<u>Original Research Article</u>

Rooftop Rainwater Harvesting: A Solution to Urban Water Scarcity

....

ABSTRACT

The burning issue of cities will be water scarcity in the coming years. The world population in cities has increased from 29.6 percent to 56.2 percent and is predicted to reach 68.4 percent by 2050. Therefore, this study has attempted to find a solution to tackle the urban water scarcity issue. Recently, rainwater harvesting has arisen as a sustainable and effective system for water conservation in urban areas. Hence, ward-wise rooftop area was calculated and, the rooftop rainwater harvesting potential was estimated by applying the Gould & Nissen, formula for Shrigonda Town. The result reveals that the total water demand in the water stress period was 41,34,41,010 litres while the total rainwater harvesting potential was 39,07,42,128 litres, which means about 94.51 % of the total demand will be met after the rooftop rainwater harvesting system is installed. The study concludes that rooftop rainwater harvesting is considered a sustainable and best alternative tool to tackle urban water scarcity.

Keywords: *Water demand, Water scarcity, Rooftop area, Rainwater Harvesting Potentials*

• INTRODUCTION

The essential renewable natural resource on the earth is water which is impacting a nation's socio-economic development. Thus, the progress of any country depends on water availability and easy access. The rate of world urbanization has increased rapidly from 1950 to 2020. The world population in cities has increased from 29.6 percent to 56.2 percent and is predicted to reach 68.4 percent by 2050 (UN, 2018). The per capita water consumption is increased due to the high standard of living and modern sanitary facilities, particularly in urban areas. The per capita availability of water decreased from 5177 cu.m. to 1820 cu.m. in 2001, and it is projected to decline to 1341 cu.m. in 2025 and 1140 in 2050 (Government of India, 2003). If this decreasing per capita water availability continues and some remedies are not applied, most metropolitan areas will face acute water shortages.

Shrigonda town is situated in southern the drought-prone area of Ahmednagar district. The average rainfall is only 536.40 mm, and about 80 percent is received from June to

September (southwest monsoon). The rainfall variability is very high and concentrated in August and September. Shrigonda Municipality has a water supply system based on the Ghod dam that provides water to dwellers. The delay in the onset of monsoon and long dry rainfall spells lead to extreme water scarcity. The resulting amount of water decreases in the dam, reducing the amount and frequency of water supply. Insufficient water supply and groundwater depletion in quantity and quality create water scarcity in the dry season. Therefore, the town experiences water scarcity from March to May. Hence, finding a sustainable and effective method to cope with the water scarcity issue during the water stress period (March to May) is most necessary.

Due to highly impervious surfaces, rainwater harvesting has emerged as a sustainable solution for water scarcity in urban areas. Imperviousness causes low infiltration and increased run-off. Rainwater harvesting is proven to rejuvenate depleted groundwater resources in terms of quality and quantity (Mohd et al., 2016). Rainwater is most reliable and less pollution-resistant if harvested and stored properly (Central Public Work Department, 2002). A rooftop rainwater harvesting system can be applied to reduce the dependency on municipal water supply, which is highly volatile due to climate change. Several studies have been carried out that reveal the potential of rainwater harvesting to tackle water scarcity.

.

- **STUDY AREA**

In the present study, Shrigonda town is a study area between 18° 36' 48" North latitude and 74° 42' 00" East Longitude with an average altitude of 552 meters. It comprises nine wards covering 79 square kilometres. It consists of Gavthan (old town), a suburban area (yellow zone), and a green zone. It has a 32000 population (Census, 2001), 40653 projected population in 2019, and 7553 constructions (residential, commercial) as per Google Images of 2019. It is a drought-prone area of Maharashtra located south of Ahmednagar City. The average rainfall is only 536 mm, most of which are received from June to September. Meanwhile, the mean maximum temperature is nearly 30°C in May, and the maximum is 12°C in December. It has developed as a residential town. The roofs of houses are mainly RCC (64.21 percent) and tin (35.79 percent) dominant in the town.

Objective

The main objective of the research is to calculate the rooftop area and rainwater harvesting potential to tackle the water scarcity problem of Shrigonda Town.

Database and Methodology

Database

The entire work depends on primary data and secondary data. Primary data were collected from the rooftops of buildings digitized with QGIS software. The secondary data about the rainfall was obtained from the Indian Meteorological Department (IMD), Pune.

Methodology

The entire research was carried out in three significant steps: rainfall analysis, ward-wise rooftop area calculation, and rooftop rainwater harvesting potential estimation.

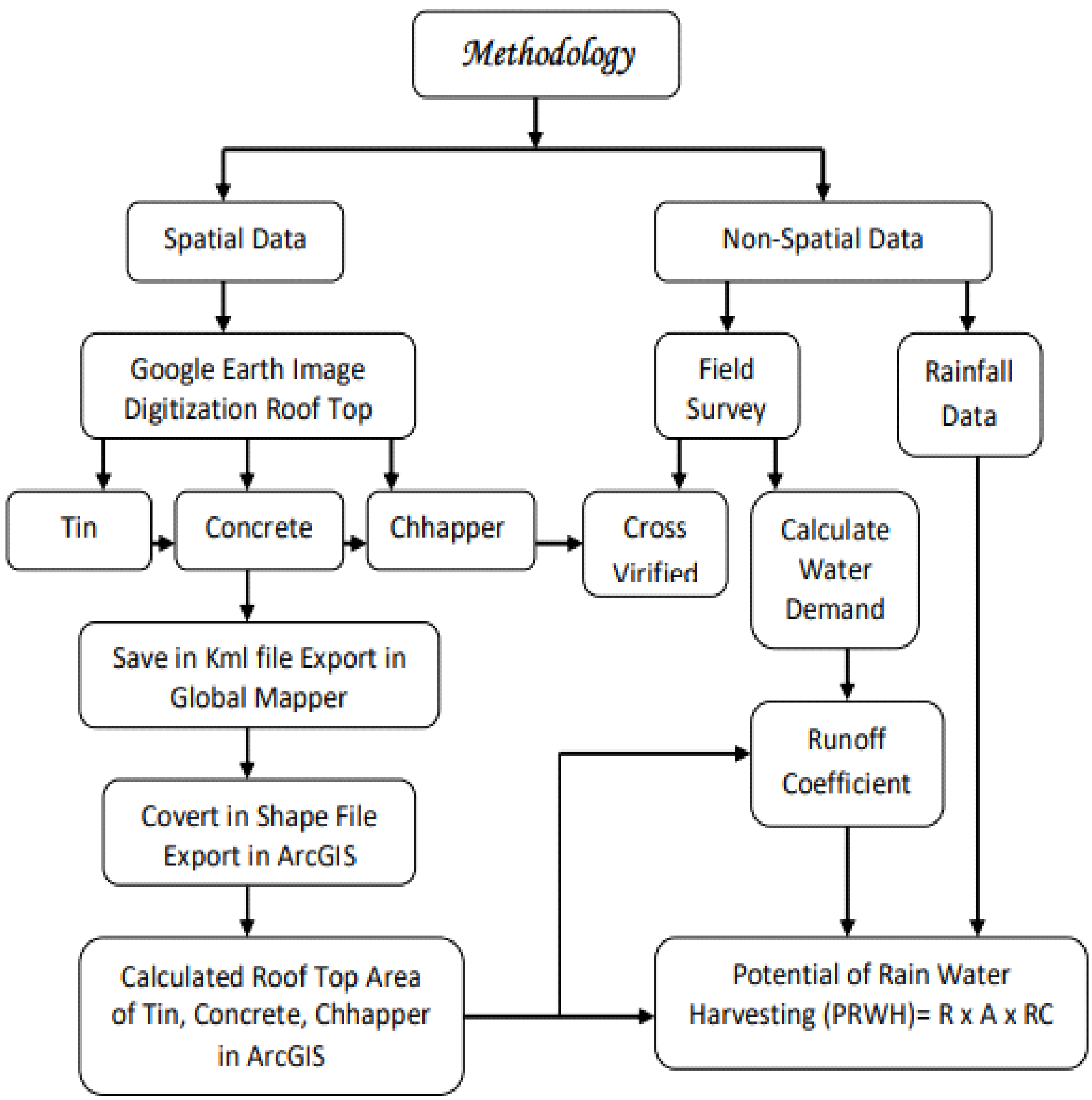

Fig. 1: Methodology to Estimate the Rainwater Harvesting Potential

First, the rainfall analysis was carried out; forty-seven years (1970 to 2017) of rainfall data was collected from the IMD, Pune, and the ward-wise rooftop areas, which were calculated by digitizing the Google Earth Pro software. After that, a field survey was conducted for ground truthing to cross-verify the rooftop types and areas. Finally, the rooftop rainwater harvesting potential was estimated using the Gould and Nissen formula (1989).

Results and Discussion

Rainfall Analysis

Shrigonda Town is located in a drought-prone area of Maharashtra, which experiences a dry summer season. The mean rainfall is only 536 mm, primarily from June to September (Monsoon period). The rainfall data from 1970 to 2017 was obtained from the Indian Meteorological Department, Pune. The month-wise average of forty-seven years' rainfall data was calculated to estimate rainfall potential.

Table 1: Average Rainfall at Shrigonda (1970 - 2017)

Months	Mean rainfall (mm)	Months	Mean rainfall (mm)
January	2.66	July	66.91
February	0.26	August	75.75
March	2.40	September	159.28
April	2.21	October	84.26
May	18.75	November	20.53
June	99.44	December	3.93
Annual rainfall (mm): 536.40			

(Source: Indian Meteorological Department, Pune)

Fig. 2: Average Rainfall at Shrigonda (1970 – 2017)

Estimation of rooftop

The Google image of 2019 was downloaded using Elshayal Smart GIS open-source software to find out the various types of rooftops and their area. The rooftops of different buildings have been digitized using Google Earth Pro software. A field survey was carried out to cross-verify various rooftop types. After cross-verification, the shape file was exported in an Arc-GIS environment, and ward-wise rooftops of different types were calculated in square meters to find the total rooftop.

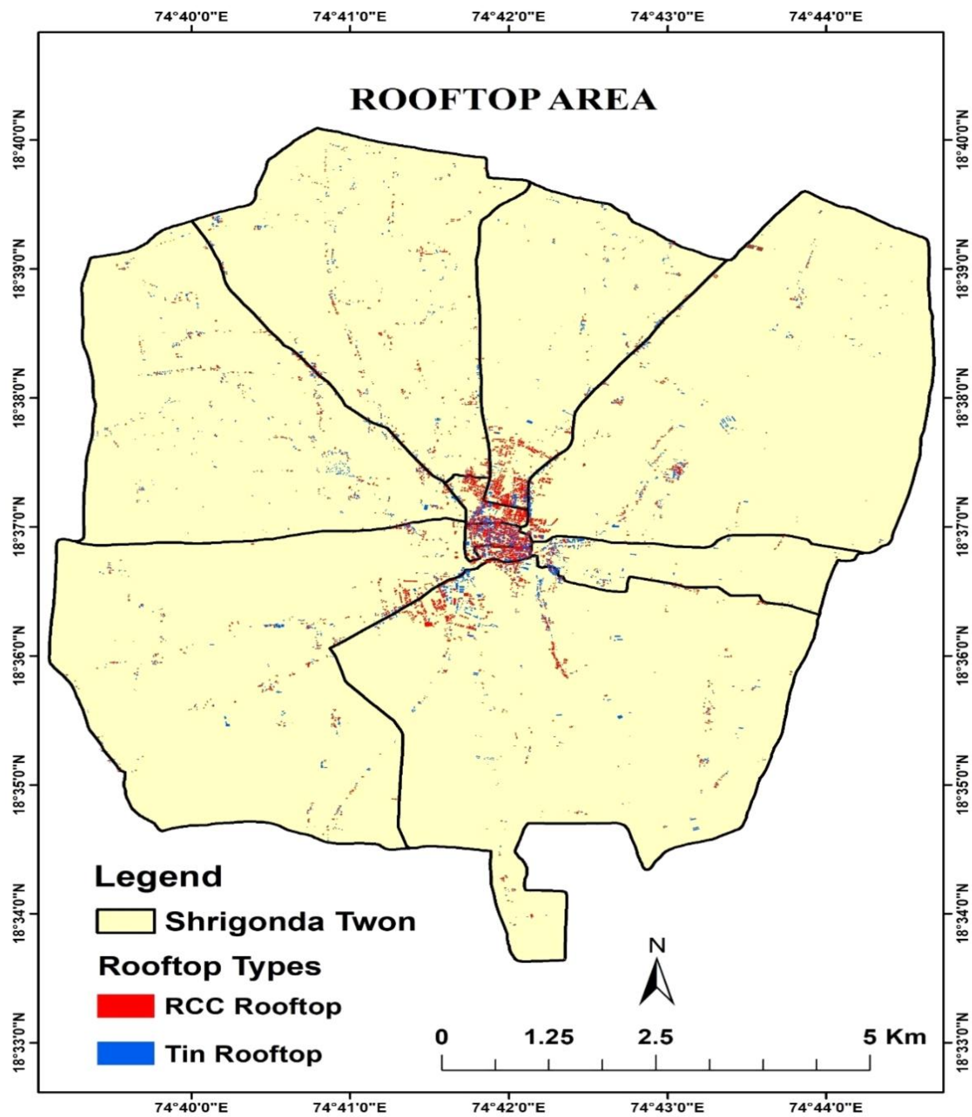

Fig.3: Types of rooftops of Shrigonda Town

Table 2: Wardwise rooftop types and area

Ward No.	Type of Roof	Total Roof Top Area (Sq. m)
1	RCC	49322.41
	GI Tin	31726.09
	Total	81048.5
2	RCC	78060.25
	GI Tin	27354.29
	Total	105414.54
3	RCC	52003.23
	GI Tin	47327.35
	Total	99330.58
4	RCC	58471.88

	GI Tin	16990
	Total	75459.89
5	RCC	41599.84
	GI Tin	16988
	Total	58587.85
6	RCC	50873.18
	GI Tin	27593.68
	Total	78466.86
7	RCC	12955.7
	GI Tin	19875.15
	Total	32830.86
8	RCC	86497.82
	GI Tin	46536.14
	Total	133033.96
9	RCC	109572.93
	GI Tin	66214.46
	Total	175787.38
Total	RCC	**539357.24**
	GI Tin	**300603.16**
	Total	**8,39,960.40**

(Source: Computed by Researcher)

The total rooftop area was about 8,39,960.40 sq. m. including the cement concrete roof (RCC) and GI tin sheet roof in Shrigonda Town. The RCC rooftop covers about 539357.24 sq. m. (64.21%) catchment areas; the highest area is occupied by ward 9, which is 109572.93 sq. m. while ward 7 covers only 12955.7 sq. m. catchment areas. The GI tin sheet roof occupied about 300603.16 sq. m. areas, among the most extensive areas covered by ward 9 (66214.46 sq. m.) and ward 4 covered only 16988 sq. m.

Rainwater harvesting potential

The potential of rainwater harvesting is defined as the capacity of a rooftop to collect the total rainwater during the rainy season. This depends on the types of rooftops and the mean rainfall of the area. Annual water volume is measured in litres (Ranade, 2000; Wifag et al., 2014). Rainwater yield depends on the size and texture of the roofing material. Smooth, clean, and impervious surfaces contribute to good quality and quantity (Mali & Pawar-Patil, 2013).

The run-off coefficient defines the ratio of the volume of water that drains out from the surface during precipitation and the total volume of rainfall (Ronalton et al., 2022). The following co-efficient of run-off of different surfaces is used to calculate ward-wise rainwater harvesting potential.

Table 3: Coefficient of run-off

Sr. No	Type of rooftop	Run-off Coefficient
1	Cement Concrete Roof	0.85
2	GI Tin Roof	0.90

Source: Pacey & Adrian, 1989; Ranade, 2000

Different roof catchments' rooftop rainwater harvesting potential is calculated using the following formula (Gould & Nissen, 1989).

Where: -

S = Potentials of rooftop rainwater harvesting (in cu. m.)

R= Average annual rainfall in meter

A=Roof area in square meter

Cr =Coefficient of run-off

Table 4: Wardwise rooftop rainwater harvesting potential

Ward No.	Type of Roof	Total Roof Top Area (Sq. m)	Annual RWH Potential (Cu. m)	Annual RWH Potential (Liter)
1	RCC	49322.41	22471.29	22471290
	GI Tin	31726.09	15304.66	15304666
	Total	81048.5	37775.95	37775956
2	RCC	78060.25	35564.24	35564250
	GI Tin	27354.29	13195.7	13195709
	Total	105414.54	48759.95	48759959
3	RCC	52003.23	23692.67	23692672
	GI Tin	47327.35	22830.71	22830713
	Total	99330.58	46523.38	46523385
4	RCC	58471.88	26639.78	26639790
	GI Tin	16988	8195.01	8195012.7
	Total	75459.89	34834.8	34834803
5	RCC	41599.84	18952.88	18952889
	GI Tin	16988	8195.01	8195012.7
	Total	58587.85	27147.9	27147902
6	RCC	50873.18	23177.81	23177820
	GI Tin	27593.68	13311.19	13311193
	Total	78466.86	36489.01	36489012

7	RCC	12955.7	5902.61	5902618.4
	GI Tin	19875.15	9587.77	9587774.3
	Total	32830.86	15490.39	15490393
8	RCC	86497.82	39408.4	39408406
	GI Tin	46536.14	22449.03	22449033
	Total	133033.96	61857.43	61857439
9	RCC	109572.93	49921.42	49921426
	GI Tin	66214.46	31941.85	31941853
	Total	175787.38	81863.27	81863280
Total	RCC	**539357.24**	**245731.10**	**245731161.40**
	GI Tin	**300603.16**	**145010.93**	**145010966.70**
	Total	**8,39,960.40**	**390742.03**	**39,07,42,128.10**

(Source: Computed by Researcher)

Google Earth Pro was applied to calculate the ward-wise digitating of rooftops. Then, the ground truthing was used for more accuracy. The total volume of harvested water was estimated at 39,07,42,128.10 litres, including 245731161.40 litres (62.88 %) from RCC rooftop areas, while 145010966.70 litres (37.22 %) were obtained from the GI Tin sheet area. Table 4 shows that the highest volume of water, 81863280 litres, will be harvested in Ward 9. whereas the lower volume, 15490393 litres, will be in Ward 7.

Table 5: Potential of RWH against water demand during the water stress period

Ward No.	Annual RWH Potential (Liter)	Daily water Requirement (Liter)	Monthly Water Demand (Liter)	Water Stress Period (March-May)	Surplus /Deficit Water (Liter)	per cent of Water Demand met through RWH	Status
1	**37775956**	473583	14207490	42622470	**-4846514**	**88.63**	**Under Potential**
2	**48759959**	502285	15068550	45205650	**3554309**	**107.86**	**Over Potential**
3	**46523385**	455842	13675260	41025780	**5497605**	**113.40**	**Over Potential**
4	**34834803**	514489	15434670	46304010	**-11469207**	**75.23**	**Under Potential**
5	**27147902**	486691	14600730	43802190	**-16654288**	**61.98**	**Under Potential**

6	**36489012**	502172	15065160	45195480	**-8706468**	**80.74**	**Under Potentia l**
7	**15490393**	534264	16027920	48083760	**-32593367**	**32.22**	**Under Potentia l**
8	**61857439**	447819	13434570	40303710	**21553729**	**153.48**	**Over Potentia l**
9	**81863280**	676644	20299320	60897960	**20965320**	**134.43**	**Over Potentia l**
Total	**390742129**	**4593789**	**137813670**	**413441010**	**-22698881**	**94.51**	**Under Potentia l**

(Source: Computed by Researcher)

From March to May there is a water stress condition due to curtailing the Municipal water supply, decreasing groundwater yield, and deteriorating water quality. The table indicates that Ward number 8 has 134.43% rainwater harvesting potential against water demand. followed by Ward number 9 with 134.43%, Ward 3 with 113.40% and Ward 2 with 107.86 percent. Whereas, Ward number 7 has only 32.22 % rainwater harvesting potential against water demand followed by Ward number 5 with 61.98%, Ward number 4 with 75.23%, Ward number 6 with 80.74% and Ward number 1 with 88.63%. The result reveals that Ward numbers 8, 9, 3, and 2 have over potential and Ward numbers 7, 5, 4, 6, and 1 have under potential.

CONCLUSION

In the study area, the rainfall is erratic, leading to a water scarcity problem. The intensity of water scarcity is exceptionally high from March to May (water stress period). Therefore, the present research emphasizes alternative sources of water to tackle the water scarcity issue. Recently, rainwater harvesting has developed as an effective and sustainable system for water conservation in urban areas. The ward-wise population, water demand, water supply, wastewater generation, and potential of rooftop rainwater harvesting were examined. The result reveals that the total water demand in the water stress period was 41,34,41,010 litres while the total rainwater harvesting potential was 39,07,42,128 litres, which means about 94.51 % of the total demand will be met after the rooftop rainwater harvesting system is installed. The study concludes that the burning issue of cities will be water scarcity in the coming years. Therefore, rooftop rainwater harvesting will act as a sustainable and best alternative system to tackle urban water scarcity but without people's participation, this scheme will not be fully executed.

REFERENCES

Athavale, R. N. (2003). Water Harvesting and Sustainable Supply in India. Centre for Environment Education, Ahmedabad: Rawat Publications Jaipur and New Delhi.

BIS. (1993,2002). Code of Basic Requirement for Water Supply, Drainage, and Sanitation. New Delhi: Bureau of Indian Standard.

Carlos Alberto, Martínez-Huitle, & Manuel Andrés Rodr (Eds.). (2018). Electrochemical Water and Wastewater Treatment. Elsevier. Doi: https://doi.org/10.1016/C2016-0-04297-3.

Central Public Work Department. (2002). Rain harvesting and conservation manual. New Delhi: Government of India.

CPWD. (2002). Manual Rainwater Harvesting and Conservation. New Delhi: Central Public Work Department.

Ghaitidak, D. M., & Yadav, K. D. (2013). Characteristics and treatment of greywater—a review. Environmental Science and Pollution Research, 20, 2795-2809. Doi: DOI 10.1007/s11356-013-1533-0.

Gilbert, F. W., David, J. B., & Anne, U. W. (1972). Drawers of Water Domestic Water Use in East Africa. University of Chicago Press.

Gleick, P. H. (1996). Basic Water Requirements for Human Activities: Meeting Basic Needs. Water International, 21(2), 83-92.

Gould, J., & Nissen, P. E. (1989). Rainwater Catchment Systems for Domestic Supply. International Technology Publications.

Government of India. (2003). Water Resources of India and the World. Ministry of Water Resources, Newsletter on fresh water year.

Jefferson, B., Palmer, A., Jeffrey, P., Stuetz, R., & Judd, S. (2004). Grey water characterization and its impact on the selection and operation of technologies for urban reuse. Water Science and Technology, 50(2), 157-164.

Kokila, K., & R., D. (2015). Analysis and Design of Cascade Aerator Construction for Mettur. National Conference on Research Advances in Communication, Computation, Electrical Science and, (pp. 42-46).

Mali, S. P., & Pawar-Patil, V. S. (2013). Potential Roof Rain Water Harvesting in Pirwadi Village of Kolhapur District, Maharashtra (India) - A Geospatial Approach. Journal of Research in Humanities and Social Science, 1(4), 19-23.

Metcalf, Eddy, & Inc. (2012). Wastewater Engineering Treatment and Reuse. Tata McGraw Hill Private Limited.

Mohd, S., Athar, H., & Gauhar, M. (2016). Analysis of groundwater quality using water quality index: A case study of greater Noida (Region), Uttar Pradesh (UP), India. Cogent Engineering, 3, 1-11. doi: doi: http://dx.doi.org/10.1080/23311916.2016.1237927.

NWM. (2023). National Water Mission. Ministry of Jalshakati, Department of Water Resources. Retrieved from http://nwm.gov.in/.

Pacey, A., & Adrian, C. (1989). Rainwater Harvesting: The collection of rainfall and run-off in Rural areas. *Intermediate Technology Publications*, 55

Purnima, B. C., & Jain, A. K. (2005). *Waste Water Engineering.* New Delhi: Laxmi Publications(P) Ltd.

Ranade, R. (2000). *A Water Harvesting Manual for Urban Areas: Case Studies from Delhi.* New Delhi: Publication Center for Science and Environment.