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Groundwater Recharge Estimation: A Case Study in Chennai City

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Abstract

As groundwater is most commonly used for domestic purposes in urban areas, it is being overused without any limit resulting in decline of groundwater levels. The groundwater levels can be improved by artificial recharge method such as rainwater harvesting (RWH). Rainwater harvesting is a procedure of group and storage of rainwater into ordinary reservoirs or it can be refreshed into sub surface aquifers. This study aims to assess the variation of groundwater levels during recent years (2011–2018) by using the data collected from "Chennai Metro Water Supply and Sewerage Board". Chennai city of Tamil Nadu is taken for study. The temporal and spatial distribution of water levels was studied. Change in storage and recharge for the study area is been calculated from the water level, specific yield and area of influence by using "groundwater estimation committee (GEC) norms".

Keywords: *Groundwater, rainwater harvesting, recharge*

INTRODUCTION

Urban areas, such as Chennai, Mumbai and Delhi, are facing two major problems. One is acute water scarcity and another one is flooding during the monsoons which occur frequently [1]. However, this rainfall occurs during short span of time with high intensities. Due to this, most of the rain water falling on the surface fails to recharge fully and leads to runoff [2]. As Chennai being coastal area, there will be a chance of sea water intrusion, this can be overcome by 'artificial recharge'. One of the best artificial methods is the "Rainwater Harvesting" (RWH) method that if capturing the runoff [3]. Collection and storage of rain water at surface or in sub-surface aquifer, before it is lost as surface run off called rainwater harvesting. The Tamil Nadu government passed an act in 2003 for implementation of RWHs; it was effectively done only in domestic houses and not in public buildings / spaces [4]. The study till 2011 revealed that there is improvement in groundwater after the implementation of RWH (2003–2011) but the impact of RWHs may be reduced after 2011 due to improper maintenance of RWHs [5].

Pawar et al. [7], overviewed the success story of rooftop RWH program in Renavi village in Sangli district of Maharashtra India. The methodology involves rainfall analysis; calculation of potential rainfall supply, groundwater quality assessment from bore well and opens well. From the discussion, it is noticed that RWH is essential in Renavi village even though there is no shortage of water, as the level of fluoride and arsenic is above the permissible limit. Rainwater is practically free of dissolved solids. About 6.57 million liters of rain water is collected through RWHs which can meet the needs of annual cooking and drinking need of population. Julius et al. [6], studied about the evaluation of ground water storage before and after implementation of RWH system in Nagercoil (Pazhayar Watershed). The groundwater contours were plotted to identify the trend and spatial distribution of groundwater levels. The influencing area of each well was delineated and calculated based on Thiessen polygon method with the capabilities of ArcInfo software. The groundwater storage was considered to be dependent on water close fluctuation technique. The results show that the implementation of RWH has increased the groundwater storage even though the extraction is increased due to increase in population.

Pradeep Kumar et al. [8], measured the stage of groundwater development of Kurmapalli Vagu basin using Remote Sensing and Geographic Information System (GIS) techniques along with the estimation of ground water resources using conventional methods. Estimation of groundwater balance involves estimation of GW from rainfall, canals, recharge due to return flow of irrigation, recharge from minor irrigation tanks, recharge from water conservation structures, total ground water draft, stage of groundwater development. The results show that stage of groundwater development of Kurmapalli Vagu basin is in semi critical stage with the value of 80.6%.

STUDY AREA AND DATA COLLECTION

A part of Chennai city is selected as a study area for the estimation of ground water recharge. Study area is bounded by Cooum and Adyar Rivers. These dual rivers are nearly stagnant through the year and do not have water flow except during rainy seasons [9]. Chennai is a coastal plain area where numerous of the water forms and normal depressions are vanishing due to several improvements. Unrestrained reproduction of built-up areas, encroachment of river / streams and additional drainage stations, damage of water forms and reduced natural zones reason flooding in the town [10]. This highlights the essential to implement water reaping procedures used for through storage and use of rain water and for renewing the groundwater aquifers [11]. The map of the study area with the specific region chosen for the study is shown in Fig. 1. Study area is spread over 67.9 km^2.

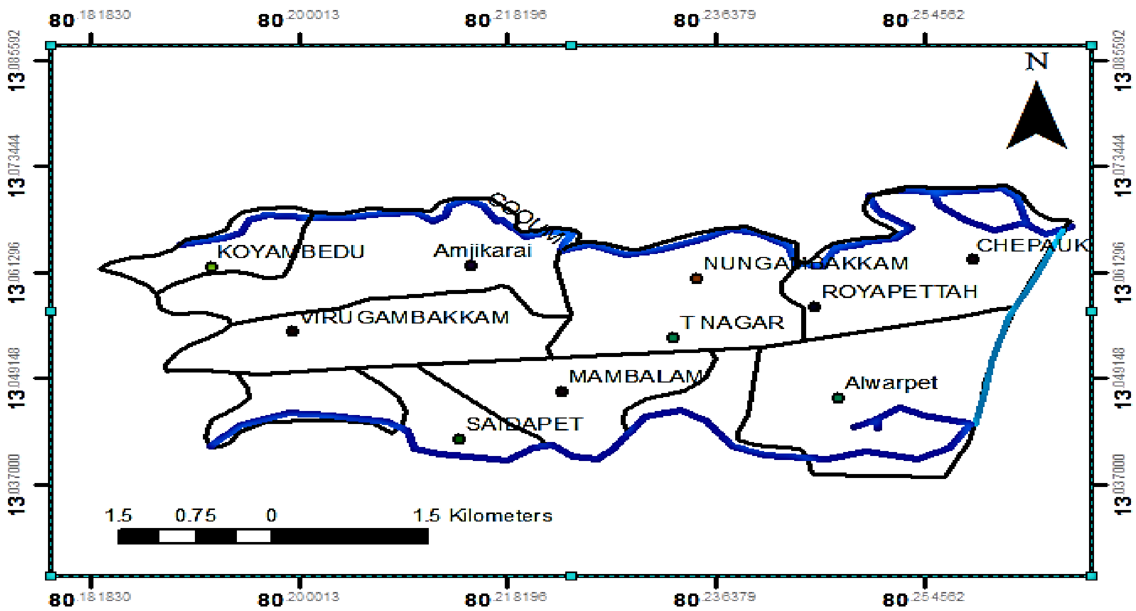

Figure 1: *Study area map.*

Monthly water level data for 23 observation wells located within the study area were collected from the "Chennai metro water supply and sewage board" for the period of 2011–2018. Monthly rainfall data was collected from 1971–2018 from India Meteorological Department (IMD), Nungambakkam, Chennai.

METHODOLOGY

The rainfall analysis was done for the period of 1971–2018. Temporal analysis of groundwater (2011–2018) was analyzed using the monthly weighted water level data. For the year 2011 to 2018, the difference of water table in the study area is calculated between pre monsoon (May) and post monsoon (Jan.), to understand the spatial variation of monsoon influence. "Groundwater Estimation Committee (GEC)" norm was used to estimate the change in storage and groundwater recharge. The change in storage and recharge is obtained by following relationship from GEC:

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

$RG - DG - B + IS + I = \Delta S$

RG = gross recharge due to rainfall and other sources including recycled water.

DG = gross ground water draft.

B = base flow into streams from the area.

IS = recharge from streams into ground water body.

I = net ground water inflow into the area across the boundary (inflow - outflow).

ΔS = increase in ground water storage.

B, Is, I are neglected, area assumed as watershed.

$R = \Delta S + DG = h \times Sy \times A + DG$

R= Possible recharge, which is gross recharge minus the natural discharges in the area in the monsoon season (RG - B + I +IS).

h – Rise in water level; Sy – specific yield; A- influence area of well.

RESULTS AND DISCUSSION

Temporal Analysis of Rainfall

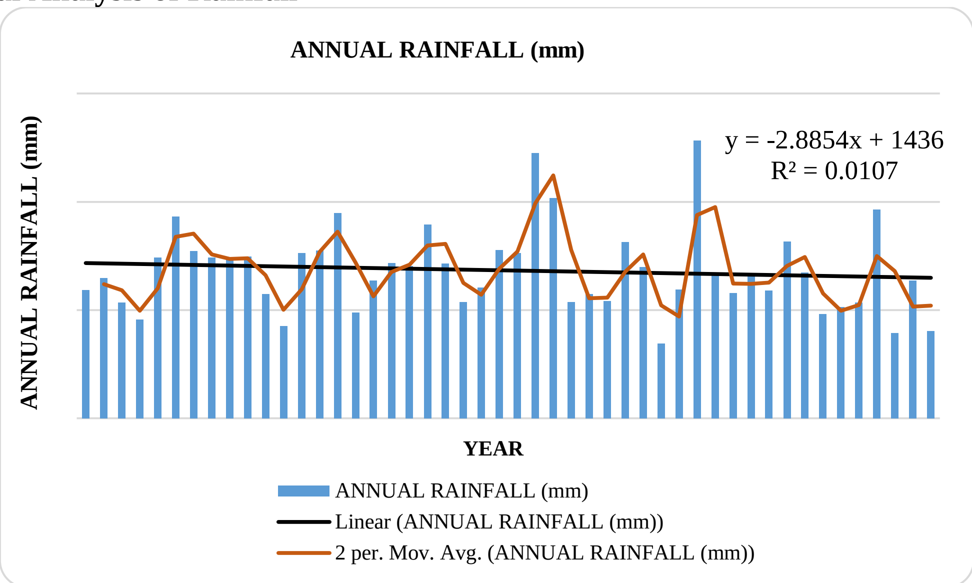

Figure 2: *Variation of annual rainfall.*

Average monsoon rainfall values of northeast are 811.12mm (59%) and southwest monsoons 453.31mm (33%) respectively. The summer and winter rainfall constitute only the remaining 8% of the total annual rainfall shown in Fig. 2.

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Temporal Analysis of Groundwater

Temporal analysis of groundwater (2011–2018) was analyzed using the monthly weighted water level data. The GW hydrograph was drawn with moving average curve in order to analyze the trend.

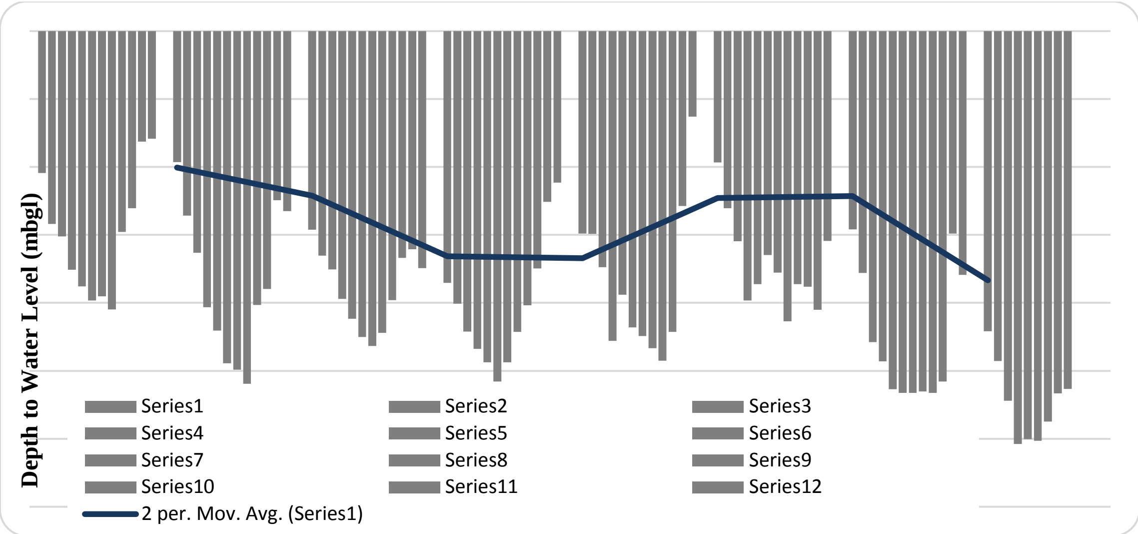

Figure 3: *Hydrograph of study area well.*

Observing the above Fig. 3 shows that there is a sharp increase in the water level from the year 2015 to 2016 as there is a significant amount of rainfall during the year 2015.

Spatial Analysis of Groundwater

By comparing the water table levels for pre monsoon month (May) and post monsoon month (Jan.), the spatial variation of groundwater levels in the study area has been studied. The spatial variation of groundwater levels are calculated from 2011–2012 and 2017–2018 shown in the Fig. 4 and 5.

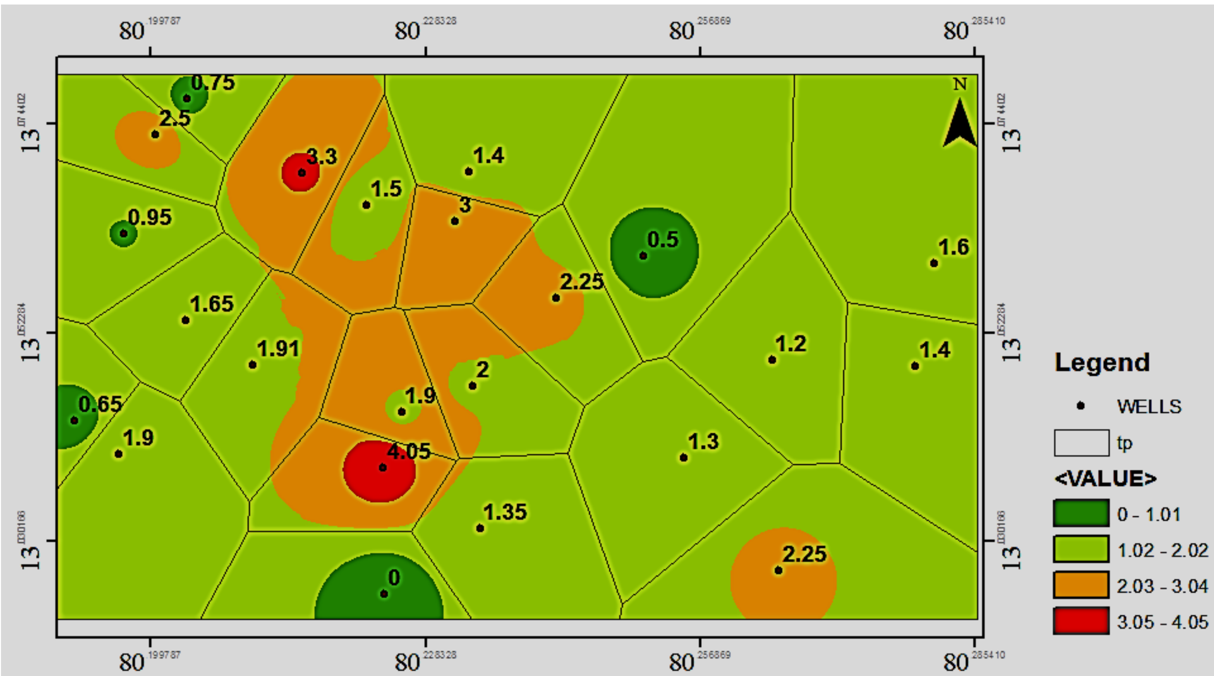

Figure 4: *Variation of GW level 2011–2012.*

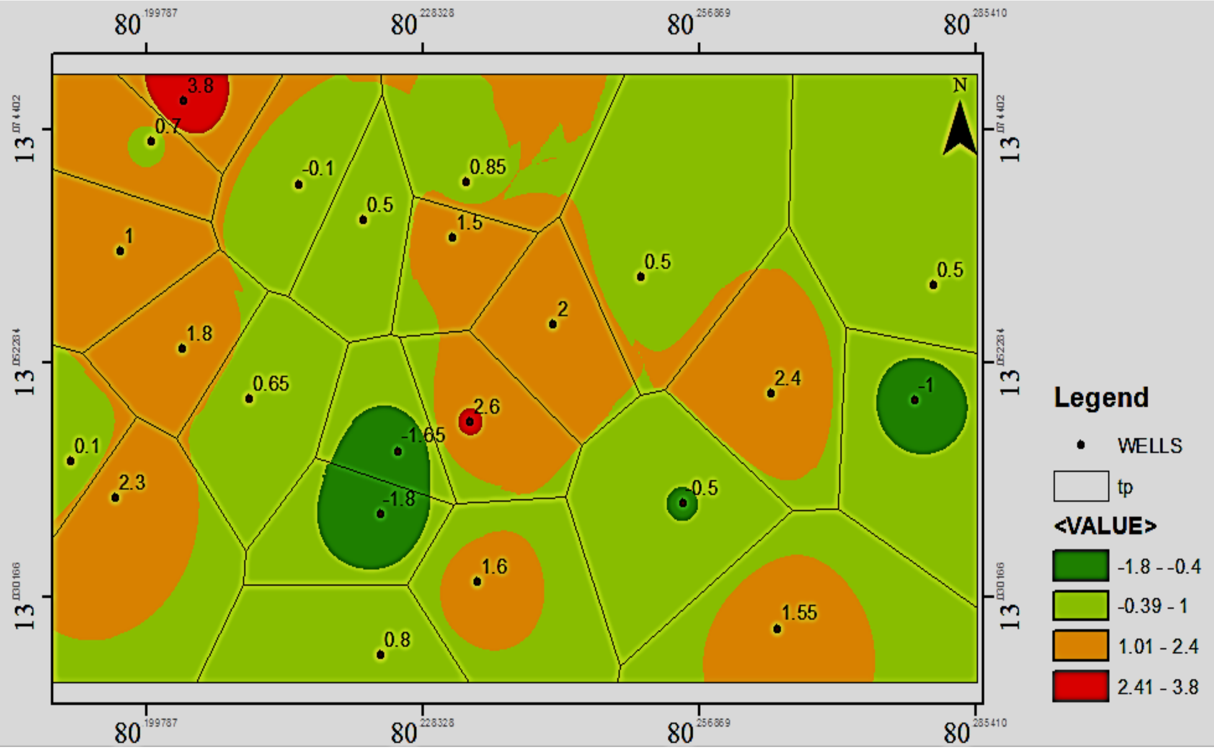

Figure 5: *Variation of groundwater level 2017–2018.*

Groundwater Recharge Estimation

In Ground Water Resource Estimation Committee (GWREC), the water table fluctuation method has been used for calculating the possible recharge for the monsoon season. The water balance approach used here is a lumped parameter approach, hence, the spatial variations of individual components are not considered. Area influenced by each well is calculated using Theissen polygon method and its value are given in Table 1 and shows in Fig. 6. The groundwater storage has been estimated using the change in water level, specific yield and area of influence. Also with the assumption of population and usage of water, the groundwater draft has been estimated. Then, recharge is calculated by adding groundwater draft with change of groundwater storage.

Table 1: *Area influenced by each well.*

Location	**Area (sq. m)**	**Location**	**Area (sq. m)**
Vadapalani (West Sivan Kovil St)	2830420	Mambalam (New Boag St)	3459650
Usman Road T. Nagar	2258500	Medavakkam (Sect Colony)	2562390
Royeppetah (EPF office)	3518080	Ice house	3486800
Presidency college well	5431340	Eldams Road (Venus Colony)	3965900
Chetput (SKPD hostel)	3268890	Mylapore	4870800
Koyembedu (Tiruvetri amman Kvl)	978094	Sourastra Nagar (Choolaimedu)	1489250
Saligramam (Kishaldoss St)	1991950	Greams Road (IT dept)	6020360
Virugambakkam	1666980	Nungambakkam	2279710
KK Nagar (Kovil Well)	4762520	Koyembedu (Kovil well)	2077630
West Mambalam (Tambai Reddy St)	1608200	Arumbakkam (MMDA)	2607460
West Mambalam (Jubiliee St)	2093880	Choolaimedu (Anjugam School)	1964230
		Chinmaya Nagar	2715370
	67908404		
TOTAL AREA	67.908404sq.km		

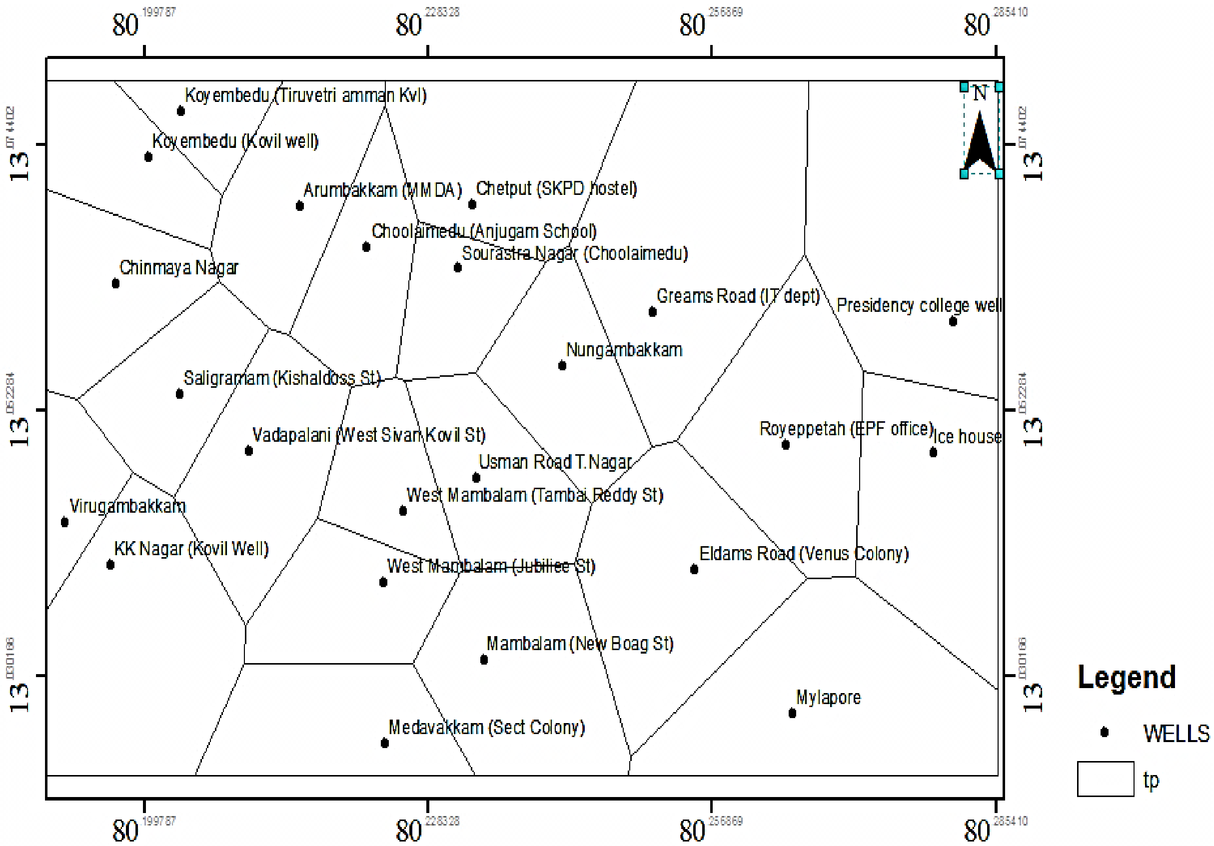

Figure 6: *Theissen polygon map.*

Table 2: *Groundwater storage and recharge for 2011–2018.*

Sr. No.	Year	Ground water draft (Mm^3)	Ground water Storage (Mm^3)	Recharge (Mm^3)	Recharge (m)
1	1995-1996	18.38	2.72	21.1	0.28
2	1996-1997	18.71	11.09	29.8	0.40
3	1997-1998	19.04	6.29	25.33	0.34
4	1998-1999	19.39	2.04	21.43	0.28
5	1999-2000	19.73	0.92	20.66	0.27
6	2000-2001	20.09	-1.89	18.20	0.24
7	2001-2002	20.51	4.37	24.88	0.33
8	2002-2003	20.88	4.53	25.41	0.34
9	2003-2004	21.26	-1.48	19.77	0.26
10	2004-2005	21.64	3.99	25.64	0.34
11	2005-2006	22.03	13.77	35.80	0.47
12	2006-2007	22.43	3.99	26.42	0.35
13	2007-2008	22.83	2.35	25.18	0.33
14	2008-2009	23.24	2.46	25.71	0.34
15	2009-2010	23.66	7.47	31.13	0.41
16	2010-2011	24.09	4.9	28.99	0.38
17	2011-2012	24.52	0.78	25.3	0.37
18	2012-2013	24.96	-2.3	22.66	0.33
19	2013-2014	25.41	1.2	26.61	0.34
20	2014-2015	25.86	-1.56	24.3	0.35
21	2015-2016	26.32	2.88	29.2	0.43
22	2016-2017	26.79	-3.6	23.19	0.33
23	2017-2018	27.27	-3.5	23.77	0.31

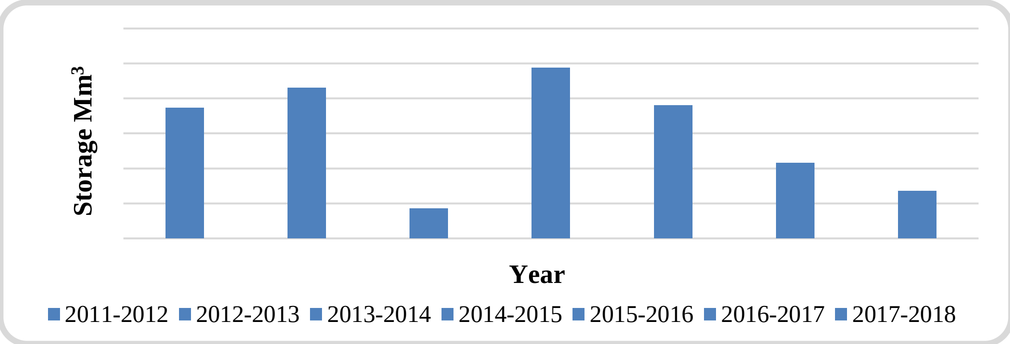

Figure 7: *Change in storage (Mm^3).*

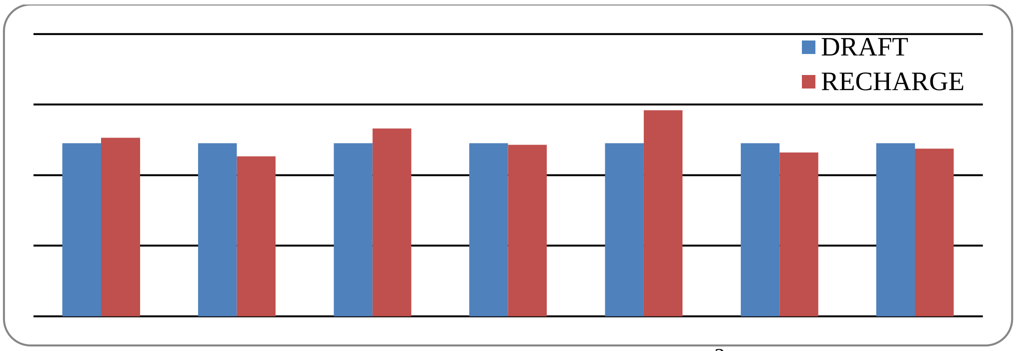

Figure 8: *Recharge vs Draft (Mm^3).*

From Fig. 7 and 8 the calculated values of groundwater storage and recharge for the period 2011–2018, it shows that the draft is also increasing along with the recharge. This results over exploitation of groundwater in the study area.

Simple Non-linear Regression Analysis

The improvement of recharge over and above the natural recharge is represented by the impact of RWH. The natural recharge components can be estimated by in putting the natural recharge parameters before RWH period and simulating for after RWH periods. Any additional recharge, if any, should have come through artificial recharge due to RWH. The rainfall values are plotted against estimated monsoon recharge (using water level fluctuation method) during pre RWH period (1995–2003) to analyze the relation between rainfall and estimated recharge, and a nonlinear regression line is developed as shown in Fig. 9.

$Y = 0.042x^3 - 0.185x^2 + 0.323x + 0.085$

Where Y is the recharge in m; and X is the monsoon rainfall in m.

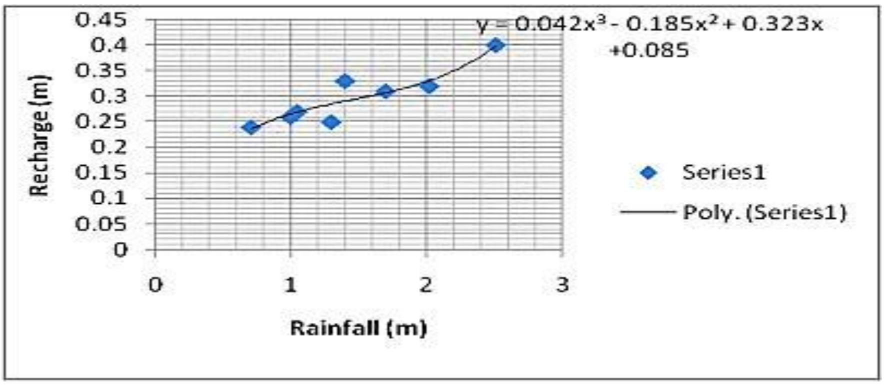

Figure 9: *Regression analysis of rainfall and recharge.*

The possible natural recharge during the post RWH period is calculated by using the non linear regression equation developed for pre RWH period for the study. The difference of NR (computed) from actual recharge for post-RWH period (estimated from water level fluctuation method) gives the artificial recharge due to RWH. Table 3 shows the recharge due to RWH during the period 2004–2010 in the study area.

Table 3: *Recharge due to RWH for post RWH period.*

Sr. No	Year	Rainfall (m)	Possible natural Recharge from Pre RWH equation (m)	Actual recharge observed (m)	Recharge due to RWH alone (m)	% of recharge due to RWH alone
1	2004–2005	0.91	0.25	0.34	0.09	26.5
2	2005–2006	1.94	0.32	0.48	0.16	33.3
3	2006–2007	1.29	0.28	0.39	0.11	28.2
4	2007–2008	1.15	0.28	0.36	0.08	22.2
5	2008–2009	1.16	0.28	0.36	0.07	19.4
6	2009–2010	1.14	0.29	0.35	0.06	17.1
7	2010–2011	1.42	0.31	0.38	0.07	18.4

Using the non-linear regression equation developed for pre RWH period for the study area, the possible natural recharge during the latest period (2011–2018) is calculated as shown in Table 4.

Table 4: *Recharge due to RWH for 2011–2018.*

Sr. No	Year	Rainfall (m)	Possible natural Recharge from Pre RWH equation (m)	Actual recharge observed (m)	Recharge due to RWH alone (m)	% of recharge due to RWH alone
1	2011–2012	0.96	0.28	0.37	0.02	6.7
2	2012–2013	1.02	0.30	0.33	0.03	10.1
3	2013–2014	1.07	0.29	0.34	0.05	14.7
4	2014–2015	1.93	0.32	0.35	0.03	8.6
5	2015–2016	0.79	0.32	0.43	0.11	25.6
6	2016–2017	1.27	0.30	0.33	0.03	9.1
7	2017–2018	0.80	0.29	0.31	0.02	6.5

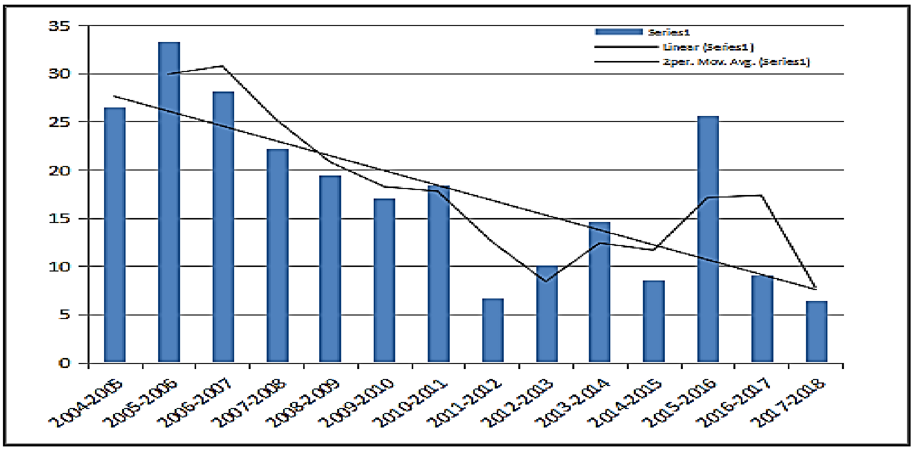

Figure 10: *Percentage of recharge due to RWH.*

Fig. 10 represents the graph for percentage of recharge due to RWH for the period 2004–2011 and 2011–2018 which shows that the percentage of recharge due to RWH structure has been decreased for the latest years because of lack of maintenance.

CONCLUSION

The rainfall analysis shows the decreasing trend. The decreasing trend of water levels for the period 2017–2018 was observed in the temporal variation of groundwater. The spatial variation of water table were drawn using ArcGis, shows the negative values of difference in water level are very high during 2017–2018. Groundwater storage and recharge is assessed using water level fluctuation method in GEC Norms. It is inferred that draft and recharge are equal which results the groundwater is overexploited in Chennai region. Impact of RWH evaluated through simple non-linear regression. Percentage of recharge due to RWH for the study area varies from 14% to 6.5%.

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