Indian Journal of Science and Technology Vol. 4 No. 1 (Jan 2011) ISSN: 0974- 6846

A comparative analysis of hydrologic responses to rainwater harvesting – A case study

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Abstract
This paper attempts to investigate the implementation of rainwater harvesting (RWH) structures and its hydrologic responses (in terms of quantity and quality of water) in two hydro-geologically different localities of Chennai city in Tamil Nadu state, India. The design of RWH structures is site specific as it involves hydrometeorology, lithology and land use. Consequently, its effectiveness depends on appropriate design and implementation. Initially, a survey based on questionnaire was conducted to collect details of implemented RWH structures and analysed. Impact of RWH for possible recharge was assessed using GEC NORMS 1997 by water level fluctuation method. Water samples were analysed for different quality parameters and checked with codal requirements of IS-10500 (1991) for possible impact of RWH on groundwater quality. It is found that the recharge and quality have improved due to the implementation of RWH.

Keywords: Rainwater harvesting, hydrology, groundwater, GEC norms.

Introduction
Currently, rainwater harvesting (RWH) is synonymous with many cities in developing countries as majority of them reel under severe groundwater exploitation. This is due to the increased demands of water for domestic and industrial uses and unplanned development works. The design of rainwater harvesting structures in any locality requires a thorough understanding of surface water (rainfall and runoff characteristics) hydrology and groundwater (movement and storage of water below the earth surface) hydrology of the area. Any lack of available or collected data in the above mentioned hydrologic aspects will reflect in the reduced response of the designed and implemented rainwater harvesting system. For example, any artificial recharge technique designed as a part of RWH has to match the intensity of rainfall with the infiltration rate and recharging is to be done to the location of the aquifer. This means that RWH has to be designed site-specific to get the desired response. This paper attempts to narrate a study made to investigate the RWH and its hydrologic responses (in terms of quantity and quality of water) in two hydro-geologically different localities of Chennai city.

Deepak Khare *et al.* (2004) have assessed the impact of RWH on groundwater quality at Indore and Dewas in India using the data from existing tube wells. The roof top rainwater was put through sand filter leading to a reduction in the concentration of pollutants in groundwater. Sharma and Jain (1997) conducted an experiment in Nagpur city where 80,000 litres of water, collected from the roof top of 100 m^2 area, was recharged. The rise in water level up to 1 m was recorded in the recharge well and adjoining dug wells. The quality of groundwater has also improved as nitrate concentrations got diluted considerably to the desirable limit.

Vijaya Kumar (2005) has evaluated the ground water potential by groundwater estimation committee (GEC 1997) norms. Venkateswara Rao (1996) has reviewed the importance of artificial recharge of rainfall for Hyderabad city water supply. A simulation model has been developed by *Srivastava* (2001) to design a system for determining catchment /command area ratio, size of tank, desirable command area of a single tank and the feasibility/economics of lining a tank.

Fayez and Shareef (2009) carried out the research to evaluate the potential for potable water savings by using rainwater in residential sectors of the 12 Jordanian governorates and provided suggestions and recommendations regarding the improvement of both quality and quantity of harvested rainwater. Sazaklia *et al* (2007) analysed the quality of harvested rainwater, which is used for domestic and drinking purposes in the northern area of Kefalonia Island in Greece. The influential factors were assessed through a 3-year surveillance. Principal component analysis revealed that microbiological parameters were affected mainly by the cleanness level of catchment areas, while chemical parameters were influenced by the sea proximity and human activities.

Study area
Chennai is the capital of Tamil Nadu and the oldest of the presidential cities in India. Two hydro-geologically distinct areas of Chennai viz. Padmavathi nagar & Besant nagar were chosen as the study areas. The lay out maps of these two localities are presented in Fig.1 and 2. Padmavathi Nagar has an area of 16,556 m^2 and buildings with roof area of 8,584 m^2. It has 69 plots, out of which 59 were constructed. In that, 10 are apartments containing an average of 10 flats in each unit. The soil condition of this area is clayey in nature up to 9 m depth followed by sandy soils. The average depth of water table

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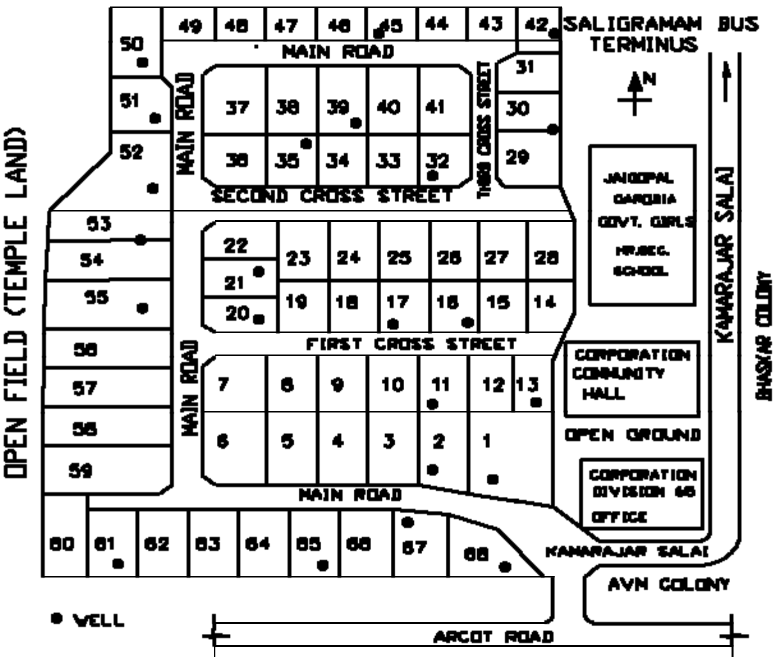
from ground level is 8.5 m. The lithology of Padmavathi nagar and Besant nagar are presented in Fig. 3 and 4. The water colour is mild yellow. In this area, all the houses have only roof top RWH systems. Most of the RWH systems are connected to open wells through filters. Besant nagar is close to the Bay of Bengal and known to yield potable water in the past as the soil type is sandy in nature.

Fig.1. Layout map of Padmavathi Nagar



Methodology

To achieve the desired results of the objectives, initially a questionnaire survey was conducted to collect details of implemented RWH structures and analysed. Impact analysis of RWH for possible recharge was done using GEC NORMS 1997 using water level fluctuation method. Water samples were analysed for different quality parameters and checked with codal requirements of IS-10500 (1991) for possible impact on ground water quality.

Questionnaire survey

The effectiveness of RWH implementation mainly depends on the designed RWH structure in place. As RWH was implemented by individual households, the technical information on cross sections of RWH structures was not documented and readily available. So, it was proposed to conduct a questionnaire survey among the residents to enquire and collect this information. Questionnaire was prepared both in English and Tamil, containing 3 major parts. The first part aims in collecting general information regarding the resident's personal details, no. of persons in the family, area of the premises, soil details, awareness about RWH system and their willingness towards this survey. The second part deals with water resources engineering which has water availability, water usage, quality of water and the sufficiency of the available water at their premises. The third part enquires the details of the RWH systems such as type of the system, features and their opinion about the RWH systems. The Questionnaire survey was conducted at Padmavathi nagar and Besant nagar. The information collected in the questionnaire was coded, represented in a coding sheet and percentage analysis was carried out. Scaling techniques were used for measuring the data. The responses sought from the respondents are mostly qualitative in nature. The merit of this technique is that with the use of scaled answers /responses, qualitative information gets recorded in a quantifiable and measurable form.

Tables 1 and 2 present the salient results of questionnaire analysis in respect of RWH implementation and related aspects.

Impact of RWH on ground water recharge

In urban areas, the natural recharge spaces are covered for roads,

Fig.2. Layout map of Kalakshetra colony, Besant Nagar

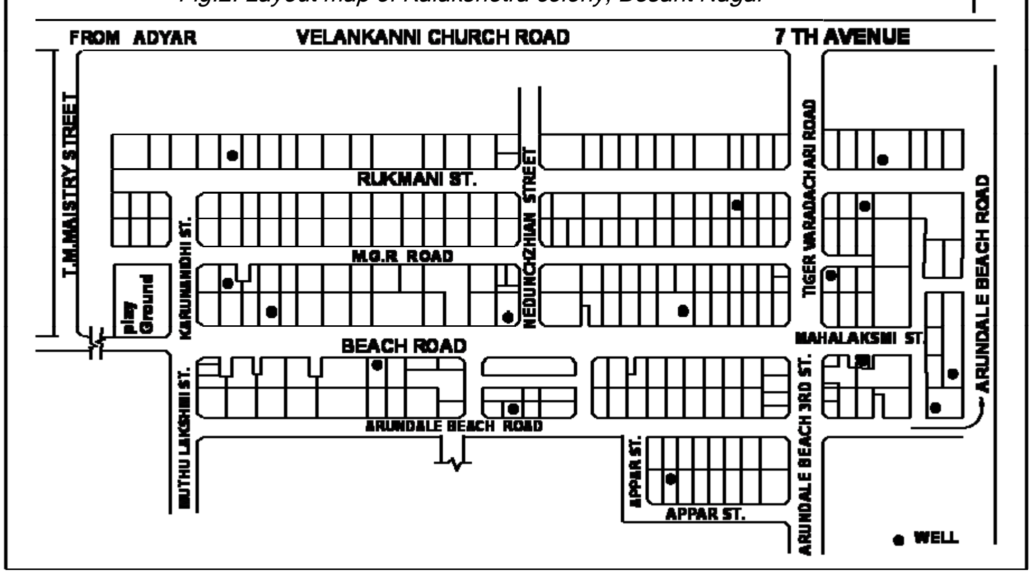


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Fig. 3. Lithology of Padmavathi nagar.

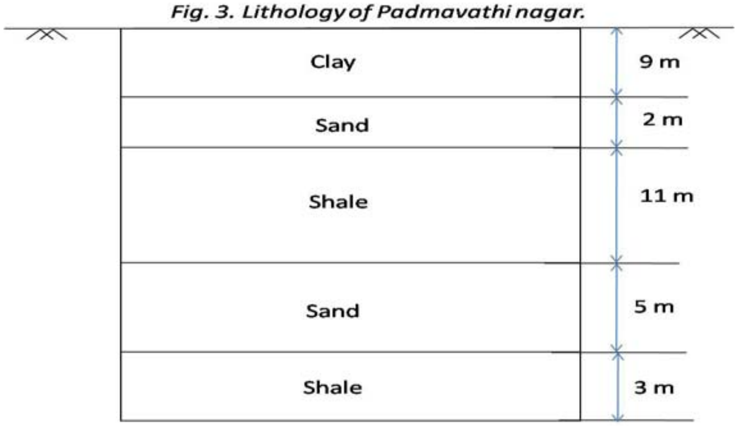

Fig. 4. Lithology of Besant nagar.

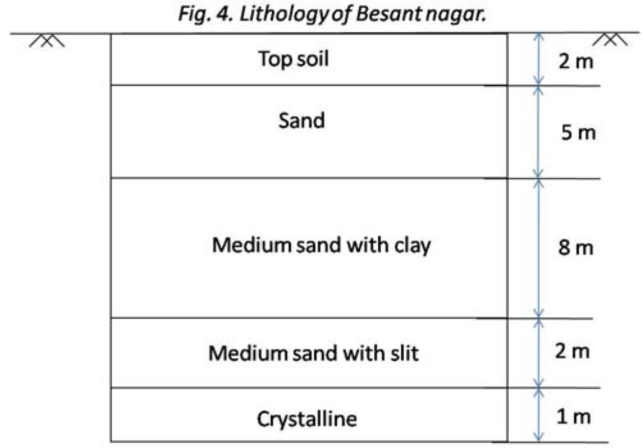

Fig.5. Impact of RWH on ground water recharge in Padmavathi Nagar

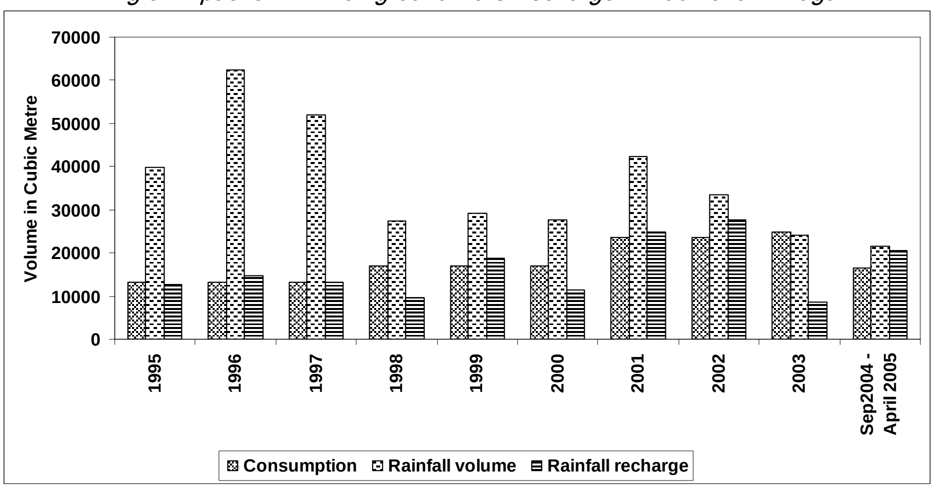

Fig.6. Impact of RWH on ground water recharge in Besant Nagar

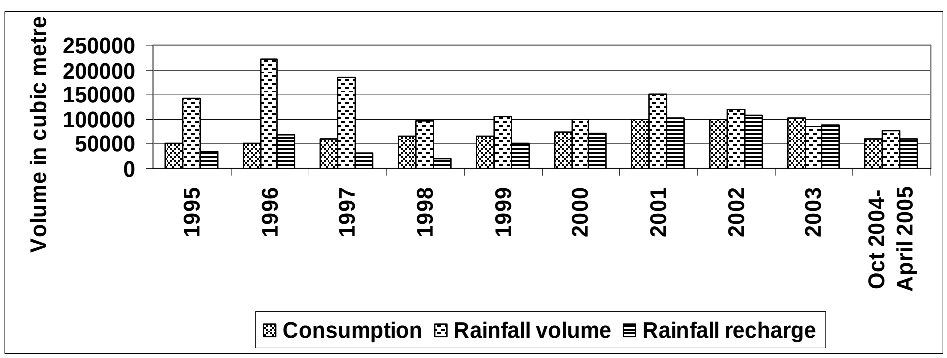

Table 1. RWH implementation.

Type of harvesting	Padmavathi nagar (%)	Besant nagar (%)
Roof top harvesting	100	100
Open space harvesting	0	61.7

Table 2. Type of implemented RWH structures.

Type of RWH structure	Padmavathi nagar (%)	Besant nagar (%)
Source well (open well/ bore well)	86.11	55.8
Recharge well	0	32
Percolation pit	13.88	8.12
Recharge well cum bore pit	0	4.08

pavements, etc. RWH aims at increasing the recharge artificially through a suitably designed and implemented structure which will transfer the runoff water available over the surface of the earth to a water bearing formation (aquifer), available at any depth. This will lead to increased groundwater potentials of the area. In order to study the impact, 23 wells were identified for continuous monitoring of water levels and 3 wells for quality analysis in Padmavathi nagar and 15 / 5 wells respectively in Besent nagar. Also, secondary data of monthly water levels and water quality data were collected from Central Ground Water Board(CGWB), Chennai. Groundwater potential assessment was carried out by water level fluctuation method. The study area is divided according to the well locations based on the Thiessen polygon approach to calculate the area of influence. Based on lithology and change in water level, changes in storage were estimated. Population details were used to estimate the groundwater draft with an assumed extraction of 100 lpcd, as the area was also served with water from Chennai metro water supply.

Water level fluctuation method

The water level fluctuation method was employed for computing rainfall recharge for the monsoon and non-monsoon seasons. This method is based on a water balance approach. The approach followed in the method is essentially a lumped parameter approach. Hence, the spatial variations of individual components in the water balance equation are not considered. The groundwater balance equation in non-command area is given by,

$R_G - D_G - B + I_S + I = S$ (GEC Norms 1997), which is simplified as $R = S+D_G$ (where R is the possible recharge ($R_G - B + I_S + I$)). Substituting the expression for storage increase S, in terms of water level fluctuation and specific yield, the equation becomes, $R = h * S_y * A + D_G$, where h is rise in the ground water level, S_y is specific yield, A is influence area of the well and Dg is groundwater draft.

$$\text{Stage of groundwater development (\%)} = \frac{\text{Existing groundwater draft} * 100}{\text{Net annual groundwater availability}}$$

Results and discussion

Tables 3 and 5 show the change in groundwater storages in Padmavathi nagar and Besent nagar respectively. The area of influence of each well was calculated using Thiessen polygon method.

Stage of groundwater development & possible recharge in Padmavathi nagar

(a) . January 1995-December 1995:

Stage of groundwater development was calculated using secondary data of water levels in wells and population details and by substituting in the equation, the possible recharge was calculated.

Per day consumption = 360(population in 1995)* 100 = 36000 l/d = 36 m^3/d

Consumption for 365 days = 36*365 = 13140 m^3

Available storage at the end of Dec 1995 (Table 3) = 25489.43*0.15*(1.36-1.5) = – 535.29m^3

Stage of groundwater development in the year 1995 = 13140/ (13140-535.29) = 104.25%

Possible recharge = -535.29+13140 = 12604.71 m^3 = 0.49 m^3/ m^2

(b) .September 2004-April 2005:

Stage of groundwater development during Sep 2004-Apr 2005 was calculated using the primary data of water level.

Per day consumption= 680* 100 = 68000 l/d = 68 m^3/d

Consumption for 242 days = 68*242 = 16456 m^3

Available storage in Apr 2005 (Table 3) = 4069.85m^3

Stage of groundwater development during Sep 2004-Apr 2005 = 16456/ (16456+4069.85) = 80.17%

Possible recharge = 4069.85+16456 = 20525.85 m^3 = 0.81 m^3/ m^2

Same way, stage and possible recharge were analysed for the primary data. Rainfall volume was calculated to check the influence in every year. Table 4 shows the summary of recharge and stage in

Table 3. Change in ground water storage during Sep 2004-Apr 2005 in Padmavathi nagar.

Well no. (As per plot)	Area of influence (Sq. m)	Specific yield	Water level in Sep 2005 (m)	Water level in Apr 2005 (m)	Water level fluctuation (m)	Change in storage (m^3)
2	816.87	0.150	7.90	6.45	1.45	177.67
61	1883.21	0.150	6.90	6.09	0.81	228.81
45	473.72	0.150	7.95	6.19	1.76	125.06
17	856.46	0.150	7.70	6.02	1.68	215.83
29/30	759.16	0.150	7.60	6.24	1.36	154.87
53/54	467.98	0.150	7.81	6.23	1.58	110.91
51	1032.26	0.150	7.40	6.73	0.67	103.74
11	775.52	0.150	7.40	6.11	1.29	150.06
1	367.98	0.150	8.20	6.89	1.31	72.31
67	606.17	0.150	8.10	6.61	1.49	135.48
55	1382.54	0.150	7.60	6.30	1.30	269.60
35	1352.51	0.150	7.85	6.54	1.31	265.77
42	569.88	0.150	7.65	6.05	1.60	136.77
50	410.72	0.150	7.70	6.47	1.23	75.78
13	343.37	0.150	7.40	6.13	1.27	65.41
68	484.24	0.150	8.10	6.73	1.37	99.51
65	1262.19	0.150	7.80	6.19	1.61	304.82
21	974.22	0.150	7.62	6.45	1.17	170.98
32	1365.02	0.150	7.54	6.09	1.45	296.89
20	6359.65	0.150	6.60	6.21	0.39	372.04
16	1158.74	0.150	7.40	6.16	1.24	215.53
52	625.77	0.150	6.90	6.29	0.61	57.26
39	1161.27	0.150	8.00	6.48	1.52	264.77
Total	25489.43					4069.85

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Table 4. Summary of recharge & stage in Padmavathi nagar.

Year	Consumption	Storage	Stage (%)	Rainfall	Rainfall volume	Possible recharge	Possible recharge
	m^3	m^3		(mm)	m^3	m^3	m^3/m^2
1995	13140	-535.29	104.3	1560.7	39781.15	12604.7	0.49
1996	13140	1567.61	89.34	2450.8	62469.18	14707.6	0.58
1997	13140	38.23	99.71	2034.9	51868.18	13178.2	0.52
1998	16972.5	-7417.4	177.6	1073.9	27372.96	9555.08	0.37
1999	16972.5	1720.53	90.8	1145.8	29205.64	18693	0.73
2000	16972.5	-5467.5	147.5	1082	27579.42	11505	0.45
2001	23542.5	1223.49	95.06	1659.8	42307.14	24766	0.97
2002	23542.5	4205.76	84.84	1313.4	33477.65	27748.3	1.09
2003	24820	-16288	290.9	948.6	24179.15	8532.25	0.33
Sep 2004-Apr 2005	16456	4069.85	80.17	846.2	21569.05	20525.9	0.81

Padmavathi nagar. Fig.5 shows the impact of RWH on groundwater recharge. The analysis indicate that the recharge rate has increased from 0.49 m^3/m^2 to 0.81 m^3/m^2, which should have been because of increased recharge due to RWH. Because of this fact, the groundwater level has not diminished even after the increased consumption in the year 2004-05.

Table 5. Change in ground water storage during Sep 2004-Apr 2005 in Besant nagar.

Well no	Area of influence (Sq.m)	Specific yield	Water level in Oct 2004 (m)	Water level in Apr 2005 (m)	Water level fluctuation (m)	Change in storage (Cubic metre)
1	8813.23	0.150	7.2	7.00	0.20	264.40
2	6738.91	0.150	11.54	11.24	0.30	303.25
3	4617.28	0.150	5.68	6.74	-1.06	-734.15
4	1845.41	0.150	3.88	5.94	-2.06	-570.23
5	3614.5	0.150	11.6	11.18	0.42	227.71
6	5200.29	0.150	6.5	6.76	-0.26	-202.81
7	10961.22	0.150	7.6	8.54	-0.94	-1545.53
8	15313.89	0.150	11.57	10.21	1.36	3124.03
9	5514.81	0.150	10.98	11.31	-0.33	-272.98
10	7089.79	0.150	13.3	12.03	1.27	1350.60
11	6570.72	0.150	4.52	6.18	-1.66	-1636.11
12	1841.55	0.150	3.37	5.02	-1.65	-455.78
13	3950.06	0.150	9.39	9.84	-0.45	-266.63
14	2318.81	0.150	3.3	5.61	-2.31	-803.47
15	6579.64	0.150	7.8	6.94	0.86	848.77
Total	90970.11					-368.92

Stage of groundwater development & possible recharge in Besant nagar

Similar analysis was carried out for the Besent nagar area. Table 6 shows the summary of recharge and stage in Besant nagar. Fig. 6 shows the impact of RWH on ground water recharge. The analysis indicate that the recharge rate has increased from 0.36 m^3/m^2 to 0.65 m^3/m^2

Impact of RWH on groundwater quality

The water samples from 3 wells of Padmavathi nagar and 5 wells of Besant nagar were collected and analyzed. In general, the quality of water is determined by physical, chemical and biological parameters. Here, water quality parameters selected for the analysis are pH, electrical conductivity, total dissolved solids, carbonate, bicarbonate, total hardness, calcium, magnesium and chloride.

Water quality data of Padmavathi nagar area (1995-2004) were collected from central ground water board and compared with the primary data of the year 2004-05 and presented in Table 7. These parameters are also compared with Indian standards and found to be within the permissible results. At the same time, the TDS is least during the years of RWH implementation indicating more filtration and dilution due to increased recharge. But, in 2005, it increases indicating reduced effectiveness due to non-maintenance without removing/replacing the top layer of RWH structures.

Water quality of Besant nagar (2001-2002) was also collected from central groundwater board, compared with the primary data of the year 2004-05 and presented in Table 8. The parameters are also compared with Indian standards and found that all parameters are not within the permissible results as per IS: 10500-1991. TDS values are between

Table 6. Summary of recharge and stage in Besant nagar.

Year	Consumption	Storage	Stage (%)	Rainfall	Rainfall volume	Possible recharge	Possible recharge
	m^3	m^3		m^3	m^3	m^3	m^3/m^2
1995	51100	-18421.45	156.37	1560.7	141977.05	32678.6	0.36
1996	51100	16374.62	75.73	2450.8	222949.55	67474.6	0.74
1997	58400	-27973.31	191.94	2034.9	185115.08	30426.7	0.33
1998	65700	-45030.20	317.86	1073.9	97692.80	20669.8	0.23
1999	65700	-13645.52	126.21	1145.8	104233.55	52054.5	0.57
2000	73000	-682.28	100.94	1082	98429.66	72317.7	0.79
2001	98550	4093.65	96.01	1659.8	150992.19	102644	1.13
2002	98550	8869.59	91.74	1313.4	119480.14	107420	1.18
2003	102200	-12963.24	114.53	948.6	86294.25	89236.8	0.98
Oct 04-Apr 05	59360	-368.92	100.63	846.2	76978.91	58991.1	0.65

Indian Journal of Science and Technology Vol. 4 No. 1 (Jan 2011) ISSN: 0974- 6846

500 and 6600 ppm but the permissible limit is 500-2000ppm. Also, chloride values range between 2500-4600 mg/l whereas, the permissible limit is 250-1000mg/l. It is found that this area has been affected by seawater intrusion, as electrical conductivity and chloride values are so high. Also, the Tsunami on 26.12.2004 has affected the groundwater quality as tested on 4. 1. 2005. After Tsunami, the quality has improved and reached its original state.

Table 7. Water quality of Padmavathi nagar.

Date	TDS (ppm)	TH (mg/l)	Cl (mg/l)
01/05/95	1527.50	580	475.00
01/05/96	1209.00	460	347.00
01/05/98	936.00	360	259.00
01/06/99	1088.75	360	308.00
01/05/00	1053.00	345	284.00
04/06/01	724.10	345	131.00
01/05/02	848.25	350	237.00
01/05/03	777.40	325	278.00
24/11/04	782.4	275	307.4
17/12/04	970.3	375	349.9
05/01/05	876.1	325	270
13/02/05	881.64	350	257.42
19/03/05	975.88	328	248.90
22/04/05	1177.80	347	272.89

Table 8. Water quality of Besant nagar.

Date	TDS (ppm)	TH (mg/l)	Cl (mg/l)
Jan-01	494.00	NA	NA
Jul-01	747.50	NA	NA
Jan-02	851.50	NA	NA
Jul-02	2470.00	NA	NA
17/11/04	4064.30	601.67	3303.93
20/12/04	4212.07	689.97	3421.70
04/01/05*	6529.33	1715.00	4606.13
14/02/05	3380.42	1003.00	2535.19
18/03/05	4129.2	962.92	2548.86
25/04/05	3962.67	962.92	2548.86

** Tsunami impact; NA-Not available*

Conclusion

Groundwater recharge is assessed based on GEC-1997 Norms by water level fluctuation method. From this, recharge per unit area was estimated and found to increase after the implementation of RWH. In Padmavathi nagar, the recharge is increasing from 0.49 m^3/m^2 to 0.81 m^3/m^2 and for Besent nagar, from 0.36 m^3/m^2 to 0.65 m^3/m^2 during the pre and post RWH implementation periods. Monthly water quality analysis shows that all parameters are within permissible limit in Padmavathi nagar but not in Besant nagar. In the later area, TDS and chloride values were found to be more than the permissible limits confirming the sea water intrusion. This methodology could be adopted for any other area and will be helpful in understanding the impact of RWH in quantity and quality aspects.

References

1. Deepak Khare, Ramakand, Ojha and Srivatsava RK (2004) Impact assessment of rainwater harvesting on ground water quality at Indore and Dewas, India. *J. Indian Water Works Assoc*. 36(2), 123-128.
2. Fayez A. Abdulla and Al-Shareef AW (2009) Roof rainwater harvesting systems for household water supply in Jordan. *Desalination*. 243, 195-207.
3. Sazaklia E, Alexopoulos A and Leotsinidis M (2007) Rainwater harvesting, quality assessment and utilization in Kefalonia Island, Greece. *Water Res.* 41, 2039-2047.
4. Sharma SK and Jain SK (1997) Ground water recharge through roof top rain water harvesting in urban habitation. Int. Conf. management of drinking water res. p60.
5. Srivastava RC (2001) Methodology for design of water harvesting system for high rainfall areas. *Agri. Water Management.* 47, 37-53.
6. Venkateswara Rao B (1996) Artificial recharge of rainfall water for city water supply-A case study of Hyderabad. *Hydrology J.* 19(4), 35-48.
7. Vijaya Kumar SV (2005) Evaluation of ground water resources: Ground water estimation committee (1997) methodology. Workshop on management of ground water in coastal and deltaic regions, 18-25.
8. Report of the Groundwater Resource Estimation Committee, Central Ground Water Board (CGWB), Ministry of Water Resources, Government of India, New Delhi, 1997.