Estimation of Groundwater Recharge Potential using Rooftop Rainwater Harvesting: Case Study from Pune Urban Area, India

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Abstract
Water scarcity is increasingly being felt in most nations includes highly developed countries. It is especially acute in urban growth centres as the demand for water increases rapidly while the supply of fresh potable water is decreasing. Ground water is increasingly being used as a source of fresh water in many cities across the world and causing depletion of the scarce resource. Groundwater recharge practices using rainwater harvesting contribute to restoring the water balance. Recharge to groundwater from rainfall has been studied extensively and numerous methods have been proposed for estimation of natural and artificial recharge of groundwater. However, most of these studies pertain to the recharge of surface aquifers. The present study covers the use of Rooftop Rainwater harvesting for recharge through direct injection to confined aquifers or deep-seated aquifers and a part of the larger study to understand the recharge potential from rooftop rainwater harvesting for Pune city. The recharge potential of roof rainwater harvesting is the capacity of a particular roof to harness the water that falls on it annually. The result of the study suggests that there is a large scope for supplementing the existing groundwater reserves of Pune city by direct injection using rooftop rainwater harvesting. The total water availability (run-off) per annum was estimated to be 49.05 million cubic metres (MCM). Even if half of this total rainwater is harvested, the recharge can supplement the groundwater annually by about 22 - 25 MCM (0.7 to 0.88 TMC) and can cater to nearly 70 % of the annual groundwater requirement of the Pune city.

1. Introduction

Water is a scarce natural resource, even though 71% of land is covered by water. Only about 2.8% of the total water available on earth is fresh water and can be used for human consumption. Water scarcity is increasingly being felt in most nations, including highly developed countries as the demand for water increases rapidly while the supply of fresh potable water is decreasing. Rapidly growing human population, changing climates and frequent droughts are contributing to the above. Coupled with this, the erratic rainfall and uncertainty in monsoon patterns has put immense pressure on the requirement of water resources both in rural as well as urban areas and led to over-utilization of groundwater.

According to the Ministry of Water Resources, India, the domestic demand for water will continue to rise and by the year 2025 is expected to increase to 47 trillion litres per annum. Domestic demand is expected to grow by around 40 per cent from 41 trillion litres per annum to 55 trillion litres per annum while irrigation will require 14 per cent more water – 592 trillion litres per annum up from 517 trillion litres per annum currently (Bhat, 2014). The demand supply gap is especially acute in urban areas which has led to the indiscriminate mining of groundwater with no restrictions. Hence, it is no surprise that the groundwater level is decreasing day by day. Wells which were once productive are drying up especially in summer when the demand is very high. Increasing population has led to the rapid urbanization of Pune area and consequently affected the land use of Pune and the quantity and quality of surface and groundwater as evidenced from lowering of groundwater levels in most bore holes.

2. Study Area

Pune Urban area covers an area of 7,256.46 sq. kms and is included in the Survey of India toposheet numbers E43H14 & E43H15. It includes Pune Municipal Corporation (PMC), Pimpri Chinchwad Municipal Corporation (PCMC) and three Cantonment Boards. Of the above extent, Pune Municipal Corporation (PMC, Pune City) covers 331.26 sq. kms (127.90 sq. miles) and has a population of 3.13 million (Pune Municipal Corporation, 2011)

Pune city is the second largest city in the state of Maharashtra and the eighth largest city in India. The study area lies between 18^0 27' & $18^0$40' N – $74^0$39' and $74^0$00' E (Figure 1) and lies within the Deccan volcanic province. The annual precipitation is 780 millimetres with maximum rainfall occurring in month of July. The annual water demand is 15 thousand million cubic feet (TMC) or 424 million cubic metres (MCM) and per capita consumption in the city averages around 205 litres per capita per day (LPCD). The area experiences three seasons - summer, monsoon & winter and usually faces a shortage of water if the monsoon has failed in the previous year.

2.1 Geology and Hydrogeology

The study area is drained by Mula-Mutha, and a small portion of Pavana, all of which are tributaries of Bhima River. The drainage is dendritic, sub-dendritic and sub-parallel. Structural control in the drainage is evident at many places (Figure 2).

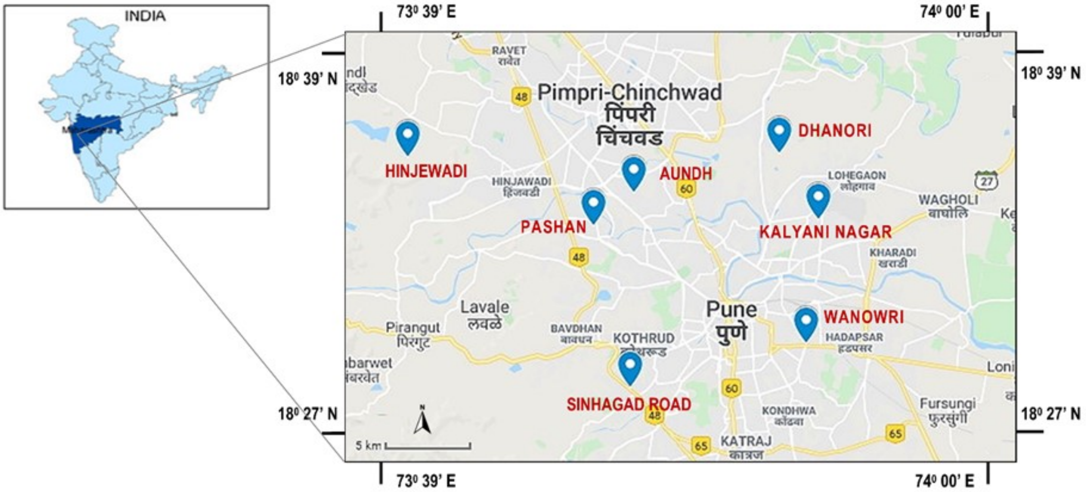

Figure 1: Location map of study area

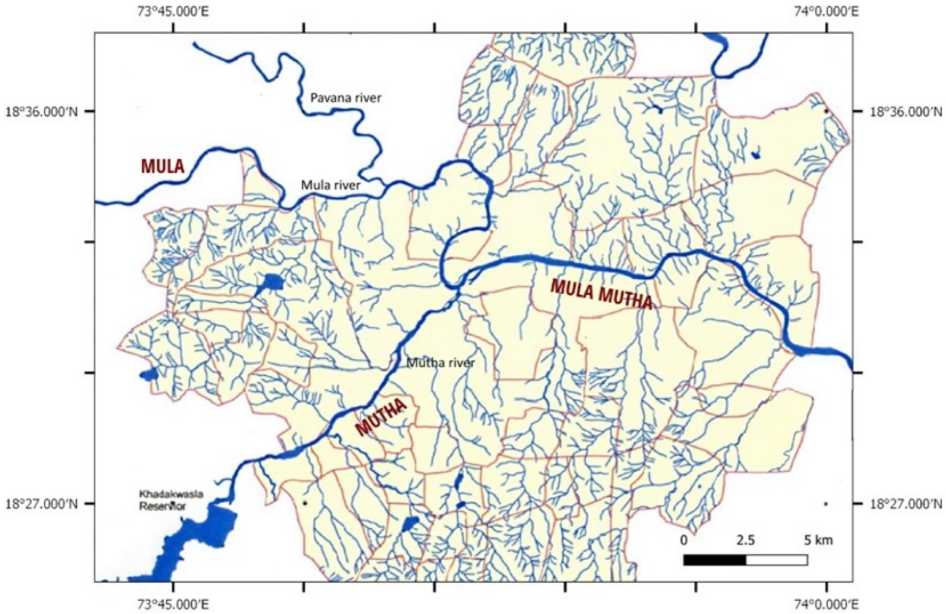

Figure 2: Drainage map of Pune city (Source – PMC)

The area forms part of the Western Deccan Volcanic Province and is underlain by basalts of Upper Cretaceous to Eocene age. The lava flow sequence exposed in the area has been divided into three Formations based on lithostratigraphy: Indrayani, Karla, Diveghat Formations of the Sahyadri Group (Figure 3). The lava flows are broadly classified based on field characteristics into two types: simple and compound flows. The flows belonging to Indrayani, and Diveghat Formations are dominantly of simple nature, while those of Karla Formation are of compound nature. The compound flows are vesicular and amygdaloidal at the top and show moderate degree of weathering at places. The hard and compact middle section is fractured and jointed and their basal sections are characterized by pipe amygdales. The average thickness of each flow is 10 to 20 meters. The simple flows have a fragmented top, a thin brecciated portion (basal clinker) at the base and a compact, massive core which is jointed.

The basalt flows generally exhibit low primary porosity and permeability. The accumulation and transmission of water is a result of the secondary porosity developed due to the presence of openings and cavities, weathering, vertical and horizontal sheet joints and the contact between flows and flow units. In terms of hydrogeological properties, the flows can be classified as vesicular/amygdular basalt (which also includes the flow top breccia (FTB), jointed basalt and massive, compact basalt. The vesicular/amygdular basalt, jointed basalt and weathered basalt have better water holding capacity and behave as aquifers, while the massive, compact basalt acts as aquitard or aquifuge. The tuffaceous clayey layer occurring between the flows acts as an aquiclude. Thus, with an alternating sequence of water bearing zones, the basalt flow sequence acts like a multi aquifer system. The schematic shows the typical internal morphology of a pahoehoe flow (Figure 4).

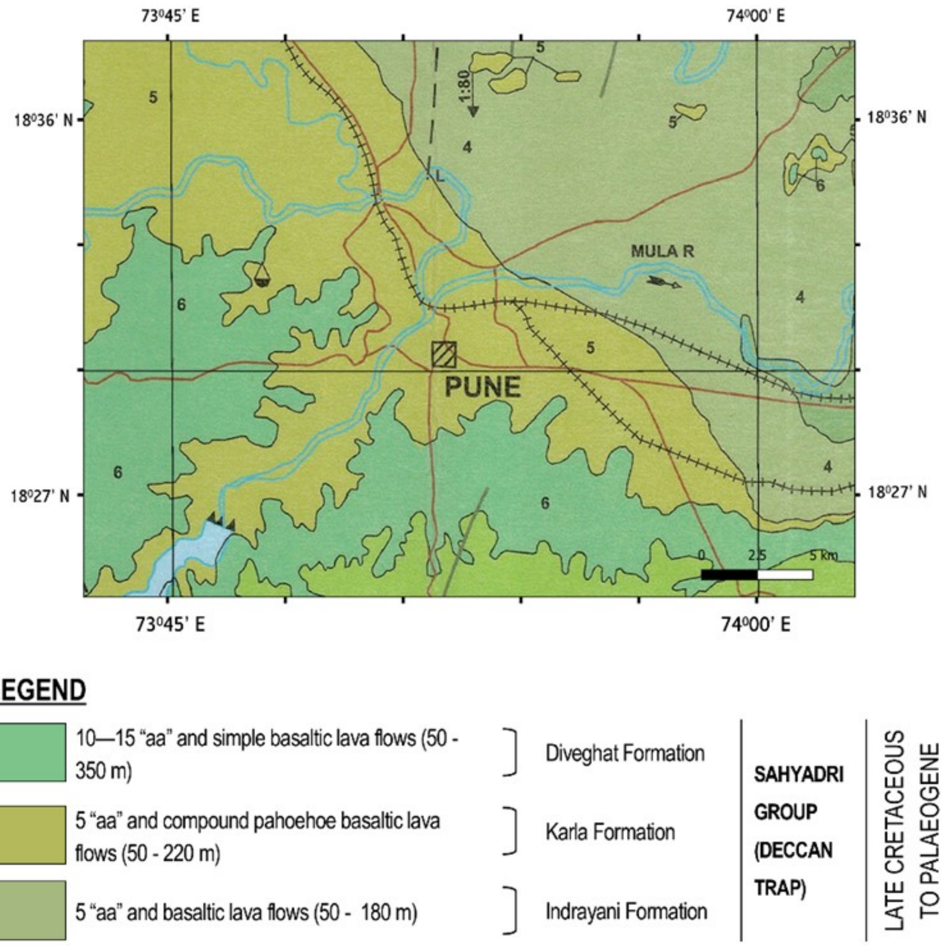

Figure 3: Geological Map of Pune city (Source – District Resource Map (DRM), Geological Survey of India, 2001)

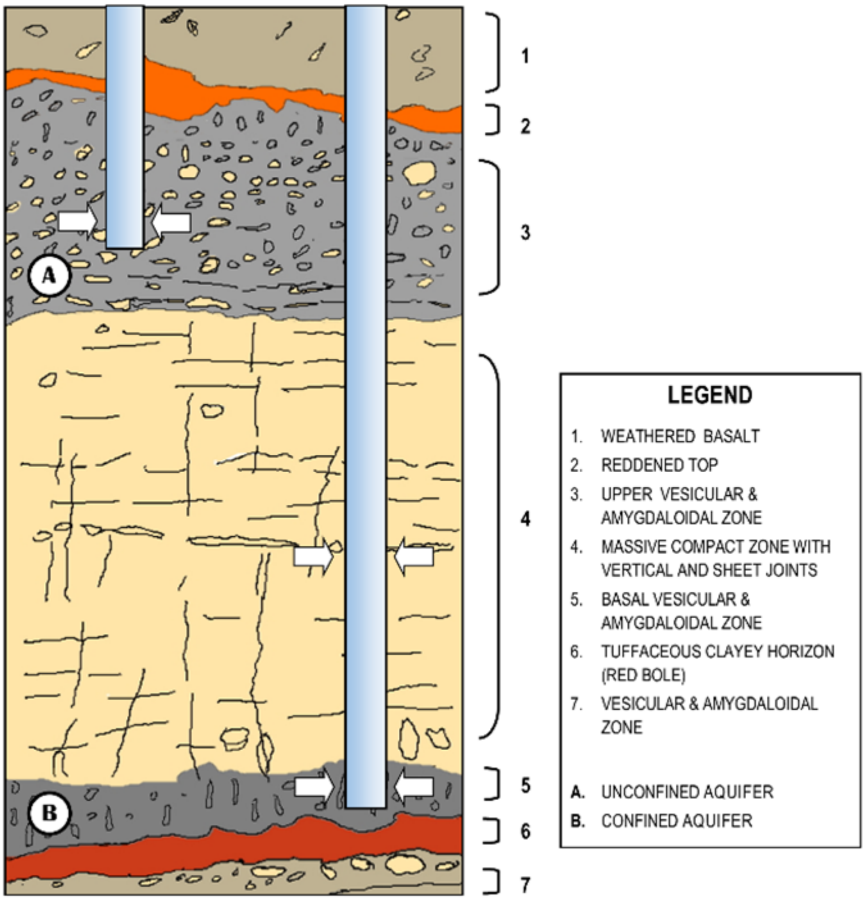

Figure 4: Schematic showing typical internal morphology of a basalt flow

The water bearing capacity of the rock formations is mainly governed by the porosity which determines the volume available for storage of water. Porosity is in turn dependent on the shape, size, arrangement, inter-connection of voids. The movement of water through the interconnected open spaces is governed by hydraulic conductivity. Storativity or the capacity to yield water is the volume of water that will be discharged from an aquifer per unit area of the aquifer and per unit reduction in hydraulic head over a unit area. The circulation of groundwater occurs in the weathered portion, through the vesicular upper sections and through the fractured portions in the massive basalt. The clayey tuffaceous horizons and massive units which lack regular systematic jointing restrict the vertical seepage to the deeper layers. The recharge to deeper horizons generally occurs through deep fractures and fractured dykes. The weathered parts of both vesicular and massive units have better porosity and permeability as compared to the fresh units. The secondary porosity also increases in the lower portion of the flows due to presence of columnar joints, sheet joints and the basal clinkers.

2.2 Groundwater Recharge

Most of India's overexploited groundwater blocks lie in hard-rock settings, where recharge provides only limited relief, and only supplements other measures such as rainwater harvesting (World Bank, 2010). Ground-water recharge is a fundamental component of the water balance of any watershed and determines the availability of groundwater for abstraction. The groundwater balance of an area is usually expressed as:

Groundwater Input – Groundwater Output = Change in Groundwater storage

The input is the recharge from precipitation, other sources, and subsurface inflow. Output refers to the groundwater draft, groundwater evapotranspiration, base flow to streams and subsurface outflow. Most groundwater resources are directly recharged from precipitation through infiltration into the saturated zone thus maintaining the recharge potential of an aquifer.

The National Groundwater Recharge Master Plan for India by the Central Ground Water Board (2005) provides a nationwide assessment of the groundwater recharge potential. The plan estimates that through dedicated recharge structures in rural areas and rooftop water harvesting structures in urban areas a total of 36 billion cubic meters can be added to groundwater recharge, at a cost of approximately US$6 billion. The additional quantity of groundwater amounts to approximately 15 percent of India's total current groundwater use (World Bank, 2010).

Physical measurement of the water balance is difficult and involves time consuming and costly procedures. Numerous methods have been proposed for estimation of natural and artificial recharge of groundwater (Scanlon et al., 2002). The use of a specific tool to estimate recharge depends upon several factors and the availability of spatial and temporal data. The results vary widely with different methods. Scanlon et al., (2002) suggest that techniques which use surface water and unsaturated zone data provide estimates of potential recharge, whereas those that use groundwater data provide an estimate of actual recharge. Due to the uncertainties involved, they further suggest the use of more than one method to get more reliable results. As mentioned earlier, the recharge to groundwater from rainfall has been studied extensively. Many different methods, both empirical and model-based have been suggested. The two most common and simple methods that are used to calculate recharge are 1) Rainfall infiltration factor and 2) Groundwater level fluctuation. Studies carried out by several workers worldwide on the recharge potential of groundwater give different estimates. The key methods for groundwater recharge estimation are numerical models, hydrological budgets, water-table fluctuations, and tracer techniques (Singh et al., 2019). Singh and Kumar (1994) estimated that the recharge by infiltration of rainfall is about 20% of the total rainfall.

Considering the very high levels of construction and concretisation, these figures may not be true for urban areas as most of the rainfall flows away as surface runoff into the drainages and streams. Also, to a large extent the recharge happens in the surface aquifers and very little reaches the deeper aquifers. Recharge by injection is the only method for artificial recharge of confined aquifers or deep-seated aquifers with poorly permeable overburden. The recharge is instantaneous and there are no transit and evaporation losses (Ravichandran et al., 2011). In urban areas, recharge of groundwater normally takes place by two methods 1) Recharge of rainwater by direct infiltration and 2) recharge from waterbodies like lakes, dams percolation tanks. Additionally, in urban areas, recharge also takes place through several other mechanisms like infiltration through storm water drainages, soak ways, leakage through sewage lines and direct infiltration in parks and open areas. Vazquez-Sune et al., (2010) carried out an interesting study to understand the origin of, and the relative contribution of different sources to total recharge. Their analysis carried out on a set of data samples of the Barcelona city aquifers suggests that the main contributors to total recharge are the water supply network losses (22%), the sewage network losses (30%), rainfall, concentrated in the non-urbanized areas (17%), from runoff infiltration (20%), and the Besos River (11%). Further, they state that a large amount of rainfall flows away as run-off due to the impervious surfaces found in cities thereby reducing surface infiltration.

Khalil et al., (2018) studied the estimated average annual areal recharge for the Mae Klong Basin in Thailand. They compared the estimates obtained from using a hydrological simulation model - Water Evaluation and Planning (WEAP) to that obtained from empirical methods. The recharge estimation using the WEAP model was 23.89% of average annual rainfall as compared to 15.63% to 28.07% recharge estimated by empirical methods. Extensive studies have also been carried out to study ground water recharge by the rainwater runoff. These have generally focused on identifying potential sites for surface recharge to the shallow aquifers in non-urban areas. Various methods like agricultural non–point source (Mohammed et al., 2004), water balance approach (Jasrotia et al., 2009), Thiessel polygon (Kim et al., 2003), Soil Conservation Service Curve Number (SCS-CN) (Kadam et al., 2012) have been used to study the rainfall runoff of watersheds and to identify potential sites for groundwater recharge. Geospatial approach and the use of GIS & Remote sensing techniques have been used extensively by researchers to identify potential recharge zones. Use of multi criteria analysis using thematic layers was found to be very useful for assessing potential groundwater zones in Sidhi Area of India (Tiwari et al., 2020). Duraiswami et al., (2009) carried out studies in parts of Pune city, India using a multi-criteria (parameter) approach and found that abandoned quarries occupied by water are good locations for ground water recharge. Based on their studies they proposed the SLUGGER-DQL model to propose suitable sites for groundwater recharge.

Adham et al., (2018) who used a GIS-based approach for identifying potential sites for construction of small dams to harvest rainwater in the Western Desert of Iraq found that success of rainwater harvesting (RWH) systems depends a lot on their technical design and on the identification of suitable sites. Das et al., (2019) delineated the groundwater potential zones of Puruliya district in to three zones using the analytical hierarchy process (AHP) and weighted overlay techniques. Kadhem and Zubari, (2020) used the weighted overlay method (WOA) multi-criteria decision-making (MCDM) methodology to identify optimal managed aquifer recharge (MAR) locations in Bahrain using different parameters like geology, geomorphology, soil type, land use/land cover, slope, etc.

2.3 Rainwater Harvesting

Rainwater harvesting is an age-old practice especially in arid and semi-arid environments to increase the availability of water. In recent times, this practice has been neglected especially in cities where the water is supplied directly to the households. Though, there is still a general lack of awareness in the common citizen and a certain apathy by the local governments towards a systematic approach to managed recharge, the increasing demand for water in urban areas of developing countries has renewed the interest in groundwater and Rainwater harvesting.

Increasing construction activity and the practice of concretising the roads leads to the run-off of the water into the drains with very little water available for infiltration. In such conditions, systematic rainwater harvesting can play an important role in augmenting the local supply of water both in unconfined as well as confined aquifers. Artificial recharge is increasingly being used nowadays to maintain the water balance of an aquifer and is now used globally though still on a very limited scale. Groundwater can be recharged in two ways – naturally and artificially. In natural recharge, the rainwater or surface water percolates or infiltrates into the shallow unconfined aquifers through the weathered and uncovered soil surfaces. On the other hand, in artificial methods, the recharge to the aquifer is done by using simple civil structures which impound the water (WaterAid in Nepal, 2011).

Studies by Jebamalar et al., (2012) on RWH systems in Chennai city located in the southern part of India, indicate that the storage capacity increased from 1.7 MCM in 1999-2000 before the implementation of RWH to 32.77 in 2009-2010 after the implementation of the RWH system. The change in storage was calculated using the GEC-197 norms and water level fluctuation method. Rainwater harvesting depends on annual rainfall patterns, water-retaining capacity, and run-off coefficient of roofs. An extensive green roof can retain up to 55% of the yearly rainfall consequential towards capacities to control the urban stormwater run-off while diminishing urban flooding likelihood (GhaffarianHoseini et al., 2015). The use of Rainwater Harvesting Recharge (RWHR) technique to recharge local aquifers in modern cities has been found to be a cost-efficient method as this saves the need for space and the cost required for building water storage tanks (Nachshon et al., 2016). Rainwater harvesting shows potential as an alternative approach to source water in cities across the world and though many existing RWH systems are focussed solely on the objective of conserving water they can also have other benefits like flood control (Campisano et al., 2017).

Nachshon et al., (2016) in their studies of Tel-Aviv, Israel estimated that for the total surface area of Tel-Aviv and an annual precipitation of 550 mm, the increase in groundwater recharge was in the range of 5.5 MCM which was more than 300% higher when compared to non-RWHR conditions. Major water conservation gains through rainfall-runoff water harvesting from residential building roofs, particularly in residential areas were also reported in Greater Amman and the entire Kingdom of Jordan. A net increase of 2.387 MCM/yr. & 6.229 MCM/yr. were seen for Greater Amman and the Kingdom of Jordan, respectively (Preul, 1994). Small dams originally built for flood control around the Gadarif city in Central Sudan also provide a groundwater resource of 2200 m3/day, which is approximately 12% of the total supply of the city (Ibrahim, 2009).

In a study of Rainwater Harvesting Techniques (RWHT) to alleviate water scarcity in African Drylands, Tamagnone et al., (2020) found that the use of RWHT can lead to a runoff retention of up to 87%. Kadhem and Zubari (2020), in their studies on artificial groundwater recharge by rainfall in the Kingdom of Bahrain suggested that recharge can be made during rainfall extreme events, where relatively large amounts of water become available in a relatively short time by enhancing their infiltration through gravity injection wells into the groundwater aquifers. Based on the 2011 census, and the average annual rainfall for the period 2009-18 the Central Ground Water Board (2020) estimated the total available rainwater from rooftop areas for the state of Maharashtra, India to be 917.87 MCM.

Considering only 50% of the households and other factors like runoff co-efficient and recharge efficiency, the ultimate recharge potential available by rooftop RWH was estimated to be 275.361 MCM.

3. Methodology

The aim of this study was estimating the potential for recharge using rooftop rain water in parts of Pune city using GIS techniques. For this, 68 apartment buildings from seven areas located in different parts of the city were chosen to carry out a representative study of rainwater which is available for recharge. Rooftop areas of the 68 apartment blocks were digitised using the polygon tool in Google Earth Pro (Figure 5). Representative rooftop areas were verified by ground checks and from the management of the societies. The surface areas thus obtained were used to calculate the potential. Comparison of physical measurements for 9 representative buildings with the digitised measurements showed a 95% accuracy for the digitisation. Location and some other attributes of 132 wells (bore and dug) were also obtained from across the city to understand the population of wells that are being used for abstraction and those being used for recharge from the precipitation.

Urbanization of Pune area has been rapid mainly due to its proximity to Mumbai. This has affected the land use and the landscape and consequently affected the quantity and quality of surface and groundwater. To understand the present and projected demand for water in the city, the population data was obtained from the Pune Municipal Corporation (PMC). LULC analysis for the period 2003 to 2019 was also carried out at four-year intervals, to recognize the changes in land use patterns. In this exercise, the city was classified into four land cover classes namely: Barren, Water, Built-up and Vegetation cover. To obtain the results, ground truth measurements from 122 different locations across Pune city were used along with geometrically referenced and atmospherically corrected satellite imagery downloaded from NASA's (National Aeronautics and Space Administration) open-access web portal (https://earthexplorer.usgs.gov/).

The data obtained from the various analysis was used for further quantification of the amount of water available from rooftops across the city.

3.1 Recharge Techniques

As discussed above, surface infiltration and recharge vary greatly and is generally limited to the unconfined aquifers. Increased urbanisation and migration to cities has led to increased construction and consequently concretising of once green areas leaving less area for natural infiltration. In hard rock area like basalts, digging wells or pits is not enough to recharge the confined aquifers. In such cases, a conduit (usually a dug well or bore well) is required to channelize the harvested rain water for recharging the aquifer.

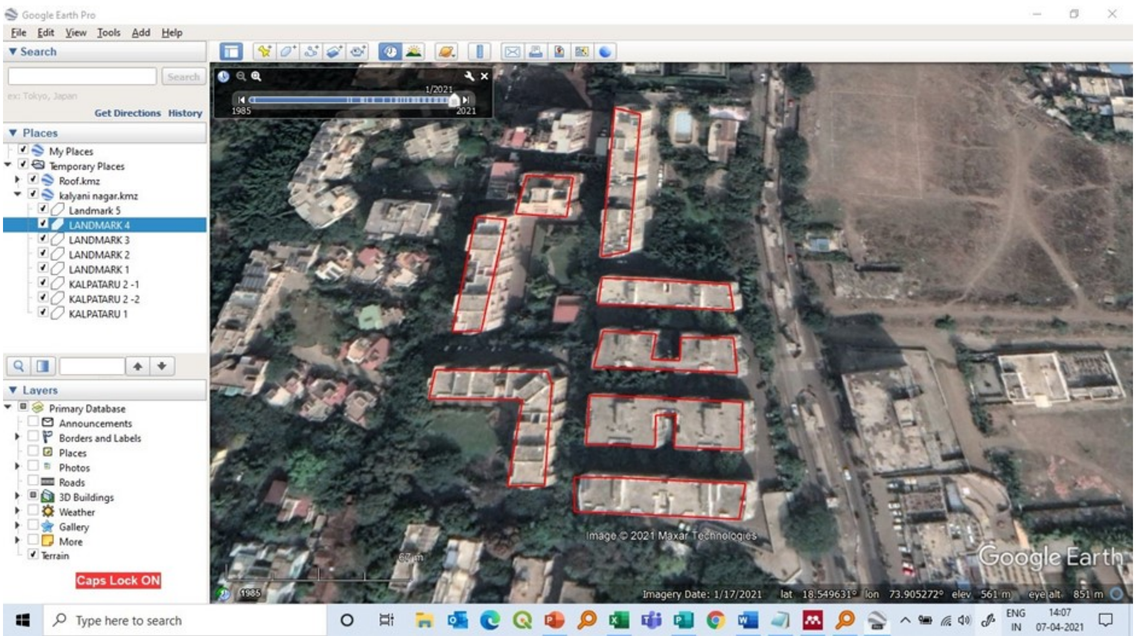

Figure 5: Digitisation of rooftops using Google Earth Pro

An effective method which can be adopted is to use existing boreholes for recharge. In this study, two methods – 1) Pit based, and 2) PVC cylinder-based filters were implemented for recharge of the deep aquifers in area of study. These are described below.

A pit-based system is essentially a square or a circular pit containing layers of three sizes of sand and a layer of charcoal for filtering the rooftop run off before it enters the well, was built, and tested. In this study, a square pit of 2 m x 2 m x 2.6 m was dug around an existing borewell with the casing at the centre of the pit. At the bottom of the pit, holes were drilled in the casing pipe and a nylon mesh was wound around the pipe. Different layers of filtering material as indicated in the diagram were laid (Figures 6 and 7). Water which falls into the pit is filtered through this four-stage filtration system before it enters the bore through the openings in the casing pipe. The advantage of this system is that it can filter large volumes of water, especially in storm like situation. However, the cost of construction and work involved in the regular maintenance prevents individuals and housing colonies from using this method.

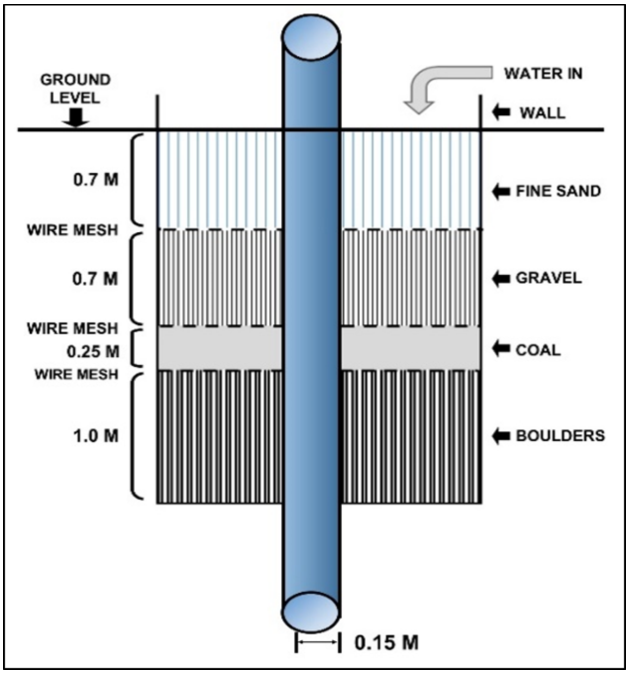

Figure 6: Schematic of recharge pit

Figure 7: Bare pit for recharge purposes

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The cylindrical PVC filter was constructed from locally available plumbing material of standard sizes. The filter uses traditional principle of three/four stage of filtration of water and uses locally available sand as the medium. It contains three different sizes of sand/gravel to filter the water before it is let into the borewells (Figures 8 and 9).

One challenge however is the periodic cleaning of the filter as it requires either a complete removal of the sand or backflushing under pressure. To overcome the above challenges, a PVC filter (Figuers 10 and 11) using stainless steel mesh as the filtering medium was designed and built. The construction is simple and consists of a PVC pipe of 100 mm diameter with the stainless-steel filter mesh wrapped around it. This barrel with the stainless-steel filter mesh is enclosed within a larger diameter 150 mm PVC pipe. The water coming in from the rooftops passes through the inner pipe during which leaves, and other debris are screened out and the filtered water passes into the outer cylinder. From here it is channelized to the bore-well for recharge. Quality of the water is maintained by installing a drain plate on the roof and using a first flush system to drain out the first rain water of the season. This filter was found to be very cost-effective as it costs much lesser than the sand filter. The prototype was constructed for less than 3500 Indian rupees (around 50USD). With mass production the cost of the filter can be brought down further. In addition to its cost-effectiveness, the filter is light weight, easy to assemble and most importantly the cleaning of the filter can be done easily using a back flush method. The life of the filter is dependent on the grade of the PVC pipe which is used and is estimated to be around 15 years. The filter shown in Figure 9 which used similar grade PVC pipe was installed in 2012. The life of the filter will be much more if it is shielded from direct sunlight.

3.2 Recharge Potential

Recharge Potential of rooftop rainwater harvesting is the capacity of a particular roof to harness the water that falls on it in a particular year covering all rainy days. The annual yield of water or the recharge potential is the product of the roof type, the total area, and the annual precipitation in that area. In India, a major part of the rainfall is received during monsoons. The southwest monsoon reaches India in June and extends normally up to September. The northeast monsoon extends from October to December. Pune is in the Western part of India and receives rainfall only from June to September.

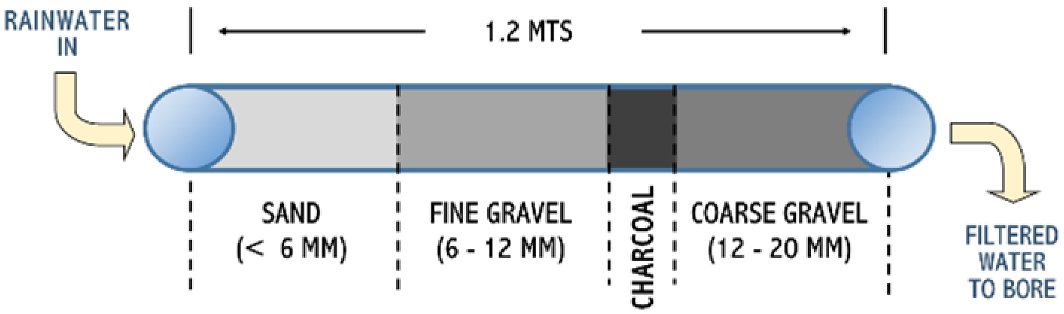

Figure 8: Schematic of PVC cylinder-based filter (Diameter of pipe is 150 MM)

Figure 9: Installed PVC barrel-based sand filter.

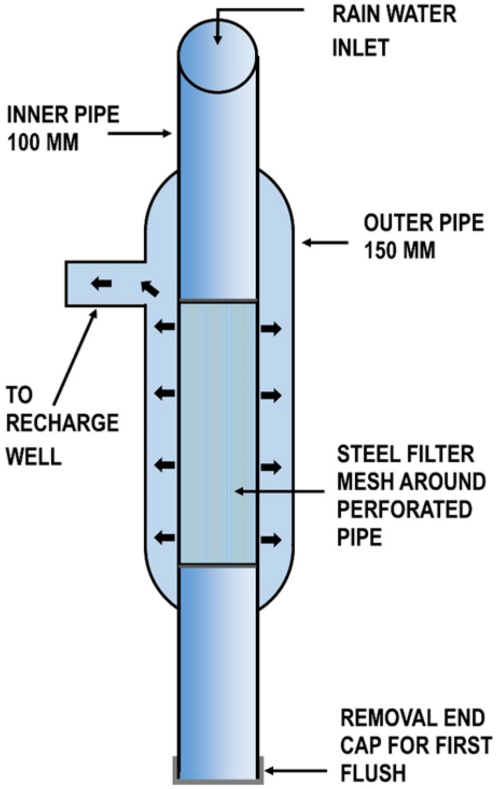

Figure 10: Schematic of stainless-steel mesh-based PVC filter

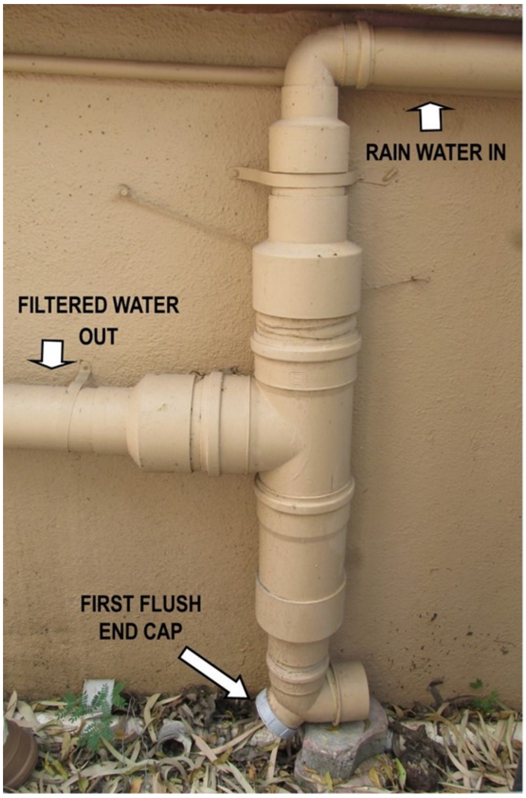

Figure 11: Installed stainless-steel mesh-based PVC filter

The recharge potential of rooftop rainwater harvesting in seven representative areas of Pune city was calculated using the formula given by Gould (2015) and a co-efficient of 0.80 (concrete roofs) as proposed by Pacey et al., (1986)

$$S = R*A*Cr \quad \text{Eqaution 1}$$

Where:
S = Potential of roof rainwater harvesting (in litres.)
R = Average annual rainfall in mm.
A = Roof area in Sq. m. Cr = Coefficient of Run-off

4. Results

The recharges estimates obtained by using the above-mentioned formula and other parameters are summarized in Table 1. The analysis shows that a large amount of water varying between 18812 and 1129 cubic metres are available depending on the size of the rooftop area. The total availability of water for the 68 buildings (65,552 sq. mts.) was estimated to be 40904 Cubic metres. The unit availability of water from rooftop run off for recharge is 624 litres or 0.624 cubic metres per square meter. Analysis of the 132 wells (bore and dug) indicates that 124 (95%) wells are perennial and are being used for abstraction especially in summer months. The rest are either seasonal or dry and do not yield water. Of the yielding wells, only 22 (18%) are presently being used for rooftop rainwater harvesting. This indicates that there is a large scope for rooftop rainwater harvesting using direct injection technique for recharge. From the LULC analysis, it can be observed that, there has been a steady decrease in barren land and an equally uniform increase in built-up area since 2003 (Figures 12 and 13). Furthermore, vegetation cover has decreased at the borders of Pune city. It can be observed that most of these are agricultural lands that have been either cleared or converted to barren and built-up areas. However, the vegetation cover at the heart of the city has seen moderate to very little change since 2003. The prominent water bodies continue to remain unchanged throughout the time frame. Further, data obtained from Pune Municipal Corporation shows the population of Pune city has increased from 1.2 million in 1981 to 3.31 million in 2011 (Table 2) and is projected to rise to 6.09 million in 2031, (Pune Municipal Corporation, 2012).

Table 1: Summary of results of estimation of annual recharge potential

S. No	Location	Number of Buildings	Roof Area SQ. M (A)	(S =R*A*Cr) Runoff (litres) (Q)	(S =R*A*Cr) Runoff (Cu. Mts.)	Runoff in Million Cubic metres (MCM)
1	Hinjewadi	23	30149.00	18812976.00	**18812.98**	**0.019**
2	Aundh	9	2846.31	1776097.44	**1776.10**	**0.002**
3	Kalyani Nagar	8	6924.00	4320576.00	**4320.58**	**0.004**
4	Dhanori	13	15976.00	9969024.00	**9969.02**	**0.010**
5	Wanowri	4	1810.00	1129440.00	**1129.44**	**0.001**
6	Sinhagad Road	4	5253.00	3277872.00	**3277.87**	**0.003**
7	Pashan	7	2594.00	1618656.00	**1618.66**	**0.002**
	TOTAL	**68.00**	**65,552.31**	**40904641.44**	**40904.64**	**0.04**

* Annual Precipitation (**R**) is 780 MM & Co-efficient of Run-off (**Cr**) is 0.8.

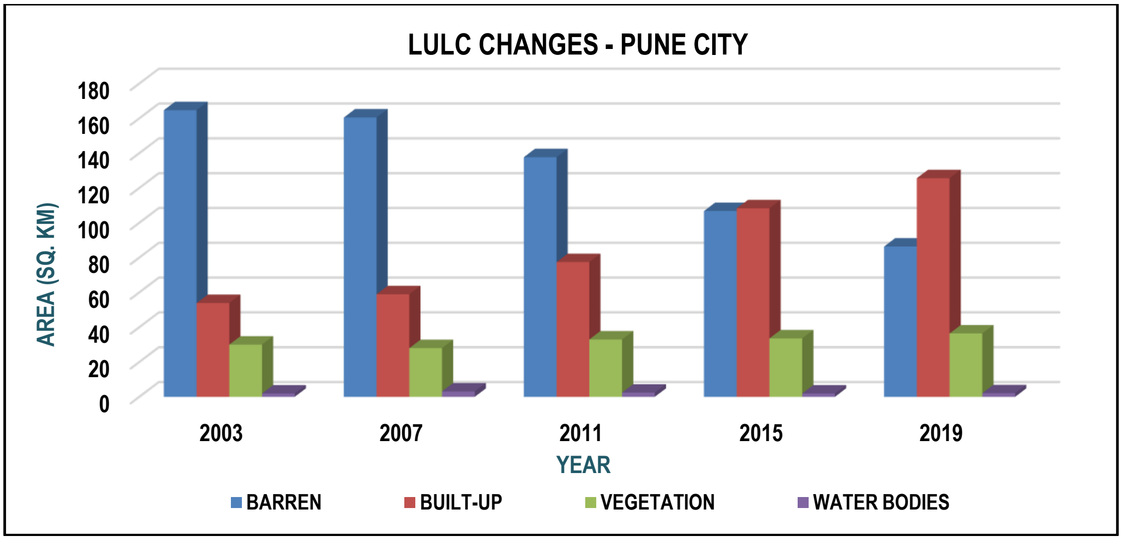

Figure 12: Graph showing LULC changes of Pune city from 2003 to 2019

Table 2: Population data for Pune City

	CENSUS – ACTUAL							PROJECTED		
YEAR	**1951**	**1961**	**1971**	**1981**	**1991**	**2001**	**2011**	**2021**	**2031**	**2041**
POPULATION	4,88,419	6,06,777	8,56,105	12,03,363	16,91,430	25,38,473	31,15,431	43,70,721	60,09,860	82,64,102
DECADAL GROWTH (%)	-	24.23	41.09	40.56	40.56	50.06	22.73	40.29	37.50	37.51

Source - Census of India, Provisional census and VSPL projections PMC, 2012

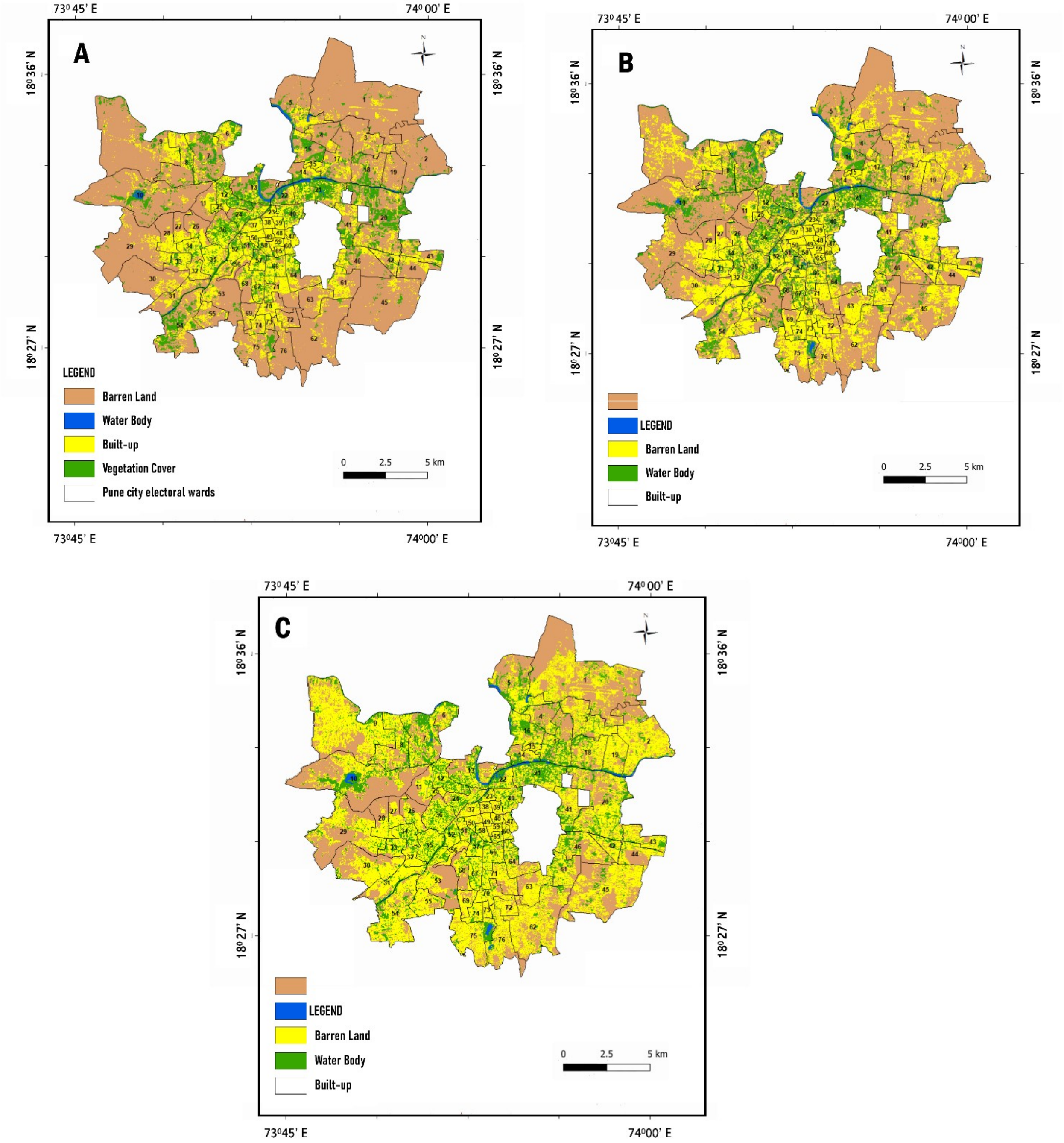

Figure 13: LULC Maps for 2003 (A), 2011 (B) & 2019 (C) of Pune city

5. Discussion

Groundwater recharge processes in urban areas are different from those in non-urban areas. Increasing construction activity and the practice of concretising the roads leads to the run-off of the water into the drains with very little water available for infiltration. In such conditions, systematic rainwater harvesting, or managed recharge can play an important role in augmenting the local supply of water, both from unconfined as well as confined aquifers. In the Pune Metropolitan region, the water level during post monsoon in urban area is shallow (< 3 Meters below ground level) and therefore augmenting of ground water at shallow depths is not feasible (Paranjape and Pawar, 2006).

As such it becomes important to gauge the potential for recharge of deeper aquifers. Understanding the potential for Rainwater harvesting (RWH) using the rooftops and existing wells is the first step in fulfilling a social need to increase availability of potable water. The total availability of water for recharge from the rooftops in the study area was estimated to be 40904 Cubic metres. The chosen buildings had a total rooftop area of 65,552 sq. mts.

From the LULC analysis results it can be observed that, there has been a steady decrease in barren land and an equally uniform increase in built-up area since 2003. Based on the LULC analysis the total built-up area in Pune has increased from 50.87 Sq. kms in 2003 to 126 Sq. kms in 2019 (Figure 7). Furthermore, vegetation cover has decreased at the borders of Pune city. It can be observed that most of these are agricultural lands that have been either cleared or converted to barren and built-up areas. The total built up area for the city as obtained from LULC analysis is about 126 sq. kms. During the period 1990-2014. 21% of the built-up area in Pune is occupied by roads (Angel et.al, 2016), Taking this figure into account, a total surface area of 99.5 Sq. kms of rooftop area is available for rainwater harvesting. The estimated groundwater availability for Pune city in 2007-08 as per Groundwater Survey and Development Agency (GSDA), Maharashtra was 34 million cubic meters (MCM) while annual use by city was estimated as 24 MCM (SANDRP, 2016). Considering the projected increase in population by about 1.3 million between 2011 & 2021, the annual use can be estimated to have increased by about 9 MCM to 33 MCM. As per the present study, the total water availability in a year works out to approximately 49.05 million cubic metres (MCM) or 1.73 TMC (Thousand million cubic feet or billion cubic feet) considering unit run-off of 624 litres per square metre, and rooftop surface area of 99.5 sq. kms. On a conservative estimate, even if half of this total rainwater is harvested, the recharge can supplement the groundwater annually by about 22 - 25 MCM (0.7 to 0.88 TMC) and can cater to nearly 70 % of the annual groundwater requirement of the Pune city.

6. Conclusion

The analysis from the present study which is a part of the larger study to systematically study and understand the recharge potential from rooftop rainwater harvesting for Pune city highlights the fact that that rooftop rainwater harvesting through direct injection using low-cost filtration techniques & clean filter mechanisms can become a viable and low-cost method to harness the rainwater, especially during the monsoon months and storm events when large amounts of runoff become available in a short period of time.

To ensure proper balance of groundwater and use it as an alternative source of supply, the authorities need to look at the twin aspects of lowering ground water abstraction and more importantly augmenting groundwater storage by a systematic or managed aquifer recharge (MAR). Systematic recharge can be done by gravity injection through existing groundwater wells. This will not only augment the capacity but also have the added benefit of flood mitigation during storm events.

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