Eco. Env. & Cons. 28 (February Suppl. Issue) : 2022; pp. (S284-S290)

ISSN 0971–765X

DOI No.: http://doi.org/10.53550/EEC.2022.v28i02s.047

Assessment of Rooftop Rainwater Harvesting Potential in Karnal Smart city, (Haryana) using Geospatial Technology

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(Received 30 June, 2021; Accepted 28 July, 2021)

ABSTRACT

The present study aims to estimate potential of rain water stored from the rooftop and to study water requirement for present day scenario using the geo spatial techniques in Karnal municipal area (Haryana). Rooftop area was digitized using World View – II (0.5m resolution) satellite data. The available rainfall data has been analysed so as to know the rainfall pattern and calculate the Rooftop Rainwater Harvesting Potential (RWHP) in Karnal city. A total of 11100 building footprints were digitized (1:1000 scale) and roof top area of 9396122 m^2 was found to be available for collecting the rainwater. It was calculated that a potential volume of 5430762.18m^3 rainwater will be available on the study area, which is sufficient for toilet flushing in the study area. In this study, we estimated that annually 3140744700 L (57%) of total harvested rain water (5430762183.29 L) can be used in toilet flushing and 43% surplus water could be used for other purposes such as home-grown fruits and vegetables and watering in park.

***Key words**: Geospatial Technology, Rooftop, RWHP, Rainfall.*

Introduction

The water supply is recognized as critical global issue for urban future to be sustainable. The increasing population, urbanization, arid climate with their enhanced water requirements have been adding to more exploitation of water. The developing countries are facing water scarcity as a globally recognised situation with diminishing sources of water supply resulting from increased population, pollution and associated climate change (Wheida and Verhoeven, 2007; Fang *et al.*, 2007). The better management policies for transmission, treatment, retrieval and storage of water with highlighting access to renewable resources could curtail the problem (Santos and Pinto, 2013). The rain water harvesting is recognised as a substituent effective in long run to fight the problem of water scarcity faced globally. The run offs from roof tops of building assets have gained attention of researchers to design rainwater harvesting systems which will act as an invaluable supplement to meet the water demands. The evaluation of performance achieved from alternate form of water availability could be aligned with the process of achieving sustainable goals (Imteaz *et al.*, 2013). The efficient rainwater harvesting is achievable within areas with adequate rainfall while the arid areas prove to be less efficient in utilizing potential of harvested rain water (Mehrabadi *et al.*, 2013). The technology to harvest rainwater is based on the collection, storage and retrieval of stored water. The water from various land surfaces (pavements), roof tops, catchment areas, watersheds, etc. are the alternate sources to conserve the water resources. Apart from this, storage dams and cisterns are simple approaches utilized for harvesting run offs within infrastructure, while the check dams constructed for similar purpose are more complicated (Abdulla and Al-Shareef, 2009). The regional, altitudinal and latitudinal variations are observed in rainfall pattern which is a key factor to determine the configuration and location of an efficient rainwater harvesting system. Sloping smoothness of rooftop is also very important parameter for the calculating the runoff coefficient. Smooth sloping roofs RWHP is approximately 50% higher than the rough flat roofs and water collected from flat smooth roofs quality is better than the flat rough roofs because of the high particle deposition (Farreny *et al.,* 2011). A researcher calculated runoff from 13.1 mm rainfall as 24,000 m^3 which as a probability of 80% equivalent to the drainage system capacity (Mahmoud *et al.,* 2014). Potential of harvesting rain water on roofs study is effortless when comparing with rain water stored on ground surface because suitable area for storage water required the various thematic layers such as Soil type, Elevation, Slope, Landuse / Landcover (LU/LC) map and rainfall data (Tiwari *et al.*, 2018; Alwan *et al.*, 2020). 7% electricity is needed to pump water from the underground and ground tank so electricity cost is reduced to store rain water (Traboulsi and Traboulsi, 2017) and if grey water is used in toilet flushes then 35% drinking water will saved (Mourad *et al.,* 2011), these two steps help to increase the sustainable water uses.

Urban population in India has grown five times more from 1951 to 2011 (Patel, 2017). In India per capita water availability is 70% reduced from 1951 to 2011 (Dubbudu, 2016). To support the sustainable development and reduced the pressure on the ground water, rain water harvesting from the rooftop and its storage can be produced as best alternate for the individual houses in urban area (Rahmat *et al.,* 2020). Collected water has been utilised for both portable and non-portable (like urinal flushing, toilet, laundry) purposes (Santos and Pinto, 2013). Remote sensing and GIS approach are used to identify the potential of rain water harvesting sites (Norman *et al.,* 2019). High resolution Satellite data are used to develop rooftop layer of the building for rainwater harvesting potential estimation (Radzali *et al.,* 2018). The increasing water demand in developing countries has focused them to carry out studies relevant to the techniques to harvest rainwater and further enhance treatment facilities (Matos *et al.,* 2014; Fonseca *et al.,* 2017). A recent study undertaken by Central Ground Water Board for Haryana has indicated that, about 12.87 m water table of Karnal block has depleted during the last 44 years. The depth of water table in Karnal block as recorded in June 2018 is 18.77 m which is estimated to have fallen from 11.69 metres as recorded in June 2004 (TOI, 2019). To reduce the dependency the need of the hour is to store the rain water so as to recharge ground the water level and by using the people for the flushing toilet, watering in park and irrigation in home-grown fruits & vegetables.

The present research work has been undertaken to demonstrate the capability of geo spatial technology to estimate rain water potential stored to be from the available rooftop and to study water requirement for present day scenario using the geo spatial techniques in Karnal smart city, Haryana.

Materials and Methods

Data used

High resolution panchromatic, ortho-rectified World View-II satellite image with a spatial resolution of 0.5 m and spectral range 450-800 nm was used as a primary data source. The rainfall daily and monthly data of 10 years was collected from the Water Resources Information Systems (https://indiawris.gov.in/wris/#/rainfall).

Description of Study Area

Karnal district lies on the western bank of the river Yamuna, which forms its eastern boundary and separates Haryana from Uttar Pradesh and its height above sea level is around 240 meters. It falls in parts of Survey of India Toposheets nos. 53C and 53G covering an area of 2520 sq.km and Municipal Boundary (study area) is situated between 76°56'26.674 to 77°2'27.409"E and 29°36'30.636" to 29°45'31.21"N (Fig.1) and occupies an area of 90.40 km^2 and comprises with 20 administrative wards in municipal boundary with a population of 286826 (Census

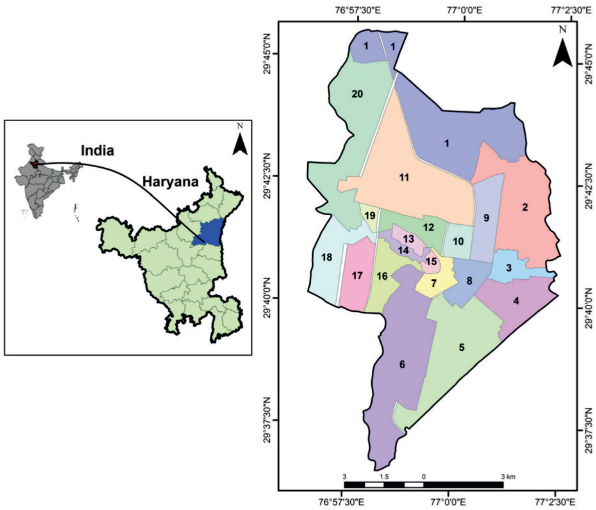

Fig. 1. Study Area Map

2011). Average rain fall of 642 mm and average Global Horizontal Irradiance varied between 0.79-5.9 kWh/m^2/day in the study area (Meenakshi *et al.*, 2021).

Digitization of Rooftop in the study Area

The high resolution panchromatic satellite data having a spatial resolution of 0.5 m (World View-II) available at Haryana Space Applications Centre (HARSAC), Hisar has been used in the present study. Based upon the image interpretation techniques such as tone, texture, shape, association and edge detection etc. the roof tops of the buildings in the study area has been identified and mapped at 1:1000 scale using the ArcGIS 10.1 software. The created shape file has been projected to WGS1984 with coordinate system WGS 1984 / UTM zone 43N.

Rainfall Pattern Analysis

The rainfall data was available for the study area (https://indiawris.gov.in/wris/#/rainfall) downloaded from WRIS (Water Resources Information System) site. The variability study of changing patterns is mandatory to decide strategic methods of harvesting rainwater being directly proportional to water availability. The variability in rainfall was also recorded by estimating variation coefficient by using the formula (Adugna *et al.*, 2018):

$$CV = \frac{\text{Standard Deviation (mm)}}{\text{mean rainfall (mm)}} \times 100 \qquad \text{(Eq. 1)}$$

where, CV = Coefficient of variance

Estimation of Rain Water Harvesting Potential (RWHP)

Area of rooftop is calculated from digitized rooftop layer by using calculate geometry tool available in ArcGIS software version 10.1. The dimensionless Runoff coefficient of rooftop (Cr) for any catchment is the ratio between volumes of runoff water to the total volume of rain falling on the Rooftop. The coefficient of runoff differs for different rooftop types and is calculated using Rande's coefficient efficiency index (Hari *et al.*, 2018). According to the data collected and during field visits it was observed that maximum roofs in the city are composed of concrete hence, the runoff coefficient for concrete was taken into consideration defined as 0.9 (Hari *et al.*, 2018). The formula given by Baby *et al.*, 2019 was used to estimate rainwater harvesting potential for the study area as given:

RWHP = Area of Roof top (sq.m) × Rainfall (m) × Runoff Coefficient (Eq. 2)

Water demand in the Study Area

Water demand has a direct proportion to the growth rate of the population in any area. The increasing population in urban area resultant of improved facilities and employment has put pressure on resources such as water and electricity. The water demand in the study area has been calculated using the population census 2011 data of study area (equation 3). Per capita consumption in India is 135 L per person and average amount of water for bathing (55 L) Washing clothes, house, utensils (40 L), toilet flushing (30 L), Drinking (5 L) and cooking (5 L) used per capita.

Water Demand = Population of study area× per capita consumption per day (Eq. 3)

Results and Discussion

Mapping of the Rooftop

With the help of satellite data interpretation, a total number of 11100 buildings were identified in 20 administrative wards and mapped (1:1000 scale) in the study area (Fig. 2), with an area of 9396122 m^2 and occupies about 10.63 % of the total study area. It was observed that the minimum size of building roof top in the study area is found to be 3.15 m^2 while the maximum size of the building roof top calculated to be 371742 m^2. Out of 20 administrative wards, 5th

Fig. 2. Digitized Building Footprint

ward has lowest rooftop area (21792.8 m^2) and 9th ward occupied maximum area (987255 m^2) while 15th ward has occupied lowest area (438376) and 1st ward has occupied highest area (12348900 m^2).

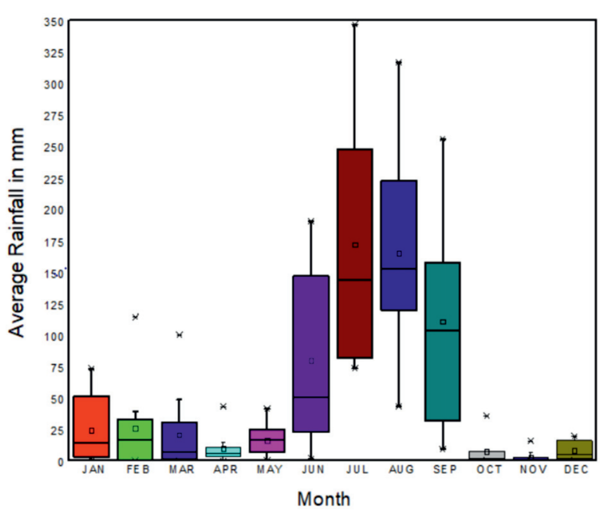

Fig. 3. Monthly rainfall variation

Analysis of Rainfall Pattern (Monthly and Annual)

The analysis of the rainfall data has revealed that average rainfall has varied significantly between each of the month. It has been observed that rainfall spanned from 2.5 mm (December) to 171.3 mm (July) during last ten year span (2010-2019). It is observed that the precipitation from June to September constituted over 82% of annual fall the study area. Further, analysis of the rain fall data has revealed that during the months of October to December did not have the significant inter-annual variation of rainfall (Fig. 3). Middle line in box plot represents the mean value of rainfall and square box shows the median value of rainfall in each month. During summer season water demand as well as rainfall is high, utilizing this rainwater can help fulfill the water demand in urban area by collection, storage and consumption of rainwater from rooftops. This will also help reduce dependency on ground water during the peak demand (Fig. 3).

Fig. 4 depicts the average monthly rainfall and average number of rainy days for the last 10 years. Standard deviation represented by the black heavy I-bar and rainy days represents by black dotted line. The observed variation in rainfall was calculated using equation 1. The variations are found to be is highly variable but for the rainfall pattern observed over a period of 10 years a modest variation of 7.4% is established which indicated the pattern of rainfall to be stable proving its worth for harvesting purposes (Fig 4).

The average annual rainfall (642.2 mm) is taken into consideration due to changing patterns of received rainfall by the city. July and August observed higher precipitation through the time span of 10 years and the computed average number of rainy days for the time period is 102 days.

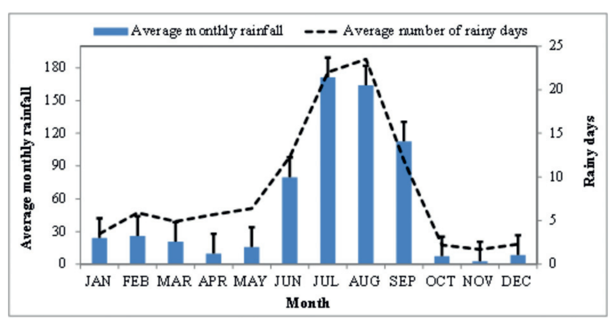

Fig. 4. Average yearly rainfall in the study area

Estimation of Rain Water Harvesting Potential (RWHP)

The analysis of the Table 1 and Fig. 5 revealed that the average monthly harvesting potential which could be generated based on the pragmatic rainfall over 11100 rooftops expanding to an area of 9396122 m^2. Based on the observed monthly rainfall and the wet months (June-September) will have a higher potential for rainwater harvesting (Fig.4). It was observed that a total 4460919 m^3 (82%) out of which, the during July 1448947 m^3 of water harvesting could be achieved, and in case of August an average of 1383377 m^3 of water can be stored while in the month of September and June month it can be 951197 m^3 and 674398 m^3. In case of the months like January, February, March and May have medium potential and very low potential in April, October, November and December for collecting and storing rainwater. For understanding the monthly variations in RWHP, spatial interpolation IDW (Inverse Distance Weighting) method is used. IDW interpolation estimates unknown values with specifying search distance, closest points, power setting and barriers.

Table 1. Mean rainwater harvesting potential over 10 years

Month	RWHP (m^3)	Month	RWHP (m^3)
Jan	203861	July	1448947
Feb.	219979	Aug	1386377
Mar	174035	Sept	951197
April	83094	Oct	61369
May	134095	Nov	21446
June	674398	Dec	71965

A close perusal of the table 2 has revealed that the study area has the capacity of 5430762183 L of rain water potential to be harvested, out of which, about 3140744700 L of water could be used for toilet flush-

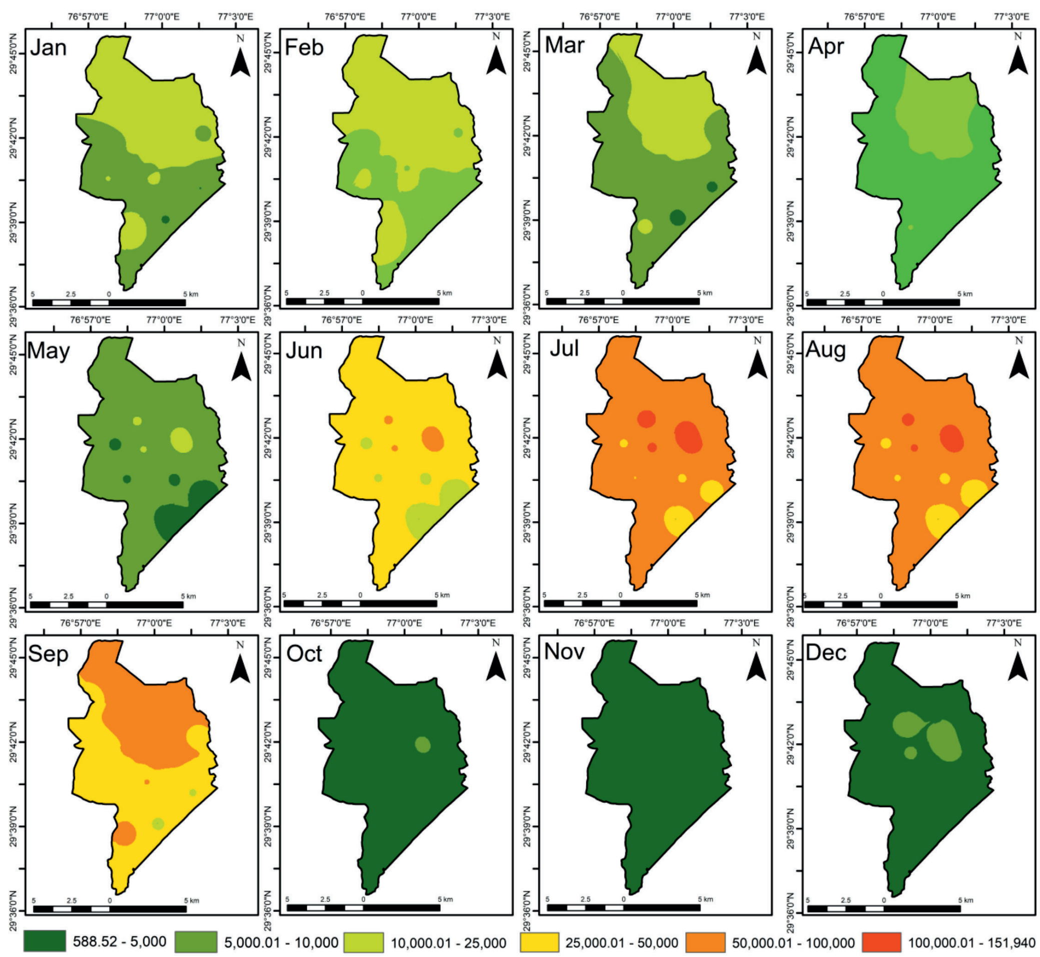

Fig. 5. Calculated Rainwater Harvesting Potential

ing demand for a population 286826, which constitutes about 57% of the total expected stored water is used for flushing. An excess of available water of 2290017483 L will be utilized for watering in park and irrigation in home-grown fruits and vegetables.

Table 2. Potential Water demand for the study area

Factors	Values
Population	286826
Per Capita Consumption of toilet flushing water	30 L
Per day water demand for toilet flushing in study area	8604780 L
Annual Demand	3140744700 L
Total Rain Water Potential in Study Area	5430762183 L
Surplus water	2290017483 L

The present investigation has demonstrated the capability of high resolution satellite data, in identifying and mapping the roof tops in the study area. A total number of 11100 roof tops have been identified with an area of 9396122 m^2. The rainfall variability which is a key factor in quantification of RWHP is considered over a period of 2010 to 2019 collected from Indian Meteorology Department. An inter-annual variation of 7.4% was found with most of the rainfall received between 0.53 m (June and September) out of the 0.64 m.

A potential of 5430762 m^3 was found over 11100 rooftops expanding to an area of 9396122 m^2.The strong focus on storing and usage of rainwater can fulfil 100% toilet flushing demand of population of the study area and surplus water 2290017 m^3 can be used for irrigation for home-grown fruits and vegetables. Further this research work will extend to estimate the volume of tank for storage expected rain water in the study area and site suitability will also identify for the storage tank in study area, Karnal.

Acknowledgements

The first author extends her thanks to all colleagues, friends and mentor who have helped in developing the methodology for the work. She also extends her thanks to the Director, Haryana Space Applications Centre (HARSAC), Hisar for providing the necessary facilities required to carry out the work.

Conflicts of Interest: The authors declare no conflict of interest.

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