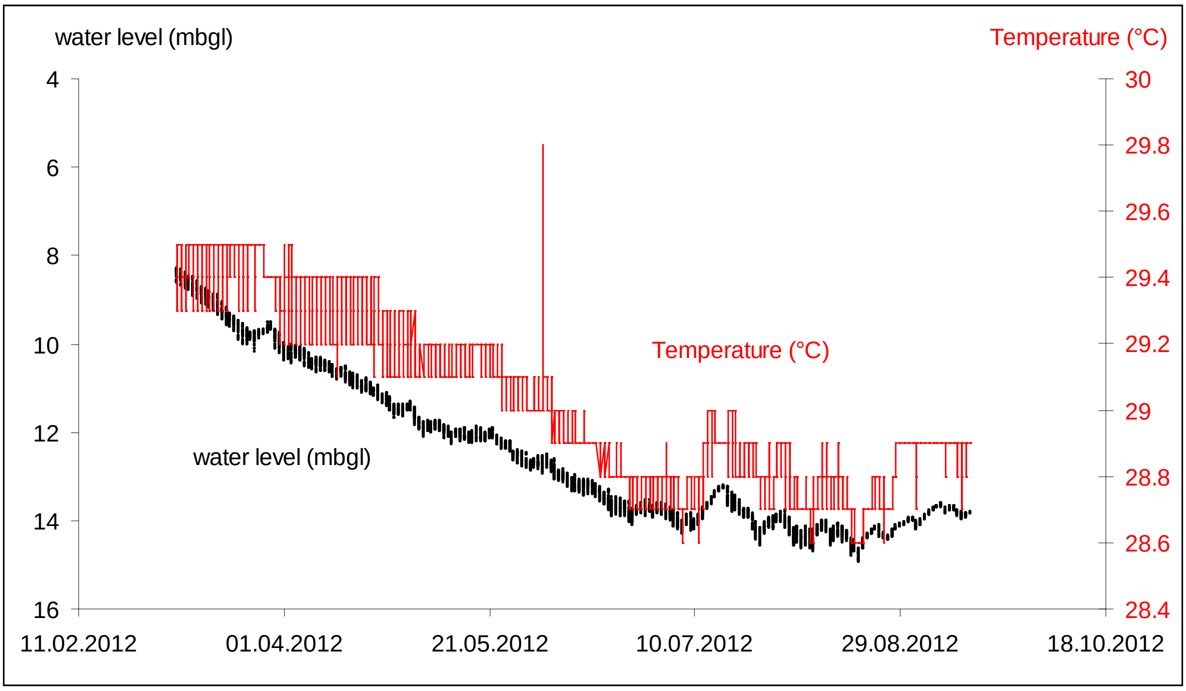

Figure 63 Water level (meter below ground level) of TW11 well close to the Paleshwaram check dam.

Table 30 Site ID, hydrochemistry given in mg/l (except for HCO_3), ion balance and field measurements.

Site ID	Site	Sampling Date	el.Cond (µS/cm)	pH	T °C	HCO_3 mmol/L	Ca	Mg	Na	K	Cl	SO_4	Br	ion balance (%)
sw1	Check dam Periyapalayam	20.01.2012	555	8.5	na	3.2	49	23.5	57	3.6	107	55	0.15	-3.8
sw1		08.02.2012	830	8.7	28.6	3.3	31	22	61	9.8	85	32	na	-0.9
sw1		06.03.2012	596	na	32.4	2.8	22	21.4	71	4.1	89	34	na	0.1
sw1		13.01.2012	605	7.6	25.3						91***			na
sw2	Aranyar River mouth	13.01.2012	1076				52	31	150	5.8	235	60	4.7	1.6
sw2		26.11.2012	537				21	13	84	9	146	35	0.4	-3.7
dw2	Andermadam village	01.02.2012	465	6.8	25.7	1.6	41	15.7	47	5.1	52	55	0.1	10.0
dw3	Andermadam school	01.02.2012	2360	8.1	26.8	5.5	63	54	305	68	350	187	1.2	7.8
		26.11.2012	14860	7.1	29.6	8.0	355	421	2940	67	4800	800	17	6.3
dw4	Temple well at coast	01.02.2012	803	7.8	27.1	4.1	42	8.9	94	12	83	26	0.16	-0.7
tw1		01.02.2012	4230	6.3	29.3	3.3	129	98	657	16.5	972	599	2	0.7
dw27	east side of check dam	08.02.2012	688	8.0	30.8	5.6	55	25	102	3.3	101	62	0.15	-2.3
dw1.1	west side of check dam	08.02.2012	880	6.9	29.9	3.7	50	18	59	4	71	30	0.14	1.8
dw1.1		06.03.2012	700	6.8	28.3	4.6	58	20	63	3.7	76	26	na	0.1
dw1.1		13.01.2012	604	6.8	29.6	na								
dw1.2	west side of check dam	13.01.2012	812	7.3	29.3	na								
bw14a	Patmarathy Nagar	08.02.2012	2600	6.8	28.7	5.8	227	68	211	3.4	620	108	1.9	1.1
bw15	Uthandikandigai	08.02.2012	4100	6.7	29.5	6.7	276	92	447	3.6	1075	168	2.2	0.3

Table 30 - continued

Site ID	Site	Sampling Date	el.Cond (µS/cm)	pH	T °C	HCO_3 mmol/L	Ca	Mg	Na	K	Cl	SO_4	Br	ion balance (%)
dw16	fresh water well	06.03.2012	1083	7.1	28.5	3.4	53.5	8.9	48	2.3	52	24	0.2	1.4
dw16		22.02.2012	734	7.1	29.5	na								
sp	Salt Pan well near Kattu abondened bore well near Kattu	22.02.2012	83200	6.4	31.4	6.1	1077	2780	16508	294	34700	5080	13	3.9
sp2		23.11.2012	53800	6.9	30.5	7.2	465	1158	9800	207	16300	2800	71	2.3
bw44		23.11.2012	69300	6.7	30.9	6.1	616	1603	12440	258	21000	3300	89	3.1
dw29	east side of check dam	22.02.2012	1710	9.6	31.2	1.3	4.5	0.9	317	17.7	466	1	1.2	0.2
tw11		06.03.2012	1772	7.5	26.6	8.0	104	37.7	241	9.1	246	116	4.9	3.6
tw77		06.03.2012	772	6.7	29.6	3.1	36	15.4	57	3	75	48	0.13	-5.2
dw31	Vishva to Nelva	06.03.2012	2950	7.2	29.9	na					475***			
dw18	Karani, north east of check dam	06.03.2012	3030	7.1	28.8	na					488***			
seawater 1	Elliiots beach Chennai	06.03.2012	1178	7.4	29.1	na					190***			
seawater 2	Marina beach Chennai	25.11.2012	44300	8.0	28.9	2.4	324	959	8080	300	14600	1920	65	-0.1
pulikat lake	Harbour Pulicat town	25.11.2012	43200	7.8	27.5		327	1000	8115	387	14500	1920	65	1.3
bw18	at Korratalyar River	23.11.2012	42700	8.2	28.2	2.4	325	916	8074	290	15000	1900	66	-1.7
bw19	south of Korratalyar River	21.11.2012	1456	7.1	28.5	4.3	111	61.5	247	7.4	500	100	2	2.4

Table 30 - continued

Site ID	Site	Sampling Date	el.Cond (µS/cm)	pH	T °C	HCO_3 mmol/L	Ca	Mg	Na	K	Cl	SO_4	Br	ion balance (%)
bw20	north of Korratalyar River	21.11.2012	690	6.5	29.3	2.5	40.9	14.3	48	3	56	57	0.2	0.7
bw21	north of Korratalyar River	21.11.2012	883	7.1	28.9	3.6	74	21.1	67	2.2	120	47	0.4	2.4