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Groundwater responses to artificial recharge of rainwater in Chennai, India: a case study in an educational institution campus

V. B. M. Sayana, [1], E. Arunbabu, [2] L. Mahesh Kumar[3], S. Ravichandran[2] and K. Karunakaran[2]
[1]*St. Peters Engineering College, Avadi, Chennai- 600054, India*
[2]*Centre for Water Resources, Anna Univ.-Chennai, Chennai 600025,* [3]*SMK Fomra Instt. of Technol., Chennai 600103*
vbms_19@hotmail.com, sravi7@hotmail.com, lmk27@hotmail.com

Abstract

This paper reports the response of the groundwater in the St Peter's Engineering College campus, Avadi, near Chennai, India. Artificial recharge of rainwater was done through roof top harvesting methods during 2004 to 2007. Based on a hydro geological survey of the campus, eleven bore well were sunk for augmenting water supply to the campus. The lithology of each bore well was also recorded. A percolation pond in 1 ha area on the south eastern side of the campus was dug to collect and store the rainwater harvested from rooftops of the campus buildings. The survey also assisted in the identification and location of about 70 number of recharge wells in the campus. Pumping test was conducted in well no:3 to assess the hydraulic conductivity and calculate other aquifer parameters during 2005. A three layer hydro geological model of the aquifer was applied in Visual Modflow ver 4.1 environment and the model fit was 84% between observed and predicted values (R^2 = 0.844). Significant increase in water level in the top aquifer during 2007 was recorded when compared to 2004. The flow profiles in the middle and deep aquifer showed responses, through changes in the direction of flow to the pumping wells (5, 6 in 2004 and 2, 3 in 2007). In 2007, with improved recharge, changes in the direction of groundwater flow and discharge of water from the aquifer in the southern part of the campus can be noticed. The flow directions in the three aquifer layers also indicated that the northern part of the study area serves as an effective recharge zone for the St Peter's Engineering College Campus. Rainwater harvesting and recharge studies form important part in groundwater restoration and management in intensely urbanized cities/townships.

Keywords: Rainwater harvesting methods, Aquifer recharge, Groundwater flow, Aquifer test pro, Visual Modflow.

Introduction

Water is indispensable for any life system to exist on earth and is a very important component for the development of any society. It has been observed that the total water resources in India are estimated to be around 1869 km^3 / year, while the average utilizable surface water in the country as on 2001 is 1123 km^3 (MoWR, 2010). In the present scenario, the population boom along with industrialisation and globalisation has ensured that the abstraction of ground water has touched the peak and the use of surface water resources alone may not be enough to tide over this demand. The number of ground water wells has increased from less than 1 lakh in 1960 to nearly 12 lakhs in 2002 (Ramaswamy Sakthivadivel, 2002). The ground water resources throughout the world have been fast depleting because of continuous pumping indiscriminately. To meet the growing requirements of water for various activities, it is imperative not only to develop new water resources, but also to conserve, recycle and reuse the water wherever possible.

To meet the increasing demand from domestic and irrigation sectors on groundwater, rain water harvesting is an efficient way of improving the situation through artificial recharge. Rain water is a major source of fresh water and the activity of collecting rainwater directly for beneficial use or recharging it into the ground to improve ground water storage in the aquifer is known as rain water harvesting. Groundwater may also have induced recharge by pumping of the water from shallow aquifers in urban areas (Giovani Pietro Beretta *et al*., 2004).

It has been reported that the stored surface water potential in our state of Tamil Nadu is estimated at 3.4 M.ha.m which is the lowest in the country and around 90% of the surface water potential has been exploited and utilized in Tamil Nadu (Mohanakrishnan, 1990). Therefore, the dependence on the groundwater to meet the growing demands has increased tremendously. When there is a gross misbalance between the natural recharge and extraction of water over a period of time, the decline of water table becomes significant with reduction of yield. One option available for the present day society is to improve the recharge over and above the natural processes. The rainwater harvesting and recharge is one such promising option that has artificial recharge methods also. Various methods of rain water harvesting have been in vogue for a long time. It is estimated that with prudent artificial recharge schemes and waste water recycling, about 25 % of India's water requirements in 2050 can be met (Ramaswamy Sakthivadivel, 2002).

Rainwater harvesting has been done from the days of ancient civilizations in India and have had improvised methods with local materials. Some methods like kul, bamboo and Kund methods are still being used in North India from pre historic times and gradually it has evolved into a scientific system now.

Surplus water releases through canals in surface drainage systems under natural flow conditions with construction of check dams at suitable intervals is also known to improve the recharge of ground water (Khepar *et al*., 2000). Construction of dams across the stream is another type of recharge method and has also been implemented in the regions of low rainfall areas such as Saudi Arabia (Abdul Azeez *et al*.,1989). Recharge had been estimated at about 6% of the pumped ground water by implementing the various recharge methods in Yamagota city of Japan (Abiko Hiroto,1999). Rain water harvesting methods have gained a significant importance and many government and non government agencies have prepared and issued guidelines for popularising rain water harvesting (David, 1998; Rees, 2000; Rees & Whitehead, 2000; CGWB, 2007).

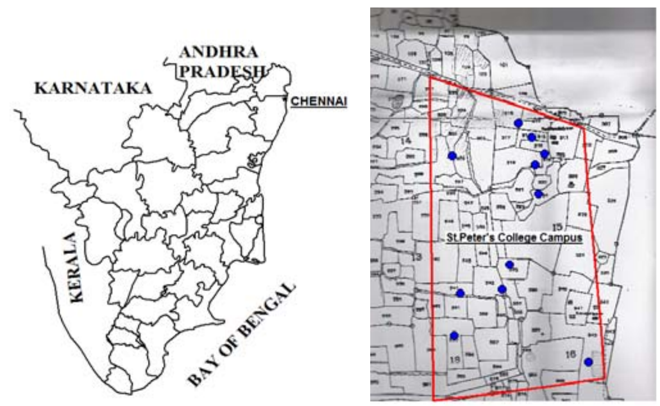
Based on the available data and the knowledge about the local hydrogeology, we can choose the most suitable recharge method and estimate the natural ground water recharge (Amitha Kommadath, 2000). The impact of the artificial recharge would depend upon four factors like slope of the area, surface infiltration, thickness of the aquifer and the quality of water (Saravi *et al*., 2006). Ground water quality in the wells has shown improvement after implementing the artificial recharge when compared with the wells in which rainwater harvesting was not implemented in Rajasthan in India (John Stiefel, 2009). The rate of the aquifer recharge is also one of the most difficult factors in the evaluation of the rainwater harvesting of ground water resources (Kumar & Seethapathi, 2002). Sea water intrusion has also been shown to be arrested or reduced by enforcing the artificial recharge (Dharmesh Mashru, 2006).

In Tamil Nadu, especially in Chennai city, the ever increasing population and the over exploitation of the ground water has led to the realisation of the need to take up rainwater harvesting methods. The Government of Tamil Nadu and its agencies dealing with water resources have taken popular measures to spread the message to the public. Therefore, there is a growing need to make scientific investigations on the role of rainwater harvesting and recharge of groundwater in improving the groundwater availability in Tamil Nadu. In this paper, we report a study undertaken in an educational institute campus in Avadi, near Chennai, on the impact of rainwater harvesting on the groundwater dynamics and storage.

Study area

The study area for this work is the campus of St. Peters Engineering College, which is located at Avadi, near Chennai in Tamil Nadu, India. The total area of the campus is 40 hectares. The terrace areas of the buildings with flat roof structures are 15000 m^2 which includes about 5000 m^2 of hostel area. The laboratories have sloped terrace roofs with an area of about 5000 m^2. The site map of the study area with the location of the wells is shown in Fig.1.

Fig.1. St Peter's Engineering College campus showing location of monitoring wells



St. Peters Engineering college campus is located at 80° 7'2.59"E to 80° 7' 20.19"E longitude and a latitude of 13° 6'3.96"E to 13° 6'34.32"E covering an area of 0.4 sq-km (40 hectares). The open space is about 95% of the total area. The study area is surrounded by Konampedu village in the east, Saraswathi Nagar in the west, agricultural lands in the south and by Annanoor in the north. The study area has a plain topography with a gentle slope towards the north east to south west direction.

Soil lithology

A number of wells have been dug in the study area during the period of study at different points of time to meet water requirements of the campus.

Table 1. The hydro geological profile of the St. Peter's Engineering College

Depth from Ground level (m)	Resistivity in ohm metre	Lithology
0-25	1-20	Clay with fine to medium sand
25-45	60-90	Coarse to very coarse sand with gravel
45-75	1-20	Clay with fine to medium sand
75-95	60-90	Coarse to very coarse sand with gravel

Soil samples were collected at various depths while excavating the bore wells at different stages while drilling bores of 6", 10" and 13" diameters for analysis and textural classification. The wells have been dug by using the rotary method with the help of the agriculture department of the Government of Tamil Nadu. The

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lithology of each of the well during its excavation was carefully recorded and the log data for each well was created. The Fig. 2 shows the details of the log data of the wells.

Table 2. The well inventory of bore wells excavated in the St Peter's College campus

Well no.	Location	Bore size (mm)	Bore casing size (mm)	Bore depth (m)	Screen length (m)	Type of drilling
1	Main Bldg	200	150	73.15	57.9	Compressor
2	SM Lab	150	100	48.76	36.57	Compressor
3	Mechanical Bldg	330	230	91.44	73.15	Rotary
4	New Canteen Block	200	150	91.44	73.15	Compressor
5	Gents Hostel	330	230	91.44	73.15	Rotary
6	Kuppan land	330	200	91.44	73.15	Rotary
7	Masilamani Land	330	175	54.86 91.44	39.62	Rotary
8	Playground	200	150	48.76	36.57	Compressor
9	Near Pond	250	150	60.96	45.72	Rotary
10	Near Old bldg	330	175	42.67 73.15	30.48	Rotary
11	Mohan Land	330	175	54.86 91.44	39.62	Rotary
12	Openwell	2400	1800	12.19	9.14	Dig

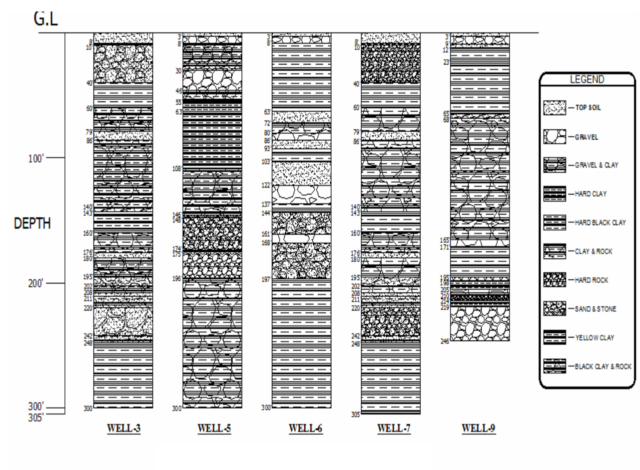
Resistivity survey

In addition, an electrical resistivity survey of the campus was conducted during 2007 to study the hydro geological profile of the campus. In the electrical resistivity method, the electrical resistance of different layers of the earth is determined by applying electric current through metal stakes (outer electrodes) that are driven into the ground (I) and measuring the potential difference in the two inner electrodes placed inside and driven into the ground (V). The resistivity offered by the geologic formation to the flow of current can be measured when a potential difference is applied through a resistivity meter. The resistance can be obtained by dividing I by V. There are two methods of studying the resistivity, one is the horizontal profiling and the other is the vertical profiling. The method of vertical exploration known as expanding electrode method or Vertical Electrical Sounding (VES) is used in this study and the general hydro geological profile of the study area is mapped and is given in Table 1.

Description of wells

In the study area, there are totally twelve wells with one shallow well and eleven deep bore wells. Well numbers 3, 5, 6, 7, 9, 10 and 11 have been excavated by using rotary method while the open well has been excavated using dug in method. The other wells were excavated using compressor method. The size, depth and elevation of the wells are given in Table 2. The log details of the wells are presented in Fig.2

Fig 2. Lithology of the study area



The well no 8 was closed after one year of observation in the year 2004 due to caving. This well was not considered for further research work or observation. The wells 1, 3, 5 and 6 are pumping wells while the others are used as observation wells. The wells 7, 10 and 11 were excavated up to 91.44m, 73.15m and 91.44m depth with a size of 150mm. It was observed that the soil is fully clay after a depth of 54.86m, 42.67m and 54.86m respectively. The water levels in each of the wells are monitored at least once in a month during the period from 2004 to 2007. Some of the wells were also observed closely at the interval of a day during some seasons of the study period. Water quality analysis was also conducted on a seasonal scale during the study period on samples collected from selected observation wells.

Percolation pond

The rainwater collected during the monsoon season through the roof water harvesting was collected and stored in a pond located at the south eastern side of the campus. This percolation pond, excavated on the south eastern side of the college campus is about one hectare area and has an average depth of 5 metres. The lithology of the pond has been observed to be from coarse to very coarse sand with gravel at shallower depths. The percolation pond is located at an elevation of 16.7 m with respect to mean sea level.

Description of recharge wells and other structures

Recharge wells numbering around seventy were dug in the campus to observe the effect of rain water harvesting in and around the college buildings up to a depth of 12 metres by using rotary method with the support of the Agriculture Department of the Government

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of Tamil Nadu. The size of the recharge wells are 330 mm and filled with different grades of pebbles. To collect the rain water from the flat roof structures, the storm water drain pipes were provided. The gutters were also provided to collect rain water from the sloped roof structures and are connected to the recharge wells.

Table 3. The porosity values of three different layers of the study area

Well Name	X [m]	Y [m]	Layer 1			Layer 2			Layer 3		
			n	Ne	Sy	N	Ne	Sy	N	Ne	Sy
OW1	505.81	925.53	0.5	0.2	0.05	0.36	0.072	0.054	0.44	0.088	0.066
OW2						0.36	0.072	0.054	0.36	0.072	0.054
OW3	561.77	785.62	0.42	0.168	0.084	0.36	0.072	0.054	0.43	0.086	0.0645
OW4	572.53	690.92	0.42	0.168	0.084	0.36	0.072	0.054	0.43	0.086	0.0645
OW5	473.52	452.00	0.2	0.08	0.05	0.39	0.078	0.0585	0.3	0.06	0.045
OW6	449.85	376.67	0.2	0.08	0.05	0.28	0.056	0.042	0.45	0.09	0.0675
OW7	294.87	221.69	0.2	0.08	0.05	0.36	0.072	0.054	0.36	0.072	0.054
OW9	740.42	135.60	0.35	0.14	0.0875	0.34	0.068	0.051	0.34	0.068	0.051
OW10	286.26	822.21	0.42	0.168	0.084	0.41	0.082	0.0615	0.41	0.082	0.0615
OW11						0.37	0.074	0.0555	0.37	0.074	0.0555
OW12	553.16	880.33	0.5	0.2	0.05	0.17	0.034	0.0255	0.17	0.034	0.0255

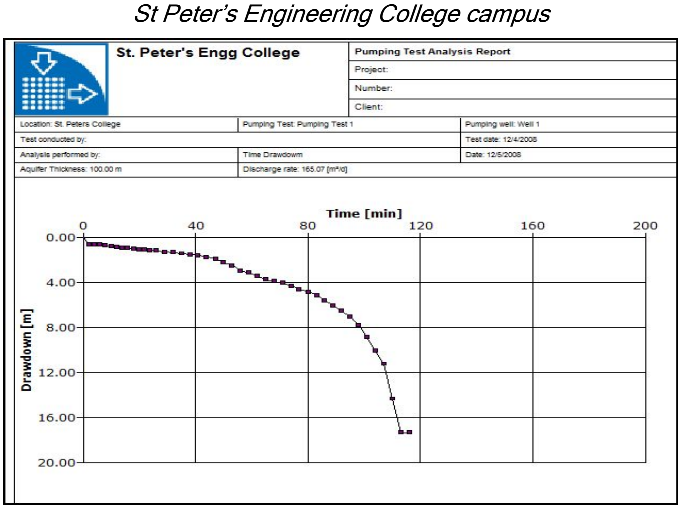
Pumping test analysis

The pumping test was conducted in one of the observation wells during 2007 to assess the hydraulic conductivity of the aquifer. The pumping and recovery test can help determine the safe yield of water from the aquifer. The determination also involves assessing:

1) Transmissivity and storage coefficients of the aquifer,
2) The lateral extent of each aquifer and the hydraulic nature of its boundaries and
3) The effects on recharge and discharge conditions.

The Fig. 3 shows the results of the pumping test analysis.

Fig. 3. The draw down curve (Theis recovery) of well no 3 in the St Peter's Engineering College campus



The transmissivity has been calculated using Theis method while storage coefficient of the aquifer has been determined using Jacob's formula and the values are found to be 0.00163 m^2 and 0.675 respectively.

The aquifer has been divided into three layers. The first layer is taken as a top layer and all the wells are covered fully in the second layer and wells 1, 3, 4, 5, and 6 are considered for the third layer as they are deep. In the first layer, natural slope of the ground is from north east to south west and at the north east corner, it was 17.5m above the mean sea level and on the south west, the elevation is 15m above the mean sea level. It shows a natural slope of 2.5m from northeast to southwest. In the second layer, wells 1, 2, 3, 4, and 12 have the same contours whereas well no 7 is 2.6m above with respect to mean sea level. In the third layer, the elevation contour level of wells 3 and 4 are at same layer and the remaining wells 1, 5 and 6 are at one regions or levels.

The porosity values for the different layers have been determined and are given in Table 3.

The hydraulic conductivity and porosity have been calculated for each well after taking the lithology test at micro level. The hydraulic conductivity varies between 9×10^{-5} to 1.43×10^{-2} in the lateral directions of the aquifer up to a depth of 15m from the ground level (Layer 1). The thickness of the layer 2 varies considerably at every well locations for which the hydraulic conductivity decreases in both lateral as well as in vertical direction.

Conductivity Kx and Ky are very low in the wells 1, 2, 3, 4, 7, and 12 and for the well 11, it was moderate. The hydraulic conductivity is significant in the wells 5, 6, 9 and 10 in the first layer of the aquifer. Kz value has been taken as $1/10^{th}$ of the Kx and Ky values. In the second layer of the aquifer, the Kx, Ky values are very low in the wells 1, 2, 3, 4, 7 and 12 and moderate in 11, whereas in wells 5, 6, 9 and 10 these values are significant. In the third layer, the conductivity values of Kx and Ky are very low in the wells 1, 3, 4, 5 and 6 and the remaining wells do not exist in the third layer of the model.

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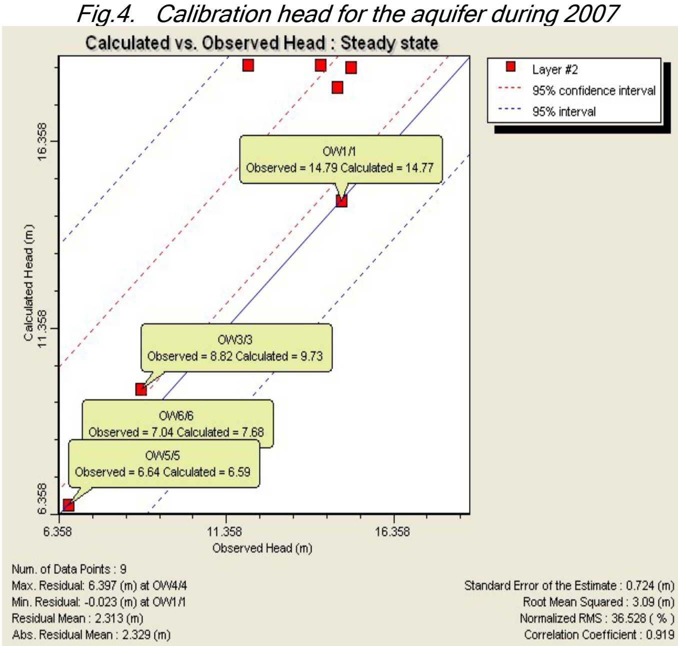
The Fig.4 shows the calibration of the model in the study area. The model fit has an R^2 of 0.844. It can be observed that from the data of 9 wells, the maximum residual is 6.397m at well no: 4 and the minimum residual is -0.23m at well no: 1. The calculated residual mean is 2.313m whereas observed residual mean is 2.329m. The standard error of the estimation is 0.724m. Root mean square is observed to be 3.09m. Normalised RMS is 36.528% and the correlation coefficient is 0.919. The pumping wells 1,3,5,6 are in the above 90% confidence levels and the other wells are below 90% confidence level. The model fit is therefore found satisfactory and is used in further analysis. The model is used for making the estimates of recharge and discharge quantities as well as to study the flow directions under the influence of the artificial recharge.

Fig.4. Calibration head for the aquifer during 2007



The pumping rate has been calculated for the pumping wells 1, 3, 5 and 6 and the total discharge in the study area has been calculated as 365m^3 per day. The recharge has been calculated by using the water balance equation and has been found to be 400 millimeter during 2007.

Flow directions

Groundwater flow

Groundwater flow analysis has been carried out to study the flow directions in the aquifer during 2004 and 2007 in the three layers. The flow directions are given in Fig. 5.

During 2004, the first layer shows well no: 5 and 6 have gone dry. The well no: 7 and well no: 1,2,3,4 show movement towards south direction. There may be inflows into the aquifer from the northern boundaries. The second layer shows the directions of flow from north towards well no: 5 and 6 (deeper wells) and the flow from the south are also towards northern direction, again towards well no: 5 and 6. The flow direction from the well no 1, 2, 3 and 4 is also towards south in the direction of well no 5 and 6. The third layer shows movement of water from the northern part of the study area towards further north direction indicating movement out of the aquifer. There is a contour showing a divide in the north eastern direction where the flow (Fig. 5) shows outward movement of water at the extreme north while the flow turns southwards a little down the southern part of the study area towards well no 5 and 6.

During 2007, in the first layer, there is water available in all the regions of the aquifer compared to the conditions prevailing in 2004. There is a flow of water from the aquifer in the entire northern part of the study area out of the aquifer. The flow from well no: 5 and 6 shows that water moves from these wells to all other directions.

Fig. 5. Groundwater flow directions for layers 1, 2 and 3 during 2004

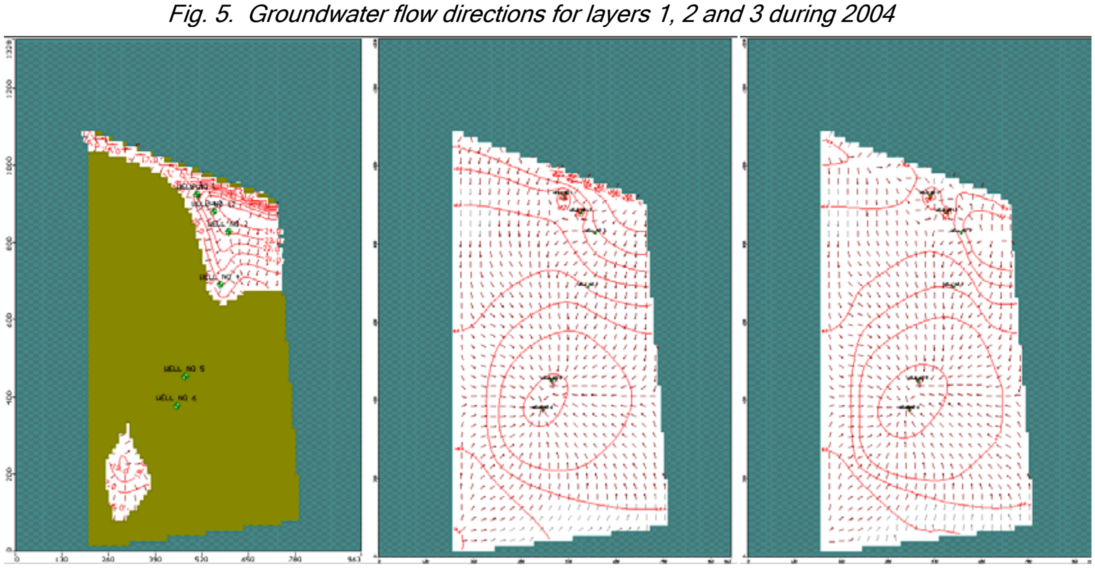
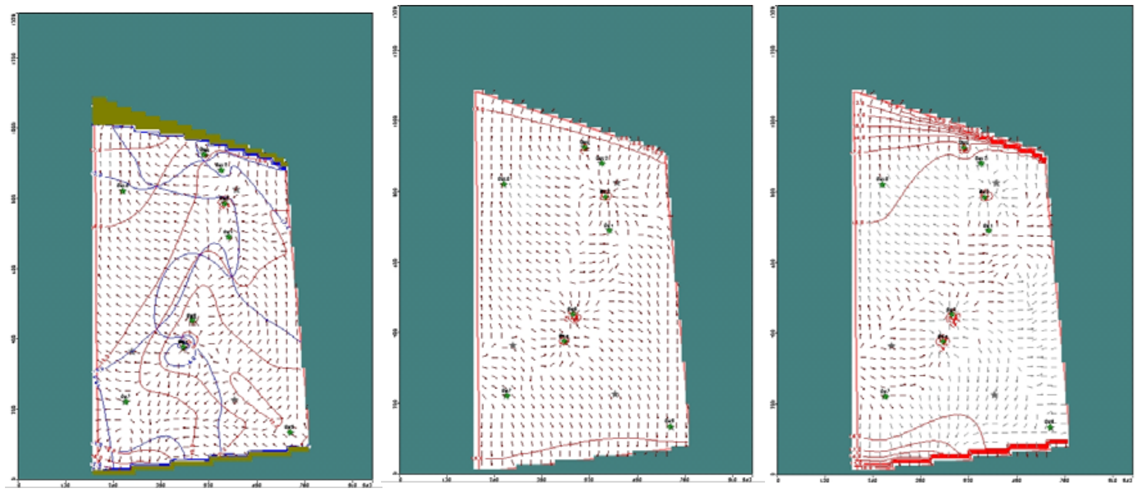


Fig.6. Groundwater flow directions for layers 1, 2 and 3 during 2007



In the southern part of the aquifer, the flow of water is towards south indicating outward flow of water from the aquifer. In the extreme eastern part of the aquifer, we find that the flow is from south to the north and from the middle of the aquifer, the movement is towards west and north western direction. In the second layer, the flow of water appears to move from well no: 3 towards northern direction. Similarly, from the middle of the aquifer, the flow direction below well 5 and 6 is towards southern direction. Though there is movement of water towards well no: 5 and 6 in the middle of the study area from all directions, we can see the movement of water towards west and then to northern direction. At well no: 7, the flow of water is from west to east direction and moving further towards south. In the third layer, we can see a division of flow in the middle of the aquifer from south west to north east direction where the flow direction is reversed. In the northern part as continuation, the flow is towards further north showing discharge from aquifer. Similarly, in the southern part also, the flow is towards south direction moving further downstream.

Water balance

The wells 1, 3, 5 and 6 are the pumping wells while the remaining wells are observation wells. The recharge has been calculated by using the water balance equation and has been found to be 400 millimeter per annum 2007. The results show that the flow mechanism is controlled by the two deep wells (5 and 6) used mainly for pumping water from the aquifer and also have similar depth. The flow towards the middle part of the study area is mainly the abstraction of water through these wells during the period of study. The volume of water pumped during 2004 was 408 m^3 per day and during 2007, it was 365 m^3 per day and the recharge was 140 mm in 2004.

During 2004, the rate of pumping from well no 5 and 6 is high, 395 m^3 per day out of 408 m^3 of water pumped from the entire study area. Therefore the flow may have taken place towards the well no 5 and 6 and may have caused the top layers of the aquifer go dry (Fig. 5). However, during 2007, the top layer shows the presence of water, inspite of nearly pumping the same quantity. The flow directions during 2004 were towards well no: 5 and 6, whereas in 2007, the flow direction has reversed and water appears to flow out of the aquifer (Fig. 6). It may also be noted that the pumping from the well no: 1 and 3 located in the northern part of the aquifer has been increased from 13 m^3 to 180 m^3 from 2004 to 2007. Still the pattern of flow reversal between 2004 and 2007 indicate that there may be fresh recharge taking place during this period which maybe due to the artificial recharge structures established in the study area. The direction of flow in the first and second layer in the northern part also shows that the flow moves all around, indicating that it may be more effective zone of recharge of the harvested rainwater.

Conclusion

The recharge structures established in the St Peter's Engineering College Campus has been effective in recharging the roof top water harvested and stored in the percolation pond in the study area as well as the recharge wells established in the campus. In a period of four years, the recharge is very effective in increasing the level of the water table in the study area and also some ground water flow appears to take place especially in the northern part of the study area to further downstream. This case study brings to the light the importance of microlevel management of water sources that may influence the sustainable management of water as common property resource.

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