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Augmentation of Groundwater Recharge in Rainwater Harvesting Systems: A Coastal City Study

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ABSTRACT: Global warming, climate change and urbanization has affected the hydrological cycle. The demand of fresh water is continuously rising and continuous dropdown of groundwater level reported from many regions of the world. The most sustainable and economically sound approach for the improvement of groundwater level can be achieved through rainwater harvesting systems (RWHs). Rainwater Harvesting (RWH) systems are implemented either to store rainwater or recharge the groundwater. One of the key parameter required to design RWH systems for groundwater recharge include the knowledge of percolation rate in the recharge systems. RWH systems implemented without considering the percolation rate leads to overflow and wastage of harvested rainwater. The percolation rate depends on the hydrogeology, porosity and permeability of the strata through which rain is penetrated. Though, estimation of infiltration rate of soils using double ring infiltrometer is a common practice, it may not be applicable in designing RWH systems, as the recharge systems are designed to bypass the soil media totally. The rainwater harvesting systems in coastal areas needs a detailed investigation of sub-surface geology. Data availability on the percolation rate of the vadose zone (i.e. the aquifer media in between the soil and water table) are very minimal; on the contrary this is the crucial zone for percolation. In the present study, slug tests were conducted in 31 locations within Chennai city in the RWH recharge wells. The tests were conducted as per Bureau of Indian Standards (BIS) IS 5529 (Part – 1): 2013. The tests were carried in two different seasons (pre and post monsoon) and in different hydrogeological conditions to assess the impact of hydrogeology and lithology on the percolation rate. The estimated percolation rate varied from 0.19 cu.m/day/m to as high as 166 cu.m/day/m. Higher percolation rates were observed in terrains where the sub stratum is more sandy while the lower percolation rates are observed in clayey sub stratum. Also substantial variation could be inferred in the percolation rates in the recharge wells located within a site and also during pre and post monsoon periods. The work outline the need to assess the nature of sub stratum, its percolation rate and accordingly to design RWH systems for implementing efficient groundwater recharge systems.

Keywords: Rainwater Harvesting, Groundwater Recharge, Slug Test, Percolation Rate.

Abbreviations: RWH, Rainwater Harvesting; T.N, Tamil Nadu.

I. INTRODUCTION

In a country like India rain water harvesting is an old practice. It evolved over a period of 2000 years and are based on sound understanding of the ecology and environment. RWH systems have been in place and practiced right from the rain starved State of Rajasthan to the rain rich State of Meghalaya wherein Cherrapunji (Mawsynram) known for its highest rainfall on the earth. The evolved RWH systems are time tested and in practice even today. These were decentralised systems, where communities played an active role in water management. Almost every part of India had its own traditional rainwater harvesting systems; the earthen bunds – constructed along the slope to capture the run off during monsoon - called Eri, is a common water harvesting system wherein the surface run off during monsoon is collected and used for irrigation and water supply in South India. The Tanka's and Kundi's–wherein rainwater is collected from catchment and stored-are the common water harvesting systems that are still practiced in western India.

In non-monsoon the stored rainwater used for different purposes [1]. The RWH is a popular approach in semi-arid environment. The two aspects of RWH are (i) collection of rainwater in surface water bodies like ponds, lakes, tanks etc. at the macro level and in storage tanks at the micro level for immediate use and (ii) recharging the collected rainwater into the groundwater aquifers. In urban areas, both the aspects of RWH have been carried out at the macro and micro levels. Intervention at the macro level involves the role of government facilitated by the community while at the micro level communities plays a major role. Very limited study have been carried out pertinent to RWH in coastal areas considering to saline intrusion in cities. In general there are three popular approaches in practice namely (i) Surface runoff harvesting a most suitable method in urban clusters (ii) Rooftop rainwater harvesting in urban areas and (iii) Recharge Pits in open fields. In coastal areas where is groundwater is salty, storing the rain water in a tank and injecting into the ground belwo10-30 feet through soil media.

The Chennai City is the capital of state Tamil Nadu, India, has provided enabling policies to facilitate the concept of RWH need to be implemented by the citizens of the city. Starting from 1994, the state constantly policy shift on RWH and finally during 2002 made it mandatory for all buildings in both urban and rural areas. The implemented designs include both direct storage and groundwater recharge system. The design for direct storage depends on the aspects such as rainfall pattern, availability of space and cost, whereas the design for groundwater recharge system involves a fairly better understanding of the sub surface lithology in addition to the above mentioned aspects. An effective RWH system designed for groundwater recharge it should recharge the harvested rainwater without getting overflowed. The non scientific RWH system without incorporating the sub surface information would lead to wastage of harvested water and may not give the expected results. The present study highlights the significance of percolation rate of the RWH systems for augmentation of groundwater recharge and taking into account of the sub surface lithology.

II. STUDY AREA

In India the state Tamil Nadu is located in the Eastern coast of India and has the state capital Chennai. Chennai has automobile industry and fourth largest metropolitan city of India. The Forbes has listed city Chennai as the top ten fastest growing cities in the world. As per the Census of India, GoI, in 2011 Chennai city population has 6.8 Million and living in 426 km^2 area. Due to migration of people in search of good life, jobs and education the pressure is continuously mounting and the population density increases 247/ha to 266/ha in 2001 and 2013, respectively in Chennai city.

The city is located near equator hence it has tropical climate. The month April to June is generally hot and during north east monsoon (December to February) the area receive heavy rainfall hence climate is pleasant [2-4]. The annual mean temperature in area ranges from 24.3℃ to 32.9℃ as minimum and maximum, respectively. Whereas the lowest and highest recorded temperature are 13.9 ℃ and 45℃, respectively. It is a coastal city hence coastal meteorology plays a significant role, the percentage of humidity ranges between 58 to 84%, respectively. The area receives majority of rainfall during north east monsoon whereas annual average rainfall at Meenambakkam station (1323.7 mm) and Nungambakkam station (1285.6 mm). The 60% contribution of annual rainfall in the area is due to northeast monsoon followed by, 30% (southwest monsoon) and 10% (from winter and summer rainfall). Hence, north east monsoon is the life line of the farmers.

The urbanization is increasing and people are settling at old sand dunes and beach ridges. The eastern part of the study area is coastal plain which is covered by sand dune, sandy and loamy soil. The coastal landform is highly eroded near the Chennai port and prone to coastal flooding. Near Ennore, coastal erosion is dominant whereas gentle slope is observed in the western part of the city [3-5]. Few mountain ridges exists near St. Thomas Mount, Pallavaram, Tambaram and Kundrathur.

The Adyar River (south) and the Coovam River (north) are two important rivers which drains the study area. The total length of Adyar river is 42 km and it originates in west of Tambaram, it flooded in Northeast monsoon season. The Coovam river originates from Coovam tank in Thiruvallur district. These rivers receives heavy pollution in the Chennai city due to direct discharge of untreated sewage and wastewater [6]. The Buckingham canal originates in Andhra carries lots of waste waters and the Otteri nalla join near Basin near Basin Bridge.

Hydrogeology: The precambarian hard rock and sedimentary rock (sandstone, shale, boulders, gravel, sand and clay) dominates in the city region. The recent alluvial deposits consist of sand dunes, marine and lacustrine deposits, covers major region of study area. The recent deposits generally cover older formations (consolidated and semi-consolidated sedimentary formations) of the Tertiary and the Gondwana deposits and crystalline rocks of the Archaean age. The crystalline rock exposed in southwestern region and sedimentary formations in the northwestern region [5,6]. The description of geological succession is presented in Table 1.

Table 1: The brief description of geological succession of the study area.

Geological Age	Types of stratigraphic discordance	Deposits
Recent to Sub recent age		Alluvium-laterite-lateritic conglomerate, and Black clay
Mio-Pliocene age	Tertiary	Pink sandstone
	----- UNCONFORMITY---- (Mean the surface of non-deposition which separates the younger strata from older rocks and it suggests the interruption in geological records)	
Upper Gondwanas	Sathyavedu bed	Conglomerate, sandstone and boulders
	Sriperumbudur beds	Clay, Shales and Felspathic sandstone
	----- UNCONFORMITY----	
Lower Gondwanas	Talchirs	Green shale and boulders
	----- UNCONFORMITY----	
Archaean Eon (4 to 2.5 billion years ago)		Dolerite (igneous rock), Charnockite (high-grade metamorphic terranes) and Gneiss (meta morphic rock) formed at high temperature and pressure

The geological succession in Chennai city shows the presence and distribution of a variety of formations occurring in the metropolitan area of Chennai. The porosity and permeability of these formations varies widely, while sand, sandstone, conglomerate and weathered rocks act as good water bearing formations, the clay, shale and laterite are generally not considered as water bearing formations. With wide variations in the permeability of the formations in the sub surface, their percolation rates also vary widely their yielding capacity. The hydrogeological map depicts the various formations are presented in Fig. 1.

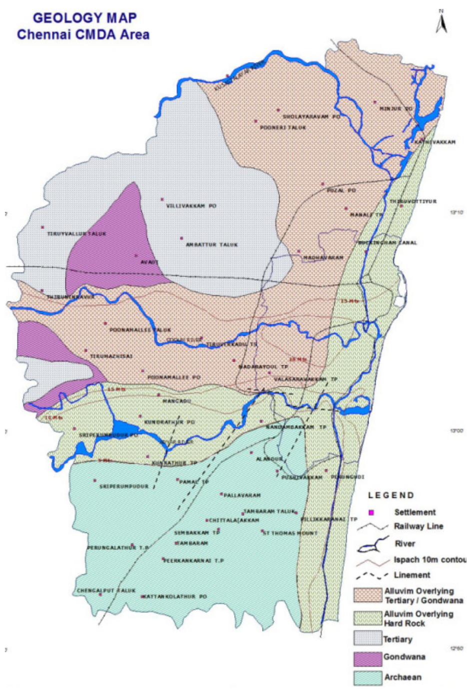

Fig. 1. Geological map of Study area.

General information: With wide variation in the sub surface lithology and their water holding capacities, designing RWH systems for groundwater recharge cannot be a one size fit for all solution particularly in the case of Chennai. Recharge dug wells are more conducive for harvesting rainwater and recharging the groundwater. These wells are constructed using Re-inforced Cement Concrete rings with the diameter varying from 0.9m to 1.8m and depth varying from 6m to 12m. Ideally, the location and number of recharge wells in an area should be arrived based on the percolation rate per recharge well and on the volume received during peak hourly rainfall of that particular area. Though the volume generated for peak hourly rainfall can be estimated, the percolation rate of recharge well is either not known or available. The rate of percolation depends upon the porosity of the sub stratum, level of saturation, level of groundwater extraction, rainfall intensity and distribution. In fact, there is very limited data available on percolation rate based on which recharge wells can be designed and implemented. Though there are attempts being made to assess the infiltration rate of soils using double ring infiltrometer in different area [7], it may not be applicable in designing RWH systems; as the recharge systems bye pass the soil media totally. Attempts made to estimate the percolation rate in the vadose zone (i.e., the aquifer media in between the soil and water table) are almost minimal in Chennai; on the contrary it is the crucial zone that plays a major role in groundwater recharge. Other methods of assessing the percolation rate were assessed for designing septic tanks but here again the depth parameter is limited from 1.5m to maximum 2m whereas our interest is beyond this depth.

III. METHODOLOGY

To estimate the hydraulic properties/characteristics of aquifers, a slug test need to perform [8], this is commonly conducted by either bailing out or introducing a known volume of water into a well that will cause a sudden rise or fall in water level. The rate of percolation was determined through analysis of water-level and its response in different seasons. The methodology was conducted in the recharge well, it is decided to conduct a falling head test wherein a known volume of water has been injected into the recharge well and the fall in water level to time was recorded to estimate the rate of percolation. The fall in water level is measured at regular intervals to assess the rate of percolation. The residual head (displacement of water level with respect to original level at time t) is plotted against the reciprocal of time i.e., ($1/T_m$) where Tm is the time following instant injection of slug of water and a straight line is drawn through observed data (Fig. 2).

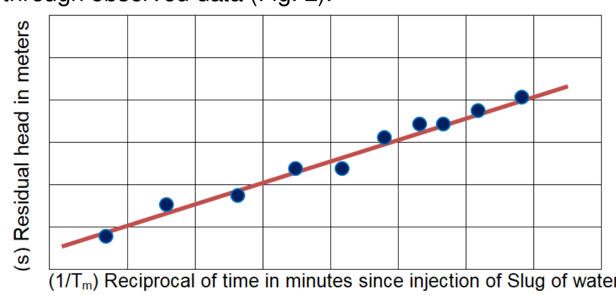

Fig. 2. Relationship between Residual head and reciprocal of time.

An arbitrary point is selected in the straight line and the corresponding values of "1/Tm" and "s" is substituted in the Eqn. 1.

$$T = \frac{114.6 \times V \times (1/Tm)}{s} \tag{1}$$

Where, T is coefficient of transmissivity in litre/ day /m, V is the volume of slug introduced, s is the residual drawdown (taken from an arbitrary point in straight line), and ($1/T_m$) is the reciprocal in time since the injection of the slug corresponding to s

IV. RESULTS AND DISCUSSIONS

The tests were conducted in different hydrogeological environs covering, alluvial deposits of both fluvial and aeolian origin, weathered rock, and also in areas with clayey sub soil conditions. Thus the tests were conducted in both sedimentary and hard rock environs. The basic idea was to generate data for different sub stratum, so that a wide spectrum of hydrogeological environs and their percolation rates can be captured. The slug test was conducted in 31 different locations in Chennai city before the North East monsoon during

2017. From all the locations the litholog data was collected and analysed for their clay and sand content based on which the sub surface characteristics were determined. The results are presented in Table 2.

Study indicate variation in the rate of percolation. The majority of the study was conduct in alluvial aquifer over lying hard rock which indicates a variation from 166 to 2.3 cu.m per day per m. In the case of alluvium overlying 4.7 to 2 cu.m per day per m. Very low values were encountered in clayey sub stratum. The weathered zone in hard rock terrain is better as compared to clayey areas. Interestingly the test was conducted in Vivekananda College before and after distiling to assess the impact of siltation on percolation. It is inferred that the siltation reduced the rate of percolation rate by 25% indicating the need of constant maintenance of recharge systems and removal of silt that gets accumulated in the recharge systems for better performance. The elevation information required at higher accuracy for identification of suitable location of recharge pits [8] and knowledge about permeability of soil [9] for proper development of rainwater harvesting systems. The study of morphometric parameters [10-12] and delineation of groundwater potential and recharge zones improve groundwater level [13-15].

Table 2: Location wise percolation rate and the sub surface characteristics.

Location	Percolation Rate in cu.m /day/m	Sub Surface Characteristics
Old cancer insitute (Kasturba Gandhi Ngr)	4.34	Weathered zone - Hard rock terrain
Gurunanak College	3.60	Clayey Sub stratum
Guild of Service (GOS), Pallipatu	0.60	
Bala mandhir	0.19	
Bhakvathsalam college	0.42	Gondwana Formation – Clay and Shale mainly
Rama Krishna Mutt (RKM) Girls hostel	166.69	Alluvium overlying hard rock – sandy aquifer
RKM Boys (South)	102.48	
RKM Main (Boys)	35.15	
Vivekanada college (after Desilting)	30.23	
Vivekanandha college (without desilting)	22.60	
Thakkar baba	14.44	
Cancer insitute (Adyar)	14.01	
Theosophical Society	13.01	
RKM School,Madley road	12.68	
TTK Hospital	11.60	
Sankara Nethralaya	9.63	
RKM Sarada Vidyalaya, Usman Road	5.54	
RKM Girls School, Burkit road	5.71	
New college Hostel	5.58	
RKM School (Near Bata), T.Nagar	4.70	
R.K. Mutt	4.43	
New college	4.30	
St. Isabella hospital	4.08	
Seva sadan	3.99	
Guild of service (Egmore)	3.28	
RKM School Bazullah road	2.33	
GOS Saligramam (primary school)	4.73	Alluvium overlying Shale– Sandy Clay aquifer
GOS Annna Nagar West	4.12	
GOS Balavihar	2.09	
GOS Saligramam(Higher Secondary School)	16.35	Alluvium overlying Shale – Sandy aquifer
Sevalaya	2.91	

V. CONCLUSION

Based on the results it is recommend that the percolation rate need to be considered for designing of RWH systems, it helps in augmentation of groundwater. The percolation studies helps to assess the rate of percolation based on location, size and number of recharge systems for the volume of rainwater to be harvested. This would help in effective harvesting of rainwater otherwise it get wasted due to overflow. Further, RWH systems need to be maintained at regular intervals at least before the onset of north east monsoon for effective functioning, else the system becomes redundant over a period of time. The water budget needs to be estimated for the region and to develop a pragmatic water conservation policy.

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