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Estimation of Roof Top Rain Water Harvesting Potential: A Proposed Solution to Water Scarcity in Shrigonda Town, Maharashtra, India

Bapu D. Deokar [a++*]

[a] *Department of Geography, Maharaja Jivajirao Shinde Mahavidyalaya, Shrigonda,413701 MS, India.*

Author's contribution

The sole author designed, analysed, interpreted and prepared the manuscript.

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ABSTRACT

The burning issue in 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 emerged as a sustainable and effective system for water conservation in urban areas. Hence, the 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.

[++] *Assistant Professor;*
**Corresponding author: E-mail: bapudeokar@gmail.com;*

Keywords: Water demand; water scarcity; rooftop area; rainwater harvesting potentials.

1. INTRODUCTION

The essential renewable natural resource on 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 [1]. The per capita water consumption is increasing 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 [2]. 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, the present work has attempted the find a sustainable and effective solution to cope with the water scarcity issue during the water stress period (March to May) in the study area.

1.1 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 kilometers. It consists of Gavthan (old town), a suburban area (yellow zone), and a green zone. The town has reported 31,134 population [3], and it projected 44000 in 2025. As per Google Images of 2023, the 7553 constructions (residential, commercial) are marked with 9 wards. Shrigonda is in a drought-prone area, 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 where the roofs of houses are mainly RCC (64.21 percent) and tin (35.79 percent) dominant,

1.2 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.

2. DATABASE AND METHODOLOGY

2.1 Database

The entire work depends on primary data and secondary data. Primary data were collected from the rooftops of buildings digitized with Google Earth Pro. The secondary data about the rainfall was obtained from the Indian Meteorological Department (IMD), Pune and population data was obtained from the Census 2011.

2.2 Methodology

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

2.3 Domestic Water Scarcity

The domestic water scarcity was calculated by applying the Supply–Demand Balance Index [4]. It is the ratio between total water supply and total water demand.

$$\mathrm{SDBI} = \frac{\mathrm{TWS}}{\mathrm{TWD}}$$

Where,
SDBI = Supply–Demand Balance Index for the year
TWS = Total Water Supply for the year in (cubic meters/year)
TWD = Total Water Demand for the year in (cubic meters/year)

The value of SDBI ranged between 0 to 1. The values 0 to 0.3 indicated extreme water scarcity, 0.3 to 0.6 showed acute water scarcity, 0.6 to 0.9 indicated moderate water scarcity, and the values 0.9 to 1 pointed slight water scarcity. In contrast, a value of more than 1 means no water scarcity.

2.4 Rainfall Analysis

The Shrigonda station rainfall of fifty-three years (1970-2023) was obtained from the Indian Meteorological Department (IMD), Pune. The long-term average rainfall was calculated from yearly rainfall. The long-term average rainfall is 536.42 mm which was used to calculate rainfall potentials.

2.5 Estimation of Rooftop

The rooftops of different buildings have been digitized using Google Earth Pro software. A ground truthing was carried out to cross-verify various rooftop types. After cross-verification, the kml file was exported in Arc-GIS software and converted into to shape file. The ward-wise rooftop areas were calculated in square meters.

2.6 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. It depends on the amount of rainfall, run-off coefficient, and type of rooftop. The runoff coefficient is the ratio of the runoff depth rate to the rainfall depth.

The value of runoff coefficient is highly variable and depends on the climatic factors including rainfall characteristics and physiographic factors of catchment (Ronalton et al., 2022). The following co-efficient of run-off of different surfaces is used to calculate ward-wise rainwater harvesting potential.

Different roof catchments' rooftop rainwater harvesting potential is calculated using the following formula [7].

$$S = R \times A \times Cr$$

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

3. RESULTS AND DISCUSSION

3.1 Domestic Water Scarcity

Water security is affected by water scarcity, which occurs when water demand exceeds supply; in dry periods, supply decreases and demand increases due to drying up surface water bodies and declining groundwater yield. Water scarcity immediately impacts economic growth, urban environmental quality, and the health and well-being of city dwellers [8]. This wastewater deteriorates groundwater quality due to discharge around the town; the municipal water supply is based on surface water (Ghod Dam), and the amount of water in the reservoir decreases in the dry season. Thus, the municipality curtails water supply in the dry season. Insufficient water supply and groundwater depletion in quantity and quality create water scarcity in the dry season.

Domestic Water Scarcity depends on the total water supply (T.W.S.) by Shrigonda Municipality and the domestic water consumption rate (DWCR) which is specified based on field survey data.

The ward-wise SDBI value during the water stress period (March to May) indicated that all wards are experiencing acute water scarcity water scarcity. Therefore, finding an alternative water source to tackle the water scarcity problem during the water stress period (March to May) is most necessary.

3.2 Rainfall Analysis

Shrigonda Town is in a drought-prone area of Ahmednagar, which experiences a dry summer season. The mean rainfall is only 536.42 mm, primarily from June to September (Monsoon period). The rainfall data from 1970 to 2023 was obtained from the Indian Meteorological Department, Pune. The month-wise average of fifty-three years' rainfall data was calculated to estimate rainfall potential.

Table 1. 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, [5]; Ranade, [6]

Table 2. TWD and TWS during the water stress period (March to May)

Ward No	Projected Population (2023)	March			April			May		
		TWD	TWS	SDBI	TWD	TWS	SDBI	TWD	TWS	SDBI
1	**4191**	14291.31	9744.75	**0.68**	14081.76	8801.10	**0.63**	14940.92	8444.865	**0.57**
2	**4445**	15846.43	10334.63	**0.65**	15335.25	9334.50	**0.61**	16535.40	8956.675	**0.54**
3	**4034**	14381.21	9379.05	**0.65**	13917.30	8471.40	**0.61**	15006.48	8128.51	**0.54**
4	**4553**	16937.16	13408.59	**0.79**	17073.75	12976.05	**0.76**	19054.31	10585.73	**0.56**
5	**4307**	14686.87	10013.78	**0.68**	14859.15	9044.70	**0.61**	15354.46	8678.605	**0.57**
6	**4444**	17220.5	13087.58	**0.76**	16665	12665.40	**0.76**	18598.14	10332.30	**0.56**
7	**4728**	16855.32	10992.60	**0.65**	16311.60	10638	**0.65**	16855.32	9526.92	**0.57**
8	**3963**	13513.83	8599.71	**0.64**	13672.35	8322.30	**0.61**	14742.36	7985.445	**0.54**
9	**5988**	20419.08	12993.96	**0.64**	20119.68	12574.80	**0.63**	20419.08	12065.82	**0.59**

(Source: Computed by Researcher)

Table 3. Average Rainfall at Shrigonda (1970 - 2023)

Months	Mean rainfall (mm)	Months	Mean rainfall (mm)
January	2.66	July	66.91
February	0.26	August	75.78
March	2.40	September	159.41
April	2.21	October	84.24
May	18.68	November	20.52
June	99.44	December	3.91
Annual rainfall (mm): 536.42			

(Source: Indian Meteorological Department, Pune [9])

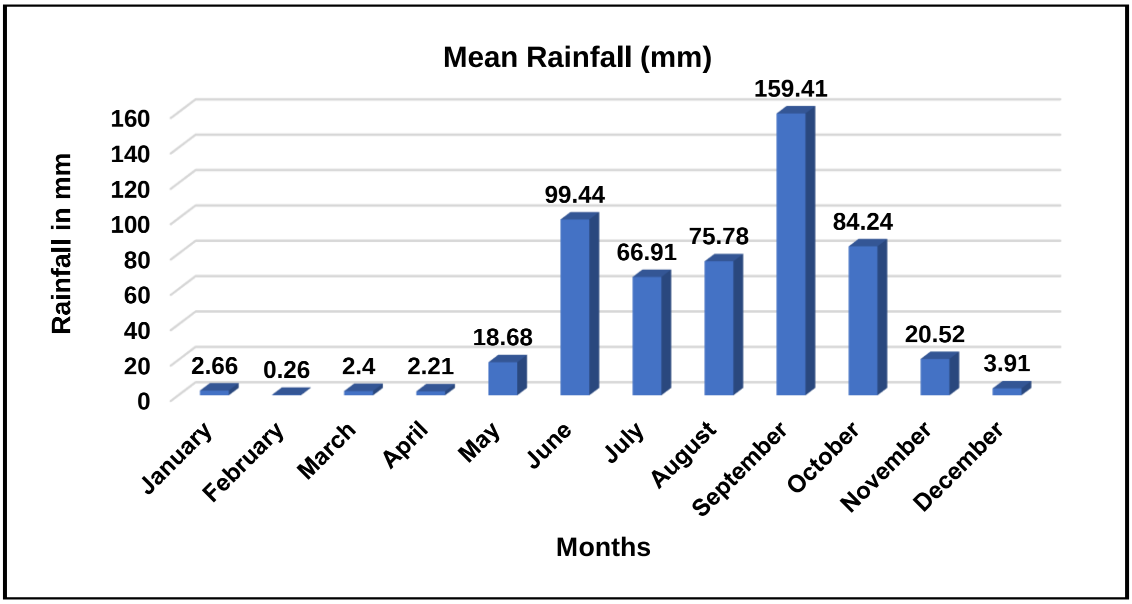

Fig. 1. Average Rainfall at Shrigonda (1970 – 2023)

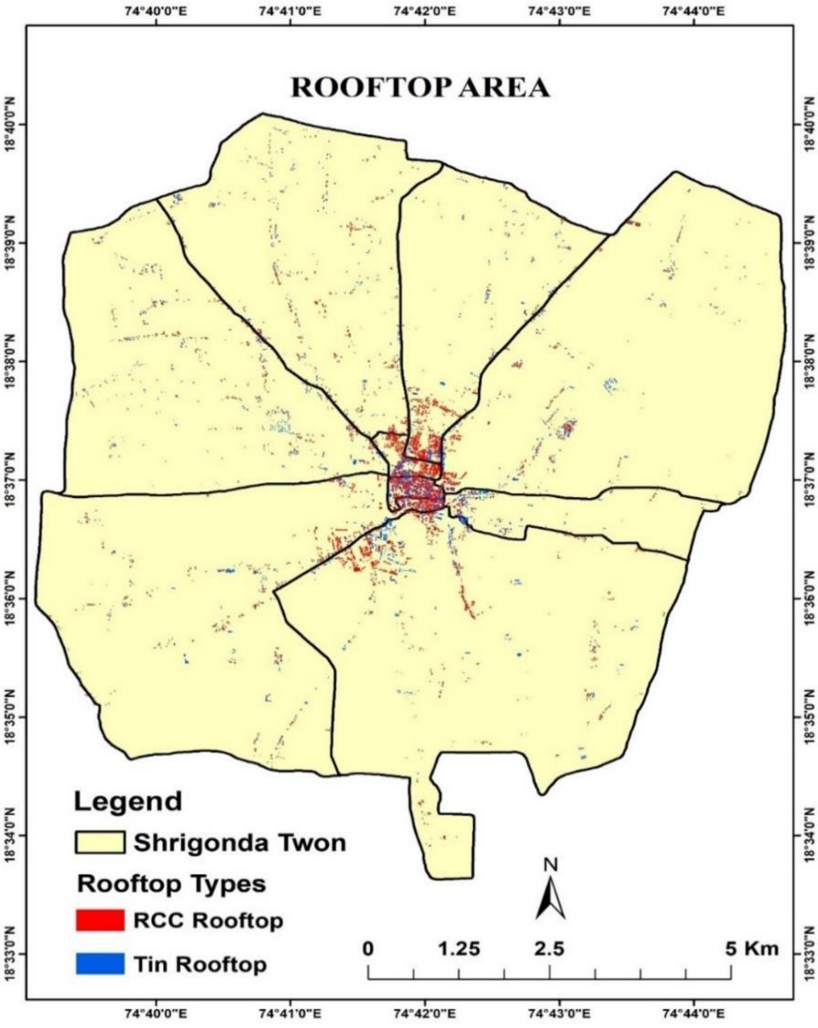

Fig. 2. Types of rooftops of Shrigonda Town

3.3 Estimation of Rooftop

The estimation of rooftop areas is a key factor in the process of calculation of rainwater harvesting potential. The ward-wise shape file of Shrigonda Town was obtained from the Municipality office and overlay in the Google Earth Pro software [10-12]. The rooftops of different buildings have been digitized using the ruler tool in Google Earth Pro. A ground truthing was carried out to cross-verify various rooftop types and areas. After cross-verification, the kml file was exported in Arc-GIS software and converted into to shape file. The ward-wise rooftop areas were calculated in square meters using a shape file. 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 [13-15]. 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.

3.4 Rainwater Harvesting Potential

After the estimation of ward-wise rooftop areas, with the help of rainfall and rain-off coefficient the rooftop rainwater harvesting potential was calculated using the [7] formula.

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 5 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 4. 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)

Table 5. Wardwise rooftop rainwater harvesting potential

Ward No.	Type of Roof	Total Roof Top Area (Sq. m)	Average Rainfall (mm)	Rain-off Coefficient	Annual RWH Potential (Liter)
1	RCC	49322.41	536.42	0.85	22471290
	GI Tin	31726.09	536.42	0.90	15304666
	Total	81048.5	-	-	**37775956**
2	RCC	78060.25	536.42	0.85	35564250
	GI Tin	27354.29	536.42	0.90	13195709
	Total	105414.54	-	-	**48759959**
3	RCC	52003.23	536.42	0.85	23692672
	GI Tin	47327.35	536.42	0.90	22830713
	Total	99330.58	-	-	**46523385**
4	RCC	58471.88	536.42	0.85	26639790
	GI Tin	16988	536.42	0.90	8195012.7
	Total	75459.89	-	-	**34834803**
5	RCC	41599.84	536.42	0.85	18952889
	GI Tin	16988	536.42	0.90	8195012.7
	Total	58587.85	-	-	**27147902**
6	RCC	50873.18	536.42	0.85	23177820
	GI Tin	27593.68	536.42	0.90	13311193
	Total	78466.86	-	-	**36489012**
7	RCC	12955.7	536.42	0.85	5902618.4
	GI Tin	19875.15	536.42	0.90	9587774.3
	Total	32830.86	-	-	**15490393**
8	RCC	86497.82	536.42	0.85	39408406
	GI Tin	46536.14	536.42	0.90	22449033
	Total	133033.96	-	-	**61857439**
9	RCC	109572.93	536.42	0.85	49921426
	GI Tin	66214.46	536.42	0.90	31941853
	Total	175787.38		-	**81863280**
Total	RCC	**539357.24**	536.42	0.85	**245731161.40**
	GI Tin	**300603.16**	536.42	0.90	**145010966.70**
	Total	**8,39,960.40**	-	**-**	**39,07,42,128.10**

(Source: Computed by Researcher)

Table 6. 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 Potential**
7	**15490393**	534264	16027920	48083760	**-32593367**	**32.22**	**Under Potential**
8	**61857439**	447819	13434570	40303710	**21553729**	**153.48**	**Over Potential**
9	**81863280**	676644	20299320	60897960	**20965320**	**134.43**	**Over Potential**
Total	**390742129**	**4593789**	**137813670**	**413441010**	**-22698881**	**94.51**	**Under Potential**

(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.

4. 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.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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