Effectiveness of Rain Water Harvesting for change of trends in Aquifer behaviour

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Abstract

Rain water harvesting (RWH) and Artificial recharge techniques are low cost solutions to water crisis. In cities, due to increasing urbanization, rain water can be harvested and recharged to the ground water artificially. This paper presents a study of effectiveness of RWH in terms of change of trends in aquifer behaviour. Chennai, formally Madras, City, capital of Tamil Nadu State is selected as the study area since major RWH structures has taken constructed during 2001-2003 because of Government legislation. Preliminary analyses of rainfall and groundwater levels were carried with respect to space and time to understand the trends. Water table contours were drawn using the Arc GIS.9.2 software. "Groundwater Estimation Committee (GEC)" rules of Government of India were used for estimation the change in storage during pre and post RWH periods, which are found to be 1.76 Mm^3 & 32.77 Mm^3 respectively. It is concluded that the implementation of RWH has improved the groundwater storage though the rainfall in the study area is decreased and the extraction is increased due to raise in population.

Keywords: *Artificial Recharge, Groundwater Estimation, GIS, Rain Water Harvesting*

INTRODUCTION

Groundwater is the largest reservoir of fresh water on the planet and is intensively exploited for domestic, industrial, commercial and institutional uses in many urban conglomerates of the developing countries. Natural recharge of groundwater aquifer is a slow process and is difficult to keep pace with the excessive and continual exploitation of groundwater resources. The net effect is declining groundwater levels, depletion of groundwater resources and several vexing problems such as reduced well yields, land subsidence and seawater intrusion, etc. In order to overcome such serious hydrologic problems and to improve the groundwater situation, it is necessary to artificially recharge the depleted groundwater resources. An underground water banking technique known as Aquifer Storage and Recovery (ASR) has emerged as a means of expanding urban water resources by harvesting waters that would otherwise be foregone.

Groundwater is derived mainly from rain which infiltrates the land surface and slowly percolates to the water table. This process of accumulating water to underground storage is called "natural" groundwater recharge. Where the materials in the earths' surface are coarse and the slope of the land is mild, there is generally more groundwater recharge than in areas where the earth consists of fine-grain material or where the slope is steep. Urban Sprawl increases the impervious areas, resulting in cutting of infiltration and augment of runoff. This creates an imbalance between reduced natural recharge and increased groundwater abstraction, necessitating artificial recharge for achieving equilibrium. The purpose of 'artificial recharge' is to increase the rate at which water infiltrates the land surface in order to supplement the rate of natural groundwater recharge.

For a sustainable urban future, society must move towards the goal of efficient and appropriate saving of surface runoff through roof- top rain water harvesting, storm runoff collection and recharge structures such as recharge wells/pits/trenches/open &bore wells. Several impact studies were reported around the world ([1]-[3]). They provided quantitative evidence that rain water harvesting improved the groundwater quantity and quality of nearby wells by artificially recharging the local aquifer. Tracer techniques, chloride mass balance and water balance were used for impact study. But, these studies had not quantified the impact of RWH in increasing the storage of the aquifer. This paper attempts to present a study to assess the effectiveness of artificial recharge with rain water in an urban aquifer by estimating the groundwater storage before and after implementation of RWH system. The methodology is demonstrated for an urban area - Chennai city in Tamil Nadu State, India, as its Government has implemented RWH through a legislation in the year 2003.

RWH IMPACT STUDIES

Matthew and William [4] reported the under-utilization of RWH systems in North Carolina, through a computer model, to simulate system performance in rain barrels and larger cisterns. Pachpute *et al* [5] assessed the impact of RWH micro dams in Makanya catchment of rural Tanzania and estimated a higher crop production in 12 - 20 ha area near RWH.

Gore *et al* [6] quantified the effects of a percolation pond by modeling groundwater coupled with a water balance model. Data of 16 observation wells were considered and estimated an increase of 8 ha. m. /year in groundwater recharge. Sharda *et al* [7] assessed ground water recharge from a number of RWH structures in Gujarat using GEC Norms. Badiger *et al* [8] reported that recharge from RWH was about 3 to 8 % of rainfall. Gontia and Sikarwar [9] reported that groundwater levels increased by 8 m in wells which was assumed to come from RWH, but no measurements were taken from the structures themselves. Deepak Khare *et al* [10] analysed the impact of RWH on ground water quality at Indore and Dewas, of Madya Pradesh. With the help of working tube wells. Sharma and Jain [11] analysed the ground water recharge through roof top rain water harvesting in Nagpur city and concluded that the rise in water level in the recharge well and adjoining dug wells is up to 1 m

STUDY AREA AND DATA COLLECTION

Chennai City, formerly known as Madras, the capital of Tamil Nadu State and the oldest of the presidential cities in India, is selected as the study area. The index map of the area with the specific region chosen for the study is presented as Fig. 1.

Chennai is located at 13.04° N and 80.17° E in the peninsular portion of India occupying a total area of 174 km^2 and is on a flat coastal plain at an average elevation of 6 m.

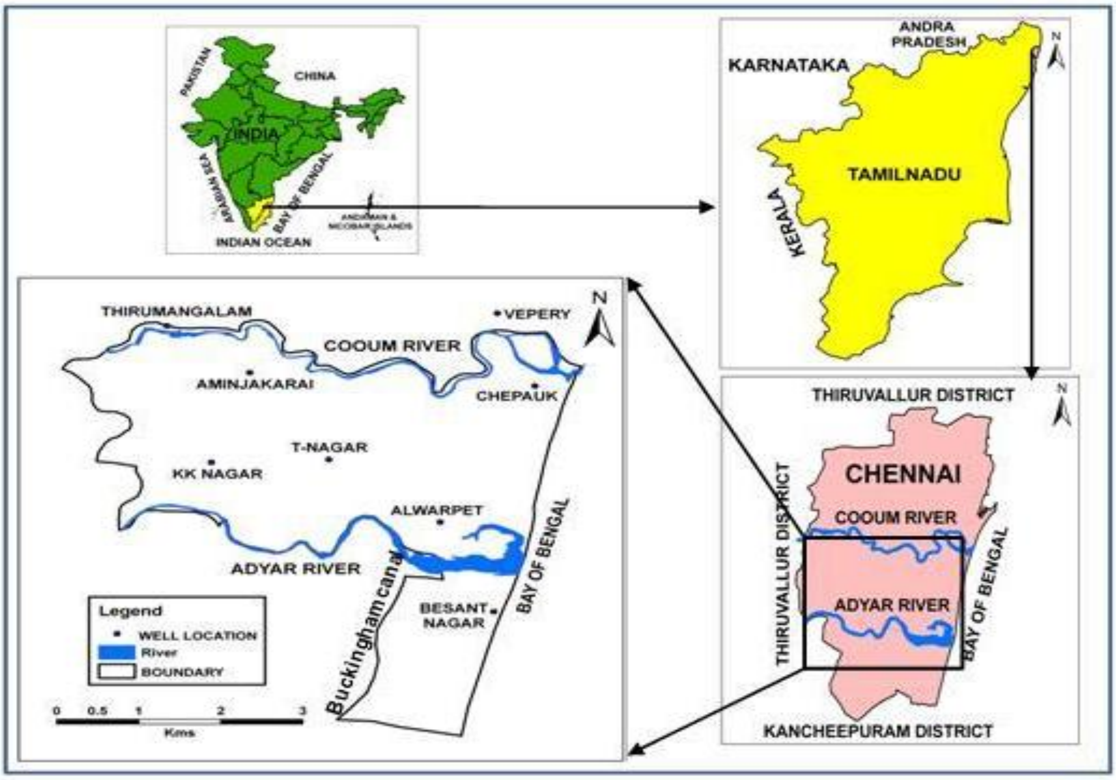

Figure 1: *Index map of study area.*

Two rivers namely Cooum and Adyar which flows through Chennai are heavily polluted due to effluents from domestic and commercial sources. Buckingham Canal travels parallel to the coast, connecting the two rivers. Chennai features a tropical wet and dry climate. The average annual rainfall is about 1,300 mm and most of it comes during the north-east monsoon (September to December). The geology of Chennai comprises mostly clay, shale and sandstone. Historically, Chennai has faced problems of water shortage as no perennial river flows through it, resulting in over-reliance on annual monsoon rains to replenish reservoirs. The city's ground water levels were depleted to very low levels in many areas forcing the residents to buy water for their drinking requirements.

Secondary data of lithology and 8 observation wells (water level & quality) and were collected from the Central Ground Water Board (CGWB), Chennai for the periods of pre (1994 to 2003) and post (2004 to 2008) RWH implementation periods. Monthly rainfall data were collected for the period 1971-2008, from India Meteorological Department (IMD), Nungambakkam, and Chennai.

METHODOLOGY

Preliminary (Temporal and spatial) analyses of monthly ground water levels were carried out to know the aquifer behaviour. In temporal analysis, groundwater hydrograph was plotted to identify its trend for the total period of data availability. In addition, moving average (to smoothen the graph, avoiding monthly randomness) graph was plotted and analyzed for pre (Before the year 2003) and post implementation (After the year 2003) periods of RWH. With the application of Arc GIS 9.2 software, contours for the groundwater levels of the observation wells were drawn to understand the spatial variation.

Groundwater Estimation Committee (GEC) norm [12] was used to estimate the change in storage. Ground water potential assessment was carried out by water level fluctuation method for the pre and post RWH implementations periods. The change in storage is obtained by the following relationship:

Change in Storage, $\Delta S = h * A * Sy$
Where, h = change in water table elevation during the given time period (m);
A = area influenced by each well (m^2); and
Sy = specific yield

The study area is delineated based on the Thiessen Polygon approach using Arc GIS to calculate the area of influence. Specific yield values as per the norms recommended by GEC by considering the geology of the study area. Using the change in water level, specific yield and area of influence, change in storage was estimated. Fig. 2 shows the flow chart for the methodology of this impact study.

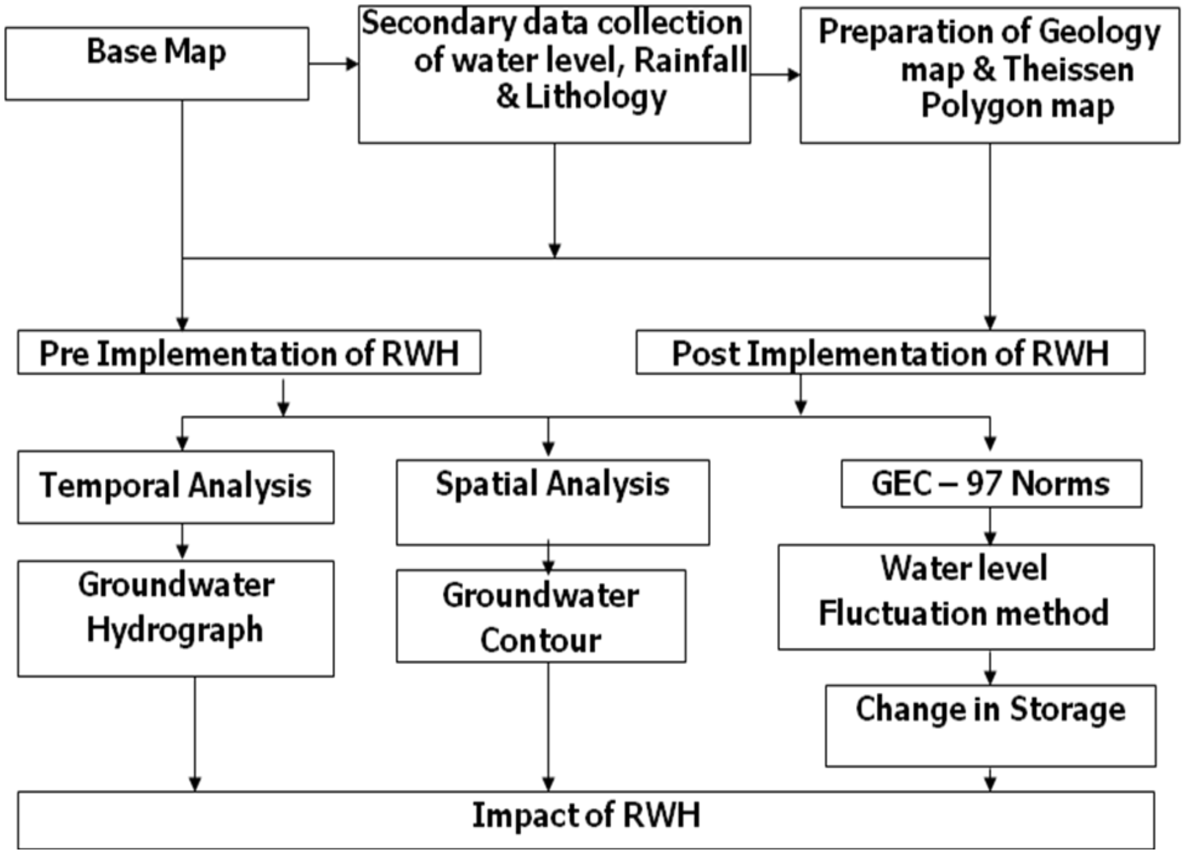

Figure 2: *Flow chart for RWH impact study methodology.*

ANALYSIS AND RESULTS

Temporal analysis of groundwater level

To understand the temporal variation of groundwater levels and its general trend, groundwater hydrographs of all eight observation wells were drawn. The moving average graph is plotted for the period 1994 to 2008 for all the wells and the sample graph for a well located in T Nagar is shown in Fig. 3. The curves are drawn to represent 12 month (continuous line) and 36 months (dotted line) moving average values. As the moving average is taken for more number of months, the curve smoothens to give a clear overall picture of the temporal deviation. There is also a distinct variation of trend during pre and post RWH implementation periods. It also shows that the average water level has gone down by about 5m during the period of 2000 to 2005 and then had gone up by 4 m during the period of 2005 to 2008.

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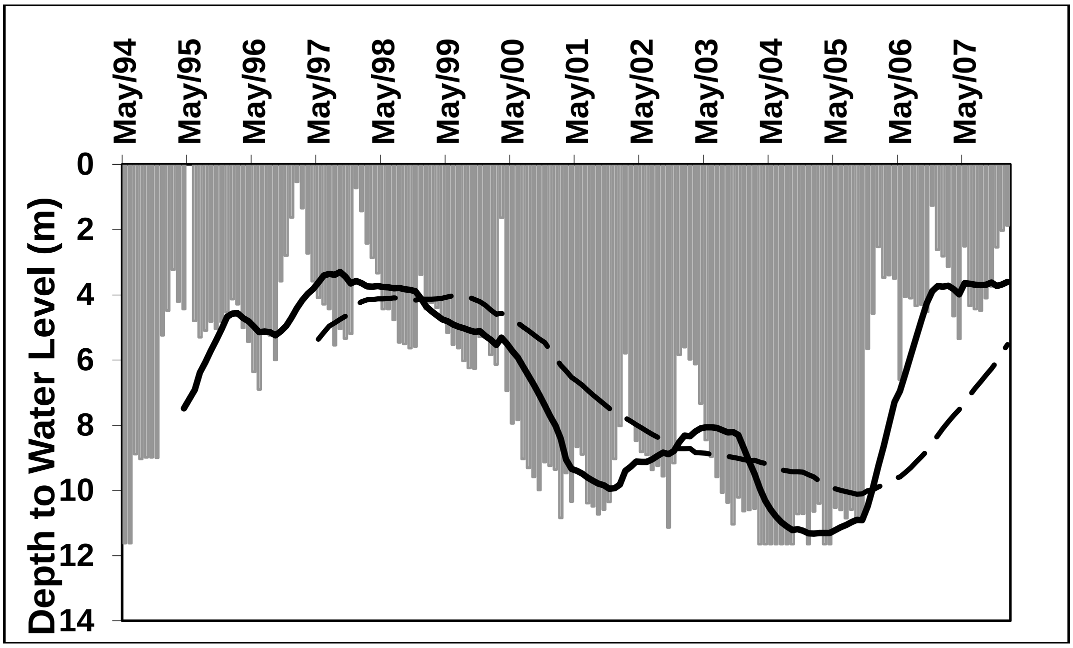

Figure 3: *Groundwater hydrograph of T. Nagar well with moving average curves.*

Consequently, the trend analysis is carried out separately for pre and post RWH periods and the results are furnished in Table 1. Sample hydrographs and trend lines for T. Nagar well during the pre &post implementation periods are presented in Fig. 4. (a) & (b).

Table 1: *Trends of groundwater levels during pre and post implementation of RWH*

Well No.	Name of the area	Slope of the trend line (m/year)	
		Pre- imple-mentation period	Post- imple-mentation period
1	Vepery	- 0.2616	0.594
2	T. Nagar	- 0.4932	2.8104
3	Thirumangalam	- 0.0732	1.8588
4	K.K Nagar	- 0.0684	1.8684
5	Chepauk	- 0.0516	0.1284
6	Besant Nagar	- 0.2172	1.236
7	Aminjakarai	- 0.2784	2.0712
8	Alwarpet	- 0.0156	0.684

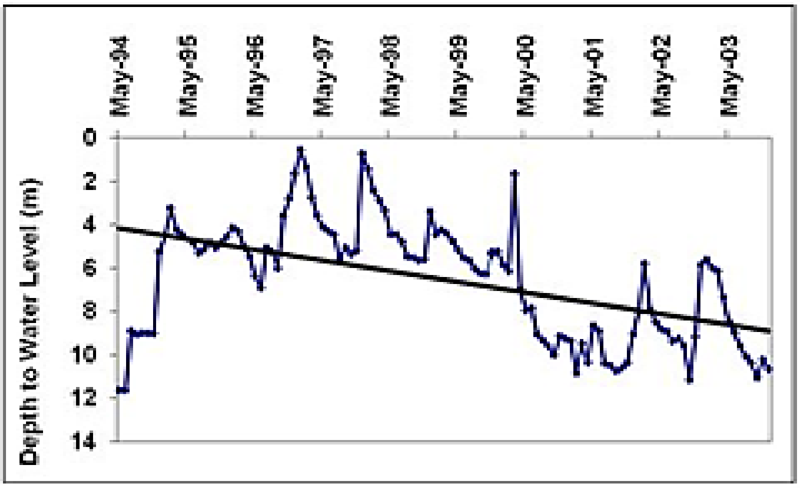

Figure 4(a): *Hydrograph of T. Nagar well (Pre RWH period).*

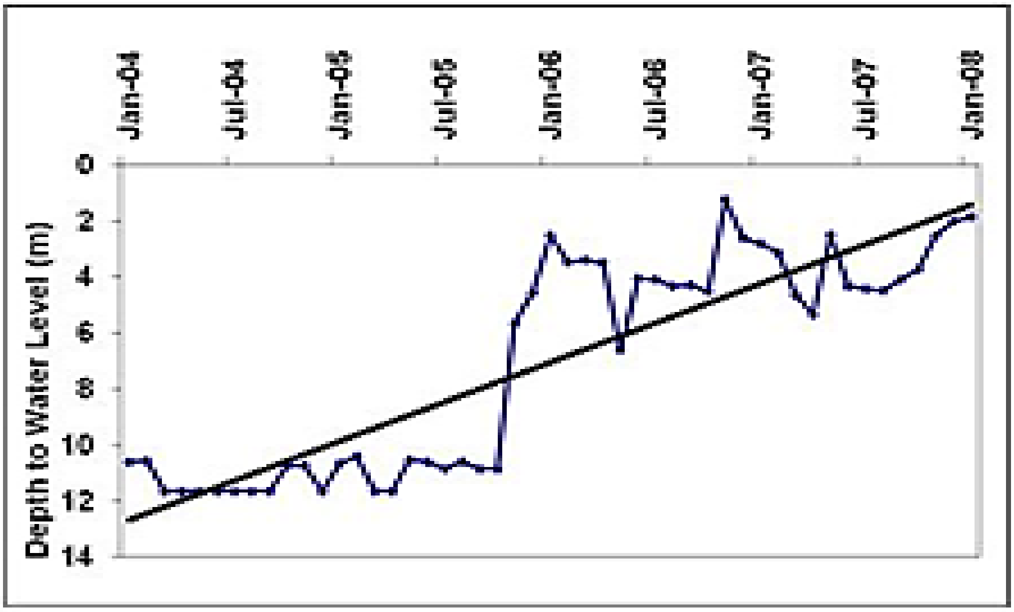

Figure 4(b): *Hydrograph of T. Nagar well (Post RWH period).*

The trends of water levels of all the 8 observation wells during pre RWH period indicate a declining nature in the range of 0.0156 to 0.4932 m/year whereas, during post RWH period, the trend is increasing in the range of 0.1284 to 2.81 m/year. After implementing the RWH structures, the water level especially in T. Nagar, Thirumangalam K. K. Nagar, Besant Nagar and Aminjakarai areas had abruptly gone up, though the extraction is more in this area. This may be due to the fact that more runoff was available for harvesting since entire area is constructed with buildings. The depth to water level varied from 1.5 m to 12.5 m during monsoon and summer periods before the implementation of RWH, but for the post RWH period, it varied from 1 m to 6 m for the same monsoon and summer periods.

Spatial analysis of groundwater table

Spatial variation of groundwater levels (reduced to MSL) across the study area was studied (for summer (May) and post-monsoon (January) months) by drawing water table contours using the Arc GIS.9.2 software. The difference in water table levels across the study area are computed and presented in Table 2. The same is also represented spatially in Fig. 5 and 6. It is observed that the water table has improved from its height in pre-implementation to that of post implementation period.

Table 2: *Difference in water table levels during pre and post RWH periods*

Well No.	Area	Water Table elevation (MSL)			
		post monsoon season (m)		Summer season (m)	
		Jan 2006	Jan 2000	May 2006	May 2000
1	Vepery	7.90	3.47	1.58	6.03
2	T. Nagar	12.02	8.71	7.95	6.61
3	Thirumangalam	11.99	11.25	5.13	6.11
4	K.K Nagar	12.67	11.28	11.43	10.23
5	Chepauk	6.38	6.13	5.14	5.23
6	Besant Nagar	5.98	2.01	4.35	1.51
7	Aminjakarai	5.65	3.88	4.26	2.88
8	Alwarpet	6.15	5.56	5.14	5.11

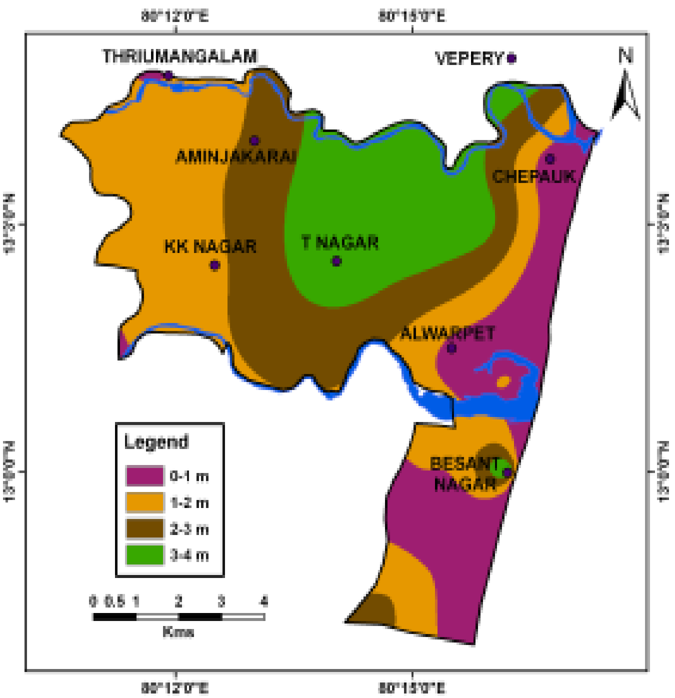

Figure 5: *Variation of groundwater table (Post monsoon).*

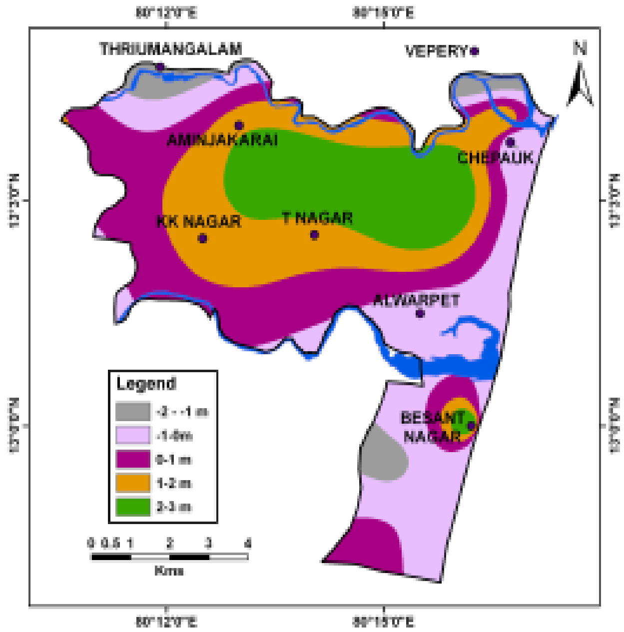

Figure 6: *Variation of groundwater table (summer).*

In the study area, before the implementation of RWH structures, water table varies from 2.01 - 11.28 m just after the monsoon (January) and the same varies from 1.51 to 10.23 m during summer month (May). After the implementing RWH structures, water table vary from 5.98 to 12.67 m during post monsoon period (January) and 1.58 to 11.43 m during summer (May) which means that the water level had gone up, indicating that the implementation of RWH structures has improved the groundwater level to a great extent.

Correlation of rainfall and groundwater fluctuation

To understand the annual rainfall's influence on groundwater levels, rainfall values are plotted with yearly average groundwater level fluctuations as shown in Fig. 7. Maximum and minimum rainfalls received are 2450 mm (1996) and 688 mm (2003). Groundwater levels start decreasing during the period of 1996-2004, though the rainfall is maximum. But, after 2004, they are increasing, though the rainfall is less. This indicates that the construction of RWH structures enhanced the groundwater quantity to a great level.

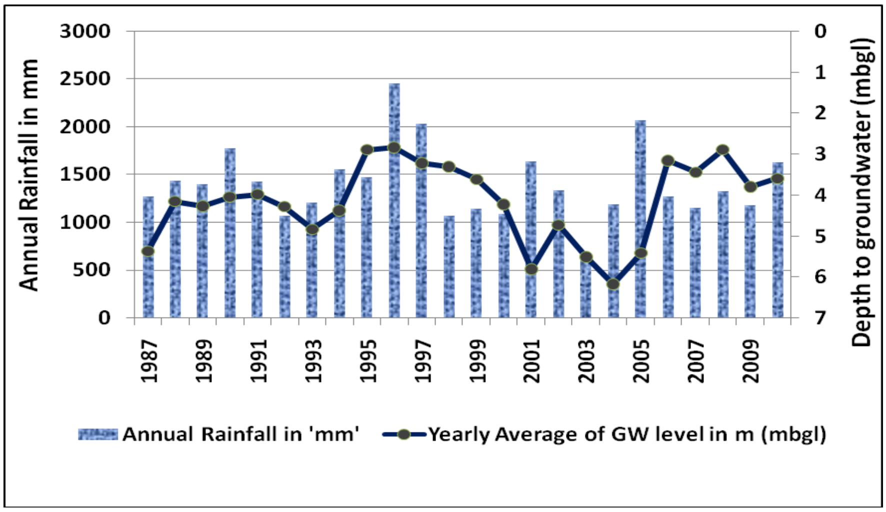

Figure 7: *Rainfall and groundwater fluctuation.*

Estimation of groundwater storage

Groundwater storage was estimated using water level fluctuation method for the pre RWH period 1999-2000 & post RWH period 2009-2010. The Thiessen polygon map of study area is drawn using Arc GIS 9.2 and presented in Fig. 8. Specific yield is taken as 15% based on the norms recommended by GEC-1997 as the geology of the study area is sandy & silty alluvium. Using the change in water level, specific yield and area of influence, change in storage was estimated for the Pre and Post implementation periods as 1.76 Mm^3 and 32.77 Mm^3 respectively, showing a substantial contribution from artificial recharge through RWH. Table 3, 4 and Fig. 9 presents the results of this analysis. Also, in T. Nagar, Vepery and Alwarpet areas, RWH has helped in building increasing net storages by recharging phreatic aquifers.

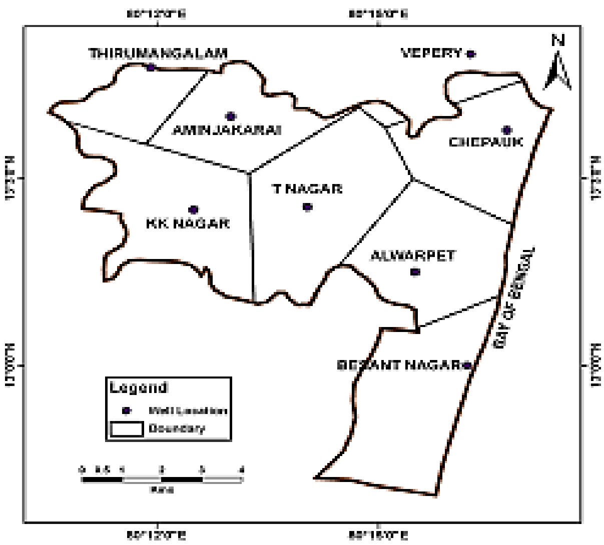

Figure 8: *Thiessen polygon map of study area.*

Table 3: *Change in storage for the year 1999-2000*

Well No.	Area of influence (Km^2)	Water Level fluctuation (m)	Change in storage (Mm^3)
1	1.574	-1.70	-0.401
2	14.394	-0.68	-1.468
3	4.759	0.92	0.657
4	13.158	0.55	1.086
5	9.338	0.89	1.246
6	13.336	0.06	0.120
7	8.192	0.69	0.848
8	11.045	-0.20	-0.331
Total	75.796		1.757

Table 4: *Change in storage for the year* **2009-2010**

Well No.	Area of influence (m^2)	Water Level fluctuation (m)	Change in storage (Mm^3)
1	1.574	3.4	0.803
2	14.394	2.91	6.283
3	4.759	1.9	1.356
4	13.158	2.08	4.105
5	9.338	2.22	3.109
6	13.336	1.67	3.341
7	8.192	2.32	2.851
8	11.045	6.595	10.926
Total	75.796		32.774

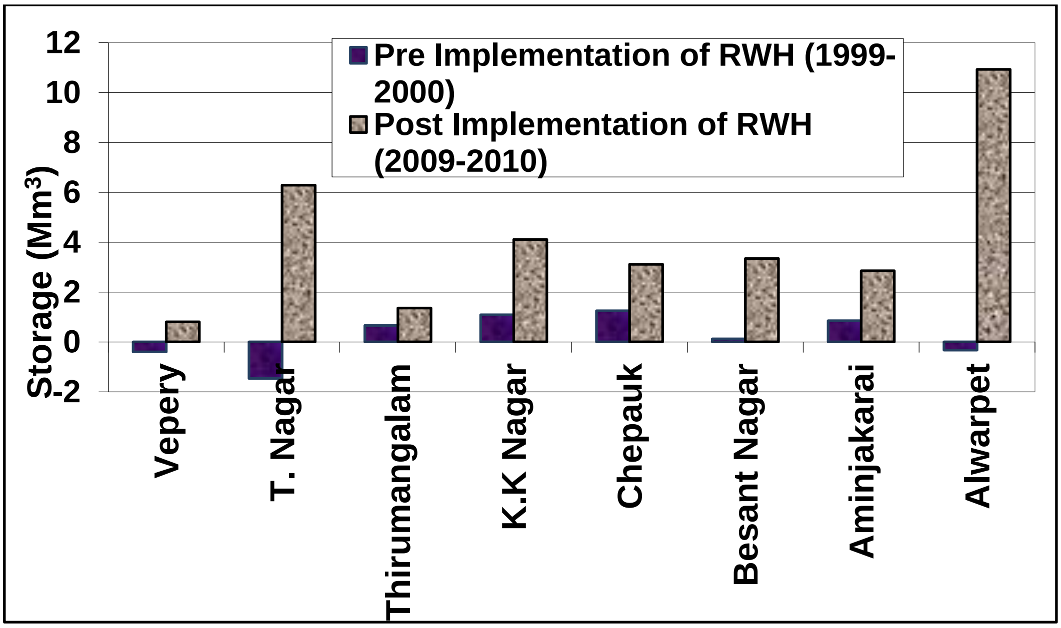

Figure 9: *Change in storage of groundwater during pre and post implementation of RWH.*

CONCLUSIONS

This study has examined the effectiveness of RWH in a coastal urban area. Groundwater hydrographs show decreasing and increasing trends during pre and post implementation periods respectively. The spatial variation of water table contours drawn using Arc GIS software shows that many of the urban areas have changed the trends from decreasing to increasing in these two periods. Ground water storage, assessed based on GEC Norms using water level fluctuation method, has also increased from 1.76 Mm^3 to 32.77 Mm^3. Hence, it is concluded that RWH implementation has definitely contributed for the increased ground water levels.

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