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Research Article

Assessment of roof water harvesting potential of Navsari city of Gujarat State, India by Remote sensing and Geographic information system (GIS)

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Abstract
Due to the water scarcity scenario in many parts of the Navsari city, Gujarat State in India, it is imperative to adopt cost-effective technologies that could harvest rainwater for satisfying drinking water requirements. The study was conducted with the aim of assessing the rainwater harvesting potential of Navsari city using remote sensing and Geographic Information System (GIS). The built-up areas of Navsari that could harness rainwater were identified by remote sensing and GIS. The effective built-up area contributing to rainwater harvesting was found to be 3.37 km^2. The classification was carried out using "Remap" to assess the extent of the built-up area. The city was divided into equal grids and classification of each grid was implemented. The ground truth data was used for the evaluation of the built-up area. The roof water harvesting potential was estimated considering the average annual rainfall of 1621 mm and adopting suitable runoff coefficients. The rainwater harvesting potential of roofs for rainfall of different probabilities was estimated. For return periods of 10 years, 25 years, 50 years and 100 years, the roof water harvesting potentials were estimated to be 0.226, 0.261, 0.287 and 0.312 Million Cubic Metres (MCM), respectively. The estimated average roof water harvesting potential of Navsari city was 164 million litres per year, capable of satisfying the drinking water demand of approximately 1.12 lakh people annually. The rainwater harnessed from the rooftop could augment the current water supply and immensely help in fulfilling the drinking water demand of Navsari.

Keywords: Geographic information system, Rainwater harvesting, Roof water harvesting structure, Remote sensing, Water

INTRODUCTION

India shares 17% of the world population but 4% of its geographical area and 2.5% of water resources (Black, 2016). India has nearly 33% of its geographical area in the semiarid and arid category. Further out of its total arable area, nearly 60% is rainfed without the benefits of surface water irrigation. The importance of groundwater recharge in arid and semi-arid regions is very important particularly as most of the population residing in these regions depend on groundwater for drinking and irrigation purposes. These areas are reeling under recurrent droughts chronically suffer from acute drinking water scarcity and miserable state of hygiene due to poor sanitation. With surface water in short supply, these areas are mainly dependent on groundwater which is, therefore, under severe strain (Das, 2019). Freshwater availability in several river basins of India is likely to decrease owing to climate change (Gosain*et al.*, 2006). The paving of pervious surfaces with roads, shopping centres and driveways ultimately lead to the reduction of infiltration into the ground and increase in surface runoff. As a consequence of the incessant growth of buildings and other urban development works, the natural terrain is replaced by almost impermeable surfaces. Almost 80% of the runoff from the built surfaces flows to the waste-water disposal system or rivers and only 20% infiltrates into the soil causing ecological damage (Markovi*et al.*, 2014) .In such scenarios, the collection and storage of rainwater to supplement existing water supply sources should be implemented. The utilization of rainwater is one of the best methods that can aid in sustainable urban development (Kim *et al.*, 2005). The rainwater collection and its utilization to satisfy the demand for arid and semi-arid regions that cannot cope with the needs of potable water apparently seem to be the only option as rainwater in most cases is the purest water source contains very low impurities. It is necessary to adopt rainwater harvesting methods in places where the conventional water supply has failed to meet the peak period demand of the people for drinking water. Rainwater harvesting is one of the most economical and practical methods to provide supplementary water supplies for drinking purposes. Also, if the drinking water supply by the rainwater harvesting structure is sufficient, then the supplementary water can be used for domestic purposes. The only cost-effective solution to minimize the demand-supply gap by augmenting the existing water supply seems to be rainwater harvesting (Shrivastava *et al.*, 2019).

Roof water harvesting is a process of collecting runoff occurring due to rainfall from the impermeable terrace on top of the house and conserving it in a tank (Durodolo*et al.*, 2020). This method is comparatively easier and reliable and provides good quality water for drinking. The collected rainwater can either be used as the principal or as a supplementary source of water. Rainwater harvesting from building rooftops and parking lots could provide a source for drinking water after proper treatment (Abdulla and Alshareef, 2009). The quality of the harvested rainwater improves with roof flushing as the rainfall events progress which indicates the importance of flushing diverted used in rainwater harvesting systems (Mendez *et al.*, 2011). The hardness of rainwater is zero, which eliminates the requirement of a sophisticated water treatment process (Jythiprakash and Sahte, 2009).

Roof water harvesting is a proven approach towards conserving water effectively and economically. Roof water harvesting should be recommended for potable water requirements in areas suffering from water scarcity after monsoon and if reliable measures are taken, water quality remains acceptable (Shrivastava *et al.,* 2019). The roof water harvesting method has been used since ancient times for providing water for drinking during water shortage. The roof water harvesting concept varies from small and basic, such as attachment of a pipe draining into an underground tank, to large and complex, such as those to collect water from many hectares serving a large number of people. Roof water harvesting was mostly used in areas that lacked alternative water supply forms such as coral islands (Datr *et al.,* 2006; Devi *et al.,*2005) and arid remote locations devoid of suitable surface or groundwater resources (Tripathi and Pandey, 2005).In India, in the year 2011, the average annual per capita water availability was estimated to be 1,545 m^3. When the annual water availability per capita is less than 1700 m^3, the condition falls under water-stressed category whereas annual per capita water availability below 1,000 $m^3$is considered as a water scarcity condition (Intended Nationally Determined Contributions Report, 2015). Ponds and pans, dams, terracing, percolation tanks, and Nala bunds are the most common types of rainwater harvesting techniques in arid and semi-arid regions (Oweis et al., 2012).The rooftop rainwater harvesting is a cost-effective method and popular owing to its simplicity (Iqbal *et al.*2015).

Lade and Oloke (2013) assessed the rainwater harvesting potential in Ibadan, Nigeria by hydrological analysis using rainfall data for 30 years from two meteorological stations, with the aim of providing a more sustainable water supply. It was found that rooftop water harvesting is technically feasible considering the current rainfall pattern, with over 90% of households having a rooftop constructed from technically appropriate materials. Results of the study indicated that an average roof of 80 m^2 collected 82,835 litre/yr (45 litre/person/day) for a family of five people, which was about the required water demand for drinking and cooking purposes. Ganguly*et al*. (2014) studied the prospects and possibilities of rainwater harvesting in the Shimla region of Himachal Pradesh, which experienced water shortages in summer periods due to increase in population and climatic conditions. The result of their study showed that rain water can be stored throughout the year without incurring any significant losses. It was revealed that around 30% of the water requirement could be met by the harvested rainwater. Panigrahi (2017) conducted a study aiming to develop awareness towards judicious use of water among masses and efficient ways to harvest roof top rain water resources at institutional / multi-storeyed buildings in the Malda district of West Bengal. It was reported that Malda district had a huge potential for rooftop rainwater harvesting. Mohanty *et al.* (2018) conducted a study of roof water harvesting structures in Marijita village of Jagatsinghpur district, Odisha. The total water demand for the selected household was about 185400 litres, out of which 5400 litres of water was used for drinking purpose considering 3 litres of water per person per day, while 180000 litres of water required for other users with 100 litres per person per day. The rooftop water harvesting system provided 148320 litres of water for the household.

Rainwater harvesting through rooftops is an appropriate method of water conservation and Indian government has mounted this as a part of watershed management programme. With the changing climate, high-intensity rains with fewer rainy days or uneven distribution of rainfall both spatially and temporally result in instant flooding and runoff. Moreover, due to the removal of vegetative cover and denuding forests and concretisation, rainwater does not get sufficient time to recharge groundwater aquifers, resulting in water scarcity immediately after the monsoon. The present study was conducted to assess the roof water harvesting potential of Navsari by estimating the roof area using remote sensing and geographic information system (GIS).

MATERIALS AND METHODS

The study was conducted in Navsari city (20.9467° N and 72.9520° E) situated in the Navsari district of South Gujarat was selected as the study area. It is the 9th biggest municipal corporation of Gujarat. The city is located at an elevation of 9 m from the mean sea level. According to the 2011 census, the population of Navsari city was 1.71 lakh. The average annual rainfall of Navsari is 1621 mm. The current population of Navsari city may have surpassed 2 lakh.

In this study, the roof water harvesting potential of Navsari city has been assessed using remote sensing, GIS and ground truth data. Rainfall endowment of the area is the total quantity of water obtained due to rainfall from a particular area and rainwater harvesting potential is the total rainwater amount that can be harvested effectively.

$$V = A \times R \times C \quad \text{..........Eq.1}$$

where,

V = Volume of water received (m^3)

A = Area of catchment (m^2)

R = Rainfall depth (m)

C = Runoff coefficient

In order to assess the rooftop rainwater harvesting potential, it is essential to have information about the mean rainfall depth in which the rainwater harvesting system is to be adopted. The data about average rainfall can be obtained from the local weather stations. In this study, the rainfall data was provided by the Department of Agro-Meteorology of Navsari Agricultural University, located in the city of Navsari. The catchment characteristics should be analysed so that the amount of runoff generated for a given amount of rainfall can be estimated. The catchment also determines the quality of rainwater that is harvested. If contaminants are present in the catchment, then the catchment should not be used for rooftop rainwater harvesting. The runoff coefficient indicates the amount of runoff that will be generated on account of the rainfall.

The type of the catchment and the area of the catchment over which the rainfall occurs, determine the quantity of runoff. The roof catchment with tiles allows maximum runoff to the extent of about 85 %, whereas rooftop catchments with brick material obstructs runoff to a certain extent and generate runoff which is only up to 60 % of the total rainfall occurring over the roof catchment (Pacey and Cullins, 1989). To obtain the volume of the rain water harvested, the depth of rainfall was multiplied by the catchment area. Roof foot print is the actual roof area that is used for calculating the volume of water. For plane horizontal rectangular or other shape roofs, roof foot print was same as the roof and thus effective area was same. The runoff coefficient is defined simply as the ratio of design runoff to design rainfall (Şen, and Altunkaynak, 2006). Runoff volume from 53 buildings were calculated and compared with the rainfall volume to obtain the average runoff coefficient.

The runoff volume from the building terraces was analysed corresponding to daily rainfall data. The average runoff coefficient was calculated by dividing the total runoff volume by rainfall volume. The building terraces were chosen based on the type of catchment. The average runoff coefficient was then used in the estimation of roof water harvesting potential. It was found thatthe runoff coefficient for roof varies with the type of roof, area of the roof, slope, degree of imperviousness and surface roughness. The runoff coefficients for various rooftops are provided in Table 1. More than 90 % of the houses and buildings in Navsari had roof made up of tiles or concrete and the slope towards the drainage was found to be mild.

The city was divided into 35 grids of equal dimensions and “Remap software” was used for land use/land cover classification of each grid in which classes such as roads, barren land, built-up area, agriculture land, ponds etc. were differentiated. Remap uses advanced remote sensing methods and the Google Earth engine to access the satellite data directly. In order to achieve the lowest error rate and highest classification accuracy, it was ensured that the training points were sufficient in number (>20) and accurately located for each class. The error rate corresponds to the percentage of all training points incorrectly classified by the model (Murray *et al.,* 2018).

The city has been continuously expanding due to the increasing population and increasing number of houses in the outskirts of the city. The satellite image of October 2020 was used to assess the roof area of the city. The city area of 17.5 km^2 was selected as it had the

Table 1. Runoff coefficients for various rooftops (Source: Pacey and Cullins, 1989)

Type of catchment	Coefficients
Tiles	0.8-0.9
Corrugated metal sheets	0.7-0.9
Concrete	0.6-0.8
Brick pavement	0.5-0.6

major potential for rainwater harvesting and the area of each grid was 0.5 km^2. The land use classification was carried out for individual grids and they were also checked with the ground truth data by using the latitudes and longitudes of the locations. A GPS meter was used to obtain the latitudes and longitudes of various locations. The grids were assigned numbers from 1 to 35 and the software was trained separately for each grid to minimize error in land use classification. The class of interest was the built-up area which included commercial and residential buildings, bungalows and small houses with roof area for water harvesting. In addition to that, ground-truthing was also carried out to analyse the areas capable of rooftop rain water harvesting. Ground truth refers to the information that is collected from the location. The information about the roof area and the feasibility of collecting rainwater for storage was obtained through ground truth. In the parking area and the surrounding open area, there was the possibility of storing around 5% of the total runoff generated through rainfall on the roof, considering the cost and the area available. A building with 461 m^2 roof area generated 597825 litres which will require a costly tank with dimensions in excess of the available area. It was feasible to construct an economic tank with 3.2 m length, 3.2 m width, and 3 m depth that can be cleaned easily. This tank had a storage capacity of 30720 litres, approximately 5 % of the total rainwater available from the roof.

The annual rainfall at various recurrence intervals was obtained using the Weibull'sprobability plotting formula using the rainfall data of 35 years (1984-2018). The annual rainfall data was arranged in descending order and rank was assigned from lowest to highest.. The following formula was used to obtain the exceedance probability of rainfall (Raghunath, 2006).

$$P(x \geq X) = \frac{m}{n+1}$$

where,
m = Rank of the event,
n = Number of events
P (x≥X) =Probability of Exceedence

Recurrence interval was then obtained by taking the reciprocal of probability (Raghunath, 2006). The roof water harvesting for recurrence intervals of 2, 5, 10, 25, 50 and 100 years were then estimated using the same methodology described above.

RESULTS AND DISCUSSION

The satellite image of Navsari divided into 35 equal grids of 0.5 $km^2$is shown in Fig 1. An example of land use classification of Grid 10 is given in Fig. 2. The land use classification of the remaining grids is shown in Fig. 3.

The land use classification of Navsari city is presented in Table 2. In the present study, the compound area and other adjoining areas are also included in the 5.62 km^2 of built-up area. The observations indicated that the roof area was approximately 60 % of the built-up area and therefore, the roof area was taken as 3.37 km^2.In most cases, the observed runoff from the roof-was found to be around 65% of the total rainfall and therefore, the runoff coefficient considered for concrete roof was taken as 0.60. The variation of rainfall depth at various probabilities and the average rainfall depth for

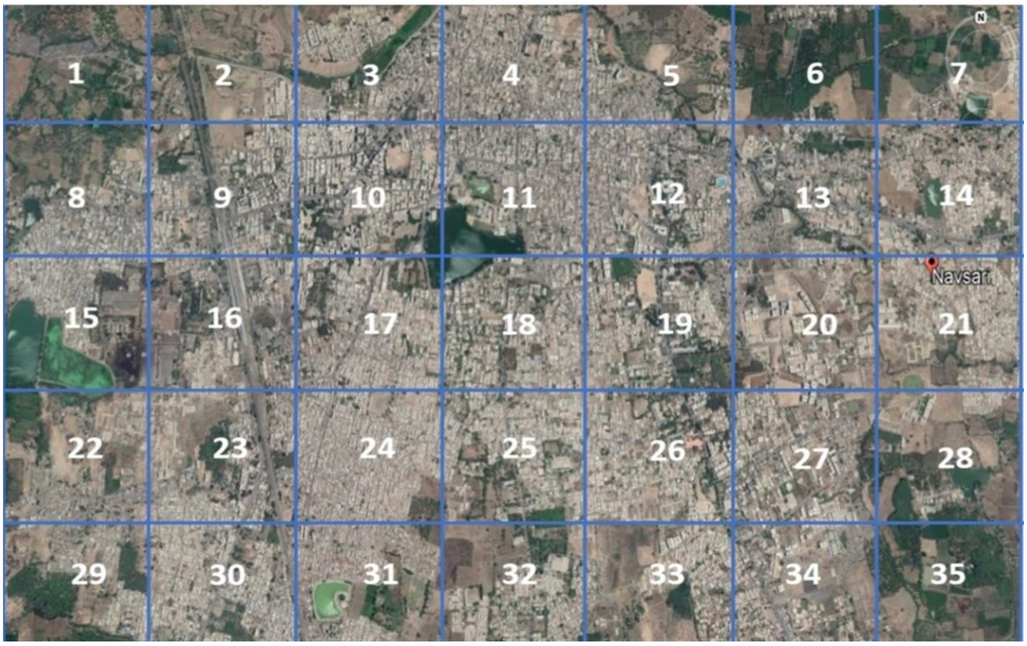

Fig. 1.*Satellite image of Navsari city (27/10/2020)*

Table 2. Land use/land cover classification of Navsari city

Sr. No.	Land use / Land cover	Area (km^2)	Percentage Cover
1	Water bodies	0.28	2
2	Barren land	6.65	38
3	Roads	1.20	7
4	Trees/ Agriculture	3.75	21
5	Built up	5.62	32
	Total Area	17.50	100

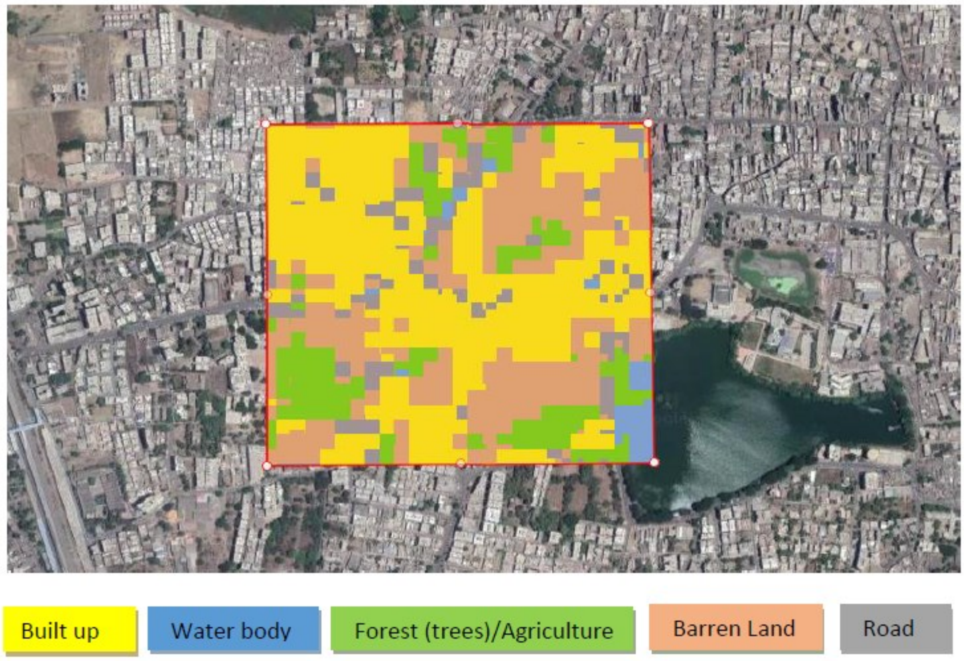

Fig. 2. *Land use / land cover classification of Grid 10 of Navsari city*

various recurrence intervals are shown in Fig. 4 and Fig. 5, respectively. The amount of rainwater that could be obtained from the rooftop was found to be 3280 million litres per year, considering average rainfall of 1621 mm. However, it will not be possible to store all the available water obtained from rooftop in all the houses and buildings, as it requires provision for an underground tank in the vicinity or in the basement of the residential area. The estimated roof water harvesting potential for the average rainfall depth is given in Table 3. The roof water harvesting potential corresponding to different rainfall depths is presented in Table 4 and Fig.6. From the ground truth data, it was observed that only 5 %of the available roof water could be stored and therefore, the estimated roof water harvesting potential was found to be 0.164 MCM. The main factors that affected the available roof water were the cost of the storage tank and the area required for the storage tank.

An average person requires approximately 4 litres of drinking water per day and therefore approximately 1460 litres of drinking water per year (WHO, 2015). The estimated amount of 164 million litres for an average annual rainfall is capable of satisfying the drinking water requirements of approximately 1.12lakh people, which is around 65.6 % of the total population of Navsari. The additional amount of water could be used for small scale irrigation and domestic purposes. However, if the water is to be used for drinking, reliable commercial filter of adequate capacity should be installed along the pipeline or a filter using appropriate media should be built underground before the water is stored in the tank. In case sufficient space is not available for an underground tank, the pipes carrying water from the roofs of several houses can be connected for

Table 3. Estimated roof water harvesting potential for average rainfall depth

Roof area	3.37 km^2
Average Annual Rainfall	1621 mm
Runoff coefficient	0.6
Available roof water	3.28 MCM
Roof water harvesting potential (5%)	0.164 MCM

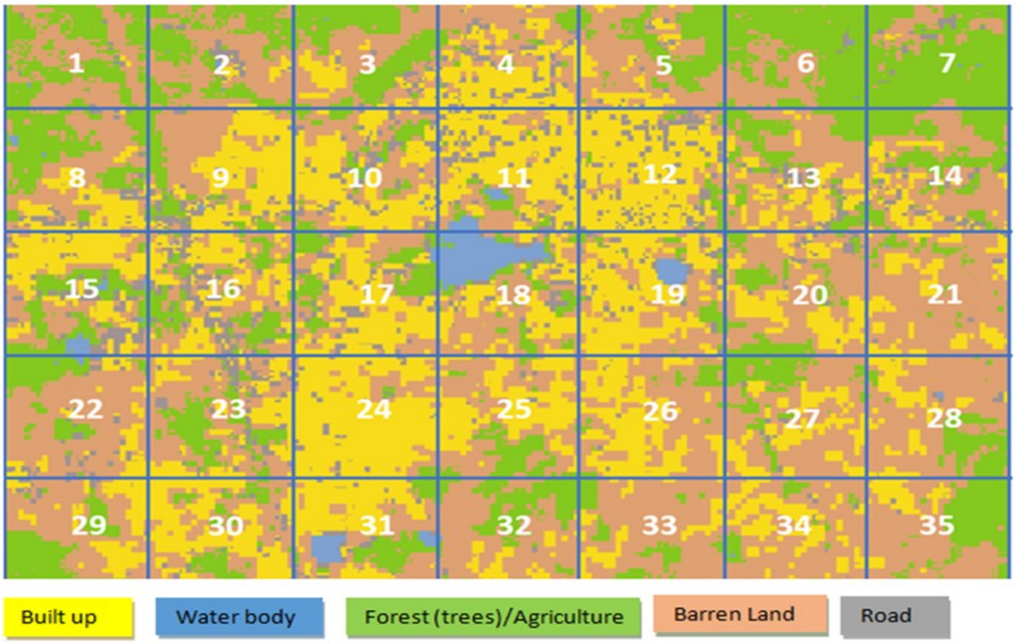

Fig. 3. *Land use/Land cover classification of Navsari city (Grids: 1 to 35)*

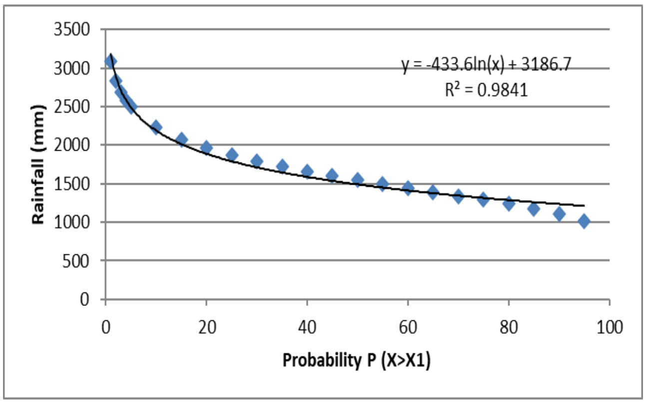

Fig. 4. *Plot of annual rainfall vs. probability*

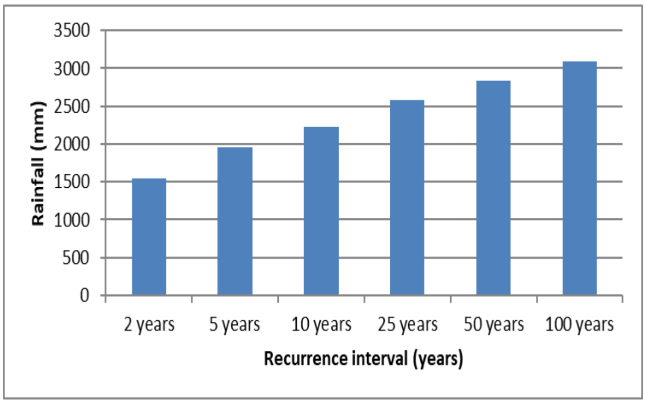

Fig. 5. *Annual rainfall depth (mm) at various recurrence intervals*

diverting water to a nearby underground water tank which can be built in the barren land or common plot. If the annual rainfall is 800 mm, which is 50 % deficient than the average annual rainfall, the estimated roof water harvesting potential would be 0.162 million litres which can satisfy the drinking water requirement of 55,397 people of Navsari city, which is around 32.4 % of the total population of Navsari city.

Villar-Navascuéset *al.* (2020) assessed the roof water harvesting potential in the city of Alicante in Spain. The results revealed that the estimated rainwater catchment potential for the whole city was 1,153,380 m^3 per year for an average rainfall scenario of 293.3 mm and a total roof area of 5.197 km^2. In the present study, the rooftop rainwater harvesting potential for an average rainfall of 1621 mm was estimated to be 163980 m^3 per year for the total roof area of 3.72 km^2. The rainwater harvesting potential was found to be considerably less than that reported by Villar-Navascuéset *al.*(2020)owing to the lack of sufficient area for tank construction in the densely populated city of Navsari. Dwivedi and Bhaduria (2006) had noted that the cost of rooftop rainwater harvesting system could be considerably less if it is planned before the construction of the house. A similar situation was observed in the study as most of the residential areas had not been designed considering the rooftop rainwater harvesting system. Closely spaced buildings, lack of sufficient area for the tank, lack of planning for the rainwater harvesting system, and economic constraints were some of the main problems the residents faced in adopting the rooftop rainwater harvesting system.

The rainwater harvesting potential corresponding to various rainfall depths is provided in Fig. 6. In the last 35 years, rainfall has seldom been less than 800 mm. The rainfall potential is based on the land use pattern of Navsari in the year 2020. For return periods of 10 years, 25 years, 50 years and 100 years, the roof water harvesting potentials were estimated to be 0.226, 0.261, 0.287 and 0.312 MCM, respectively. Therefore,

Table 4. Annual rainfall depth at various recurrence intervals

Return period (years)	Annual Rainfall (mm)	Roof water harvesting potential (MCM)
2	1544	0.156
5	1958	0.198
10	2232	0.226
25	2578	0.261
50	2835	0.287
100	3090	0.312

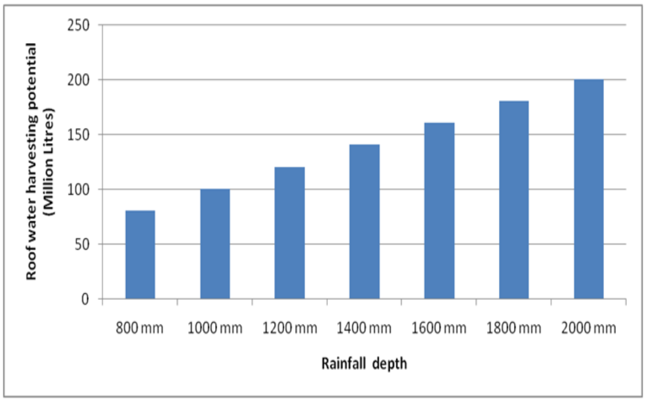

Fig. 6. *Roof water harvesting potential for various rainfall depths*

if sufficient provisions are made to harvest rainfall, the roof water can successfully reduce the drinking water problems of the people. However, significant investment is required to construct tanks of appropriate sizes in the house, residential buildings, schools etc. to store the required quantity of water.

Conclusion

In the present study, the estimated amount of roof water harvesting potential of Navsari city was found to be 164 million litres, capable of satisfying the drinking water requirements of approximately 1.12 lakh people. The estimated roof water harvesting potentials corresponding to a rainfall return period of 25 years and 50 years are 0.261 MCM and 0.287 MCM, respectively. The water that can be obtained through rooftops can certainly reduce the burden on the main water supply. The city planning commission may consider the tremendous scope in harnessing rainwater to satisfy the drinking water demand of the people. The civil engineers may design the houses with sufficient space for rainwater harvesting. The estimation of roof water harvesting potential in Navsari city has not been attempted before. This study focussed on the quantity of water that can be harvested through rooftops. There is scope for detailed research on the assessment of variations in terms of the quality of harvested rainwater in various areas of the city.

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Conflict of interest

The authors declare that they have no conflict of interest.

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