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Rooftop rainwater harvesting for groundwater recharge in capital city, Bhubaneswar

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ABSTRACT

A rooftop rainwater harvesting structure (RRHS) was constructed at Hydrology Project building in Bhubaneswar to study the effect of groundwater recharge. One dug well along with three recharge shafts were constructed inside the campus for artificial groundwater recharge. The diameter of dug well was 6.0 m and depth was 10 m (with 9.0 m below ground surface and 1.0 m above ground). Three numbers of recharge shafts of 125 mm diameter each were constructed upto a depth of 35 m based on the geomorphology of the area. The cost of the project was ₹ 7,60,000/–. The study reveals that an average amount of 2500 m^3 of water can be recharged annually through this project. The data on groundwater level shows a rise in summer water table by 0.70 m and in post monsoon period rise is 2.04 m though regular pumping in two productions bore wells. Thus, the study reveals that there is increase in groundwater level due to the recharge structure. This study shows the effectiveness of RRHS for groundwater recharge that can be made in each housing project in urban areas which will reduce decline of groundwater table.

1. INTRODUCTION

Groundwater represents the largest available source of fresh water in the hydrologic cycle. It is the major source to supplement the surface water for domestic and irrigational use. Since groundwater is limited and at all times difficult to locate, great care is needed to be taken for assessment and exploitation of groundwater. The unplanned exploitation of groundwater and excessive dependence on it has resulted in depleting groundwater resource, declining water table and other related problems (Panigrahi *et al.,* 1995; Suryawanshi and Pendke, 2009). It has become one of the major concerns in urban planning. Over exploitation of groundwater resources and as a consequence decline in water table are the causes of serious concern in many areas including both at rural and urban sectors. Getting water through river diversion schemes and water transport to urban areas often has technical, socio–political and complex environmental concerns. To add to this, lack of unpaved area and excessive withdrawal through bore wells are leading to critical sceneries in most cities. Increase in housing area, decreases the cultivated and fallow areas; consequently, closes the path for groundwater recharge in many of the urban areas. In this context rainwater harvesting is a cost–effective and relatively lesser complex way of managing our limited resources assuring sustained long–term supply of water to the community (Reddy and Rastogi, 2008).

Under such circumstances, recharging of freshwater zones in declining water table areas with artificial means is a viable solution to maintain the groundwater table at optimum levels. Rooftop rainwater harvesting is an appropriate option for augmenting groundwater storage in urban areas, where natural recharge has been considerably reduced due to increased urban activities and not much land is available for implementing any other artificial recharge measure. This also reduces surface runoff which chokes the storm drains and to avoid flooding of roads. Artificial recharge is important for groundwater management as it provides storage space free of cost, avoids evaporation losses and allows the use of stored water in dry seasons. Several recharge methods for rooftop rainwater like abandoned dug well, abandoned hand pump, recharge pit and trench, recharge shaft and defunct bore well method are practiced. Artificial recharge by wells has been attempted in India only during the last decade. The recharge through this technique is fast and has no transition or evaporation losses (Bhargava *et al*., 2006; Patel and Desai, 2010; Paul and Panigrahi, 2016).

Over exploitation of groundwater resources and as a consequence decline in water table is now the major causes of serious concern in capital city of Bhubaneswar. Rising population and consumption patterns have put increasing pressure on the limited freshwater resources. In this context rainwater harvesting is a cost effective and relatively lesser complex way of managing our limited resources assuring sustained long–term supply of water to the community. Now the rooftop rainwater harvesting structures (RRHSs) are gaining importance in urban areas for artificial ground-water recharge as almost all urban development authorities have made this mandatory alongwith construction of new houses in the Country.

Keeping this in view, the effectiveness of a RRHS for groundwater recharge and analysis of quality of the recharged water was taken up for study for Hydrology Project (HP) building of Directorate of Groundwater Survey and Investigation, Bhubaneswar with financial assistance from Government of India.

2. MATERIALS AND METHODS

Study Area

The study area of Hydrology Project (HP) building of Directorate of Groundwater Survey and Investigation, Bhuba–neswar is situated at latitudes of 20°15'N, longitudes of 85° 52'E and 25.9 m above mean sea level. Bhubaneswar is sub–tropical in climate, where the average annual rainfall is 1485 mm, which is received mostly during the south–west monsoon from June to September (78%). The mean monthly maximum temperature ranges from 28.2°C to 40.1°C and mean monthly minimum temperature ranges from 14.8°C to 26.6°C. The mean monthly humidity ranges from 63 to 85% and the wind speed varies from 4.2 to 14.0 km hr^{-1}. The groundwater table in the study area ranges from 10–14 m during pre–monsoon and 5–6 m during post–monsoon season.

In order to find out the effectiveness of the RRHS, the rainfall analysis during the period of study and the aquifer study was made alongwith other studies like groundwater table fluctuations and water quality. The rainfall data collected over the period of 36 years (1970–2005) were analysed and rainfall at different probability levels were estimated by Weibull plotting position method as suggested by Panigrahi (1998) and Panigrahi and Panda, 2001.

The area of the HP administrative building campus is 3500 m^2. There are 3 to 5 m unsaturated strata available for storage of groundwater through rainwater harvesting. Three numbers of recharge shafts were constructed to act as recharge wells inside a dug well for the groundwater recharge. Dug well proposed to be used for recharge, was 9.0 m depth as the water level is at 9.0 m below ground level (bgl).

The building is having rooftop area 1000 m^2. The rooftop area of adjacent Odisha Water Planning Organisation (OWPO) quarters is 800 m^2 and nearby Rengali liaison office is 450 m^2. Thus, the total rooftop area of the project is 2250 m^2. Fifteen numbers of rainwater outlets at the rooftop were connected with 15 numbers of vertical PVC pipes of 100 mm diameter to bring down the rainwater to the collection chambers at the ground. The collection chambers were half filled with gravels to filter the rainwater. The chambers were connected with 150 mm diameter PVC pipe laid underground to connect with the excavated dug well at the backyard of the building.

The silt settlement chamber *i.e.* collection chamber, filtration units, screens and other arrangements were provided appropriately. The roof was maintained properly and cleaned frequently. The silt collection chambers were also protected from contamination. The site plan of the scheme is given in the picture.

The project was monitored weekly by taking water table measurements of four sites *i.e.* water level of dug well, monitoring well, 2 numbers of production bore wells. The quantity of rainwater during various rain spells was measured to workout the rainwater volume. The rainfall record has also been maintained from the rain gauge installed in the vicinity. The change in yield in the two bore well pumped by OWPO colony and office building was also noted from time to time.

3. RESULTS AND DISCUSSION

Analysis of Rainfall Data

Based on the 36 years rainfall data, weekly average rainfall for 52 standard meteorological weeks are calcu-lated. It is observed that more amount of rainfall occurs during the period of 21–41 weeks. But the maximum rainfall is observed in the 38th week with 96.7 mm. There are 3 weeks with no rainfall. Variations of average weekly rainfall are presented in Fig. 1.

The monthly rainfall analysis for 36 years is done at different probability levels and the estimated values have been presented in Table 1. It is observed that the highest rainfall occurred at 40% probability of occurrence and found to be 222.3 mm in the month of June whereas the lowest rainfall occurred in the month of December (0 mm).

Excess and Deficit Analysis of Rainfall

The excess and deficit rainfall analysis in all the weeks has been carried out (Fig. 2) to know the trend of the deficit cycle and to suggest the time of supplementary irrigation to crops *i.e.* more utilization of groundwater. It is widely believed that during *kharif*, irrigation is not required. But it is not true. At 70% probability of rainfall and 30% probabil-ity of evaporation, the deficit of water in the study area started even from middle of 37th week to middle of 39th week *i.e.* from 13th September to 27th September (Fig. 2). But regular deficit is observed to occur from 41st week *i.e.* 8th October and onwards. This warrants supplementary irrigation during this time. During the survey of the nearby

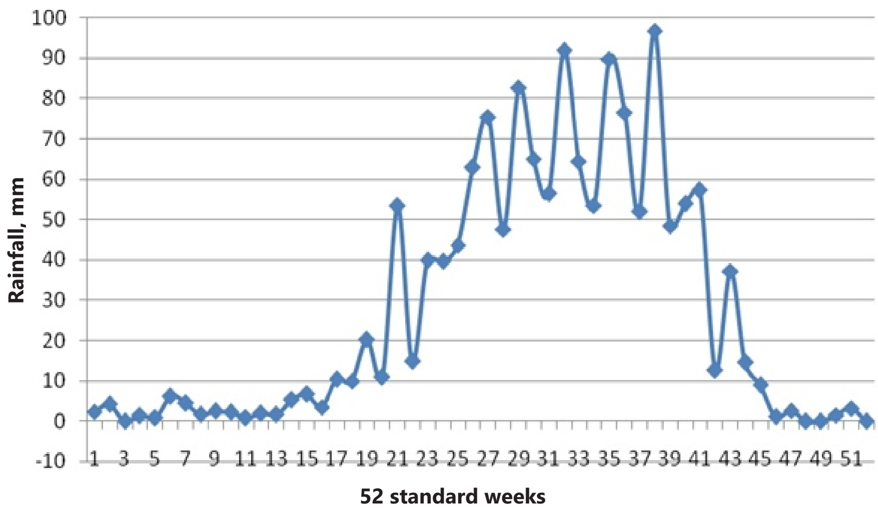

Fig. 1. Variation of average rainfall data

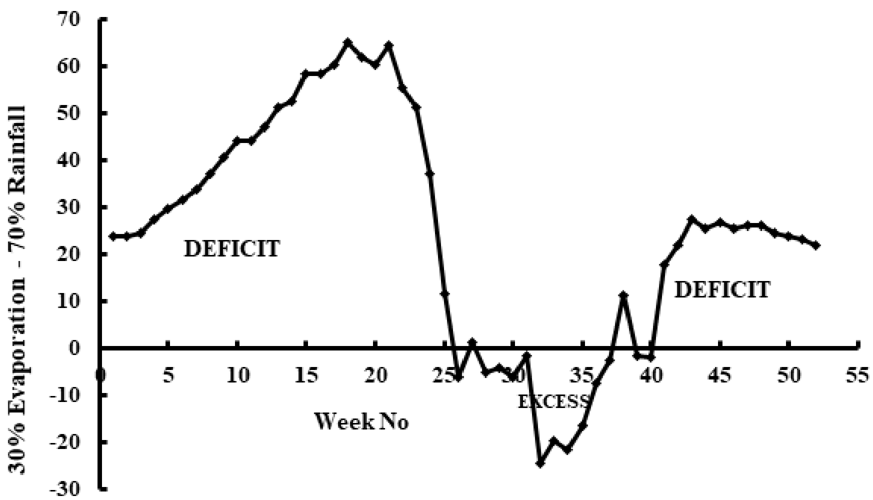

Fig. 2. Excess and deficit period at 70% probability of rainfall and 30% probability of evaporation

Table: 1
Probability analysis of monthly average rainfall data

Months	Rainfall, mm Probability of occurrence (%)				
	40	50	60	70	80
January	0.5	0.4	0.4	0.4	0.4
February	2.5	2.4	2.3	2.2	2.0
March	1.0	0.9	0.9	0.8	0.8
April	6.3	6.1	5.8	5.6	5.2
May	96.4	92.5	88.6	84.7	79.4
June	222.3	213.3	204.2	195.2	183.1
July	186.6	179.0	171.3	163.8	153.6
August	208.1	199.6	191.1	182.7	171.3
September	200.0	192.4	183.7	175.6	164.7
October	111.5	106.9	102.4	97.9	91.8
November	17.0	16.3	15.6	14.9	14.0
December	0	0	0	0	0

farming area, it could be found from farmers that there is need for irrigation from mid of September onwards and at times it is given during 1st week of September also which necessitates use of more groundwater for irrigation. Beginning of excess period in case of 70% probability of rainfall and 30% probability of evaporation is 26th week and it continues up to 37th week. From this excess deficit study it can be said that, more quantity of groundwater utilization for agricultural use starts from 1st week of September along with normal use for domestic purposes.

The water levels in the pre and post monsoon period was recorded in the existing bore well in the campus and is presented in Table 2. The water level data shows there is no continuous decline in water level. Rather it shows haphazard fluctuation in water table indicating the recharge well has become defunct and hence it needs renovation.

Table: 2
Water table fluctuation during pre and post monsoon

Year	Water level (m) below ground level	
	Pre monsoon	Post monsoon
2006	7.6	5.24
2007	9.8	5.88
2008	9.31	5.79
2009	9.2	5.81
2010	8.82	5.91
2011	8.6	5.99
2012	9.0	6.30

It is observed that during monsoon period depth of water level is below 5 m ground level and so sufficient scope exists to raise the water level by 3 to 4 m through rainwater harvesting. This additional recharge is going to enhance groundwater resources, which would be used during non–rainy season. Considering these points in view, the defunct RRHS structure was renovated in the year 2013.

Geomorphology

The area comprises of two major geological units *i.e.* weathered and fractured sand stone and lateric top soil. The thickness of top soil varies between 3 m to 5 m in the area. The soil is reddish clay in nature due to concrete / *pucca* basement the natural infiltration is very negligible and runoff is very high due to sloppy topography. The area is gently sloping from north to south. The elevation of the ground is 46.161 m from mean seal level. The local slope of the ground is in the campus is towards east–west direction. The weathered fractured sandstone and laterite is the principal water bearing formations in the area below topsoil upto a depth of 50 m. Groundwater in the campus area generally occurs under shallow aquifer and fractures in deeper zone. The groundwater level is 7 m to 10 m bgl in dug wells in the vicinity. The water level in bore well was observed at 13 m to 15 m bgl during summer months. In the area the de–saturated zone of weathered, fractured sandstone and laterite can be used to store large quantity of groundwater.

One dug well along with three recharge shafts were constructed inside the campus for artificial groundwater recharge. The diameter of dug well is 6.0 m, depth is 10 m, with 9.0 m below ground surface and 1.0 m above ground level to prevent entry of surface water to the well. Three numbers of recharge shafts of 125 mm diameter each has been constructed upto a depth of 35 m based on the geomorphology of the area (Fig. 3). The details of dimensions and study area including photo of recharge pipes for collection of rainwater and photo of recharge dug well constructed in the campus are presented in Fig. 3 to Fig. 6.

Quantification of Recharge

After renovation of the structure in the year 2013, its performance on recharge from rainfall was assessed. The rainfall data of three years *i.e.* 2014 to 2016 were collected and recharge of rainfall in each year was calculated. It is

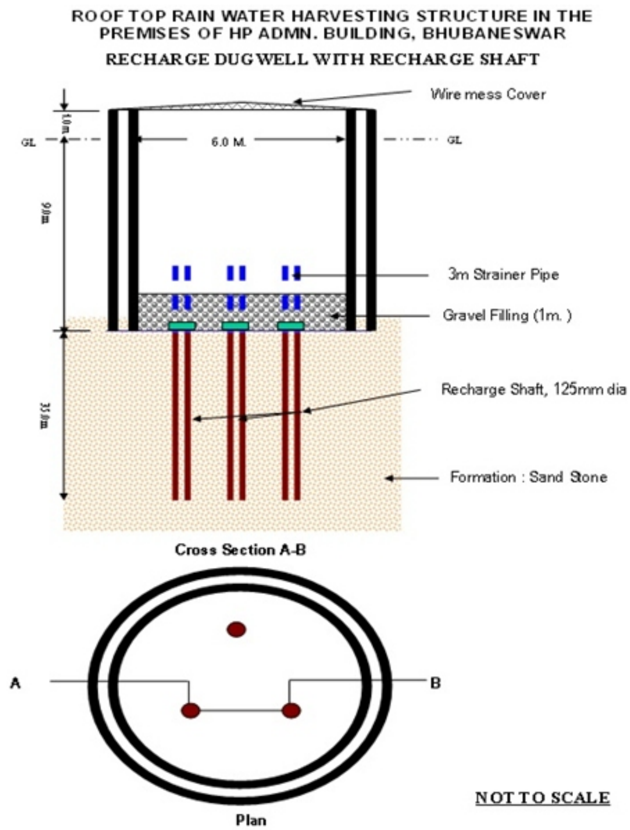

Fig. 3. Detail dimensions of the structure of dug well and recharge shafts

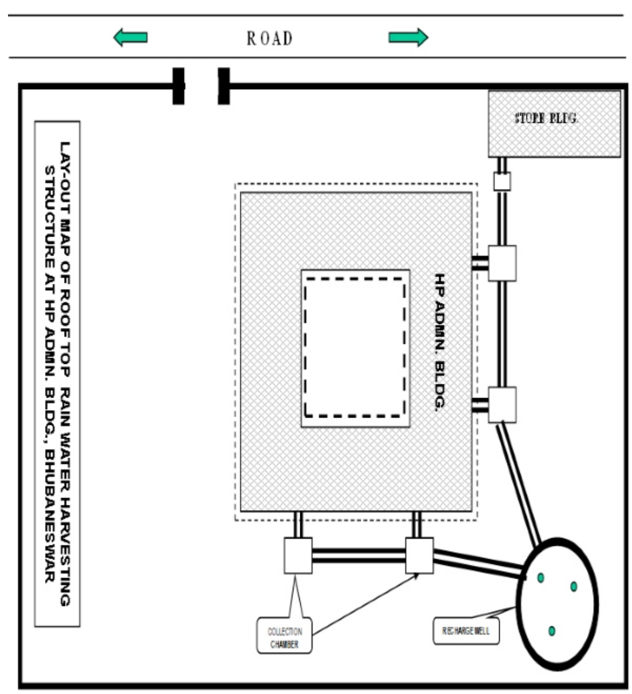

Fig. 4. Plan of the study area

Fig. 5. Recharge pipe for rainwater collection

Fig. 6. Recharge dug well

observed that in 2014, there was 1096 mm rainfall, in 2015 there was 1579 mm and in 2016, there was 1881 mm rainfall. It was estimated that total 2096 m^3 of rainwater was harvested during the year 2014 from the rooftop out of which 1781.6 m^3 (around 85%) was actually recharged in to the dug well. Similarly in the year 2015, rainwater recharged to groundwater through recharge well is 2566.86 m^3 and in 2016, it is 3150.04 m^3. So average recharge for the three years is 2499.5 m^3.

A study made at the Narwana branch canal in Kurukshetra district of Haryana for recharging of confined aquifer by injection tube wells has indicated that water recharge at the rate of 7.2 m^3 day^{-1} $tube^{-1}$ well increased the water table at a rate of 10.5 cm annually (Kaledhonkar *et al*., 2003). Similar study was made at IARI farm, New Delhi to determine the performance of injection wells for groundwater recharge using surface runoff with respect to its groundwater recharging potential and impact on groundwater quality. The mean recharge rates of 21.2 m^3 day^{-1} and 8 m^3 day^{-1} were observed for injection wells installed below water table (saturated zone) and above water table (vadose zone), respectively. It was also found that injection rate was more for the well constructed in the saturated zone than the injection well installed in the vadose zone since soil formation of the former had higher proportion of coarse sand mixed with gravel (Kumar *et al*., 2008).

Increase in Groundwater Yield

The entire requirement of campus is met from the groundwater sources. The water supply from the bore well was regulated to detect any change in the discharge during the recharge period. It was observed that the discharge of the existing water supply bore wells located at a distance of 20 to 30 m have increased by 500 to 1000 lits $pumping^{-1}$ hours during the monsoon and post monsoon season. This is due to the rise in water level resulted in the area from additional recharge to groundwater.

A study was made for the roof top rainwater harvesting scheme in the hostels 12 and 13, IIT Bombay. Two alternatives were suggested for tank design, which take separate approaches towards rainwater harvesting. The underground RCC tank may be constructed if all of the rainwater potential is preferred to be utilised. The alternative, Ferro cement tanks, may be constructed for partial fulfillment of some of the water needs of the hostel at a lower cost (Reddy and Rastogi, 2008). Similar RRHS was designed and installed at the Soil and Water Conservation Engineering (SWCE) workshop complex of Tamil Nadu Agricultural University (TNAU), Coimbatore. It generated enough storage of rainwater to meet the various needs for water within the workshop complex. The harvested rooftop rainwater could meet the water demand during non–rainy seasons for subsequent usage towards supplemental irrigation, drinking water and laboratory needs (Ray *et al*., 2009).

Change in Depth of Water Level

The analysis of the water level of the recharge well and observation bore well is represented in the graphical form (Fig. 7). The graph indicates the instant response of rainwater harvesting on the dug well where 1 m to 1.5 m of rise in water level is reflected (Table 3). The impact of recharge is

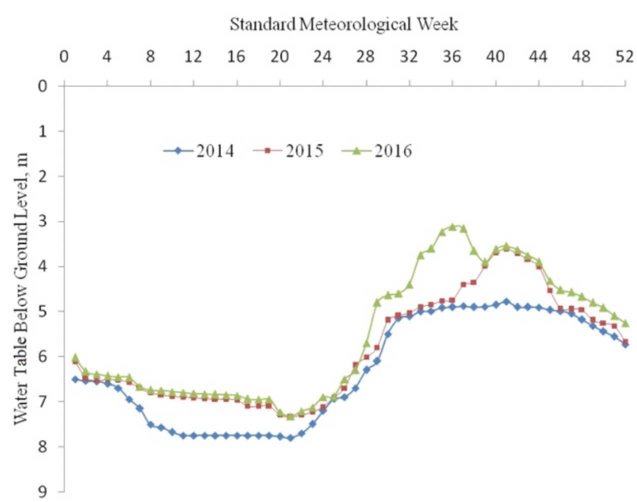

Fig. 7. Groundwater table fluctuation in the well

also reflected in the nearby bore wells. The rise in water level in the bore wells and dug wells mostly matches with the rise in recharge wells. However, minor fluctuation is observed caused due to regular pumping of groundwater for supply to quarters and offices.

The comparison of depth of water level of recharge well with nearby bore wells and dug wells are given in the table below. The data on groundwater level showed rise in summer water table 0.70 m and in post monsoon period rise is 2.04 m though regular pumping in 2 productions bore wells. So there is increase in groundwater level due to the recharge structure.

Table: 3
Depth to water level in nearby dug well

Month	Depth of water level bgl, m	Whether fall or rise	Remarks
June–13	8.70	Rise	Rise in summer water table 0.70 m and in post monsoon period rise is 2.04 m though regular pumping in 2 productions bore wells.
Oct–13	5.24	Rise	
June–14	7.80	Rise	
Oct–14	4.50	Rise	
June–15	7.40	Rise	
Oct–15	4.20	Rise	
June–16	7.25	Rise	
Oct–16	4.0	Rise	

Analysis of Groundwater Quality

The quality analysis of groundwater of the study area was conducted before the construction and after the project. After analysis of the groundwater quality, following results were found (Table 4 and Table 5). The groundwater quality improved substantially as can be seen from the Tables 4 and 5. Similar results on the laboratory analysis of pre and post–recharge groundwater samples has shown considerable improvement in chemical qualitiesat IARI farm, New Delhi (Kumar *et al*., 2008).

Cost Estimation

The estimated cost of the proposed work as per present schedule of rate is ₹ 7,60,000/–. The abstract of the estimate is as follows (Table 6). This cost of ₹ 7,60,000/– is well within the limit fixed by Government. The Odisha government is now giving incentive in urban areas through Directorate of Groundwater Development Department for RRHS for groundwater recharge.

4. CONCLUSIONS

One RRHS with provision of a dug well having 3 recharge shafts was constructed to study the effect of groundwater recharge. The study of geomorphology of the area shows water bearing formations approximately 7 to 50

Table: 4
Chemical analysis of groundwater sample during pre–project period

S.No.	Name of the parameter	Site 1 (17/5/02)	Site 2 (18/7/02)	Site 2 (13/6/03)	Site 2 (06/2/04)	Site 2 (30/6/05)
1	pH	7.23	5.18	7.02	8.23	6.51
2	Electrical conductivity in μ mhos cm^{-1}	181	148	139	489	156
3	TDS in mg l^{-1}	134	93	96	387	99
4	Total alkalinity as $CaCo_3$ in mg l^{-1}	25	10	30	215	10
5	Total hardness as $CaCo_3$ in mg l^{-1}	50	35	55	90	35
6	Calcium in mg l^{-1}	12	8	12	20	18
7	Magnesium in mg l^{-1}	3.64	3.645	6.075	9.72	-2.43
8	Sodium in mg l^{-1}	13.7	19	7.6	66	15.7
9	Potassium in mg l^{-1}	0.9	1.3	0.7	3.1	1.6
10	Chloride in mg l^{-1}	28.36	31.905	21.27	7.09	31.905
11	Sulphate in mg l^{-1}	0	0	0	0	17.3

Table: 5
Chemical analysis of groundwater sample during post–project period

S.No.	Name of the parameter	Site 1 (23/12/14)	Site 2 (19/6/15)	Site 1 (29/3/16)	Site 2 (21/6/16)
1	pH	5.87	8.29	5.91	6.66
2	Electrical conductivity in μ mhos cm^{-1}	240	338	219	149
3	TDS in mg l^{-1}	159	274	158	114
4	Total alkalinity as $CaCo_3$ in mg l^{-1}	30	120	40	20
5	Total hardness as $CaCo_3$ in mg l^{-1}	50	145	50	30
6	Calcium in mg l^{-1}	12	46	12	6
7	Magnesium in mg l^{-1}	4.86	7.29	4.86	3.645
8	Sodium in mg l^{-1}	25.6	18.7	28.4	16.9
9	Potassium in mg l^{-1}	5.6	4.9	4	1
10	Chloride in mg l^{-1}	46.08	38.995	42.54	31.905
11	Sulphate in mg l^{-1}	0	0	0	0

Table: 6
Estimate of the structure

S.No.	Items of works	Amount (₹)
1	Provision for fixing 100 mm Φ PVC vertical pipes from roof top to ground level chamber at centre and corner of the building walls with all fittings for 200 m	36,000/-
2	Construction of rainwater collection chamber (4 nos.)	14,000/-
3	Laying of PVC pipe line of 200 m length of 150 mm Φ	1,00,000/-
4	Construction of recharge well with cover	4,50,000/-
5	Provision for 3 nos. of bore wells for making recharge shafts at the bottom of the recharge wells	1,00,000/-
6	Cost of filter pit, 2 nos.	50,000/-
7	Provision for chemical treatment	10,000/-
	Total	7,60,000/-

m bgl. The cost of the project is ₹ 7,60,000/–. An average amount of 2500 m^3 of water can be recharged annually through this project. The recharged water increases the groundwater level continuously. The data on groundwater level measured in three years from 2014 to 2016 showed average rise in summer water table 0.70 m and in post monsoon period rise is 2.04 m, though regular pumping in 2 productions bore wells, which shows, there is increase in groundwater level due to this recharge structure. The groundwater quality analysis showed substantial improvement during post project period. This study shows rainwater harvesting structure can be made in each housing project in urban areas, which will reduce decline of groundwater table.

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