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ROOFTOP RAINWATER HARVESTING POTENTIAL AT BHARATHIAR UNIVERSITY

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Abstract

Rapid urbanization, population growth, and climate change have escalated the demand for water resources, significantly widening the gap between water supply and demand. Among various strategies for water resource management, rainwater harvesting emerges as a sustainable and efficient solution. This study evaluates the rooftop rainwater harvesting potential of Bharathiar University Campus, Coimbatore, utilizing its 96,839 m² rooftop area as the catchment. Water demand for entire university was calculated by combining the supply of water to the use of all buildings, research laboratories and gardening from university water supply unit. The total rooftop rainwater potential was calculated combining total catchment area (m2), amount of rainfall (mm) and runoff coefficient. The analysis revealed that the campus rooftops could annually harvest 4,90,28,274 liters of rainwater. This harvested water has the potential to meet approximately one-fourth of the campus's total water demand (13,36,91,625 liters), providing a viable strategy to alleviate water scarcity while reducing dependency on external water sources and groundwater extraction.

Keywords: *Rainwater Harvesting, Rooftop, Water demand, Storage, Water supply, Water management*

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1. Introduction

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Water is one of the most critical resources for sustaining life on Earth. Despite its vast presence, with an estimated 1.386 billion cubic kilometers (333 million cubic miles) of water globally, only 2.5% is freshwater, and a mere 0.3% exists in liquid form readily available for use (Gleick, 1993). Of this, just 0.15% is accessible for human needs, highlighting the acute scarcity of usable water. India, with a total water resource of 1,859 cubic kilometers, accounts for roughly 4% of the world's freshwater, while Tamil Nadu retains only 2.5% of India's share (ENVIS, Tamil Nadu, 2020). This scarcity is further exacerbated by global challenges. According to UNICEF (2021), one in five children lacks access to sufficient water for daily needs. By 2025, nearly two-thirds of the global population will experience moderate to severe water scarcity, and by 2040, about 25% of children worldwide may face extreme water stress. In India, approximately 50 million people across 15 cities struggle to obtain clean and affordable drinking water. The growing water crisis is driven by rapid population growth, urbanization, unsustainable development, changing consumption patterns, poor water management practices, environmental degradation, climate change, and extreme weather events (Wu et al., 2020). Bridging the widening gap between water demand and supply requires innovative and sustainable solutions. Among various water management strategies, Rainwater Harvesting (RWH) has emerged as a sustainable and efficient method. It combines conservation, allocation, and behavioral adaptation with engineering practices, offering benefits to both stakeholders and the environment (Che-Ani et al., 2009). Although RWH is an ancient practice, its modern implementation as a Rainwater Harvesting System (RWHS) has proven to be a reliable solution for capturing, storing, and utilizing rainwater sustainably (Yannopoulos et al., 2017; Mishra et al., 2020). The effectiveness of RWHS depends on factors such as rainfall patterns, intensity, duration, and the design of appropriate storage structures (Wallace et al., 2015). Scientific measures are crucial to ensure the quality of harvested rainwater, which can be compromised by pollutants, debris, and biological contaminants (Chidamba and Korsten, 2015).

Public institutions, with their extensive rooftop areas, hold significant potential for implementing Rooftop Rainwater Harvesting Systems (RTRWH) (Adugna *et al*., 2018). These systems can serve as focal points for addressing water scarcity, especially in large campuses. Despite this potential, initiatives for RTRWH remain underreported in institutional and government buildings, including universities (Saeedi and Goodarzi, 2020).

The primary objective of this investigation is to assess the annual Rainwater Harvesting Potential (RWHP) of the rooftops of buildings at Bharathiar University, Coimbatore. This study involves a comprehensive analysis of the campus's current annual water demand, actual water consumption, and total water supply. Additionally, it evaluates the gap between water demand and supply, aiming to determine the extent to which rooftop rainwater harvesting can bridge this gap, either fully or partially. Uncontrolled groundwater extraction has led to a significant decline in the groundwater table, and in severe cases, the drying up of wells has been observed on the university campus. This has resulted in a widening gap between water demand and supply. To address this situation, it is imperative to implement appropriate measures. One of the most immediate and effective solutions is the collection of rainwater,

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particularly through Rooftop Rainwater Harvesting (RTRWH). The university spans approximately 880 acres, with 69 buildings featuring tiled, asbestos, and galvanized iron (GI) rooftops. Currently, a substantial amount of rainwater that falls is either drained away through existing drainage systems or flows across open land, contributing to soil erosion in unpaved areas and clogging the drainage system. By taking proactive steps to collect, treat, store, and utilize this rainwater, the university could significantly benefit from this natural resource. As highlighted by Kalia (2013), the implementation of a rooftop rainwater harvesting system emerges as a viable and sustainable solution to combat the ongoing water scarcity on campus.

2. Methodology

The average monthly rainfall data of Coimbatore was collected from Agro Climatic Research Centre (ACRC), Tamilnadu Agricultural University. The information of total rooftop area of Bharathiar University buildings was received from University Engineering Division. The total population of the campus was received from the university office. Water demand for entire university was noted by combining the supply of water to the use of all buildings, research laboratories and gardening from university water supply unit. The total rooftop rainwater potential was calculated combining total catchment area (m^2), amount of rainfall (mm) and runoff coefficient. Runoff coefficient indicates losses due to catchment surface wetting, evaporation, infiltration and spillage.

2.1 Location of the Study Area

The study area is the Bharathiar University Campus, which is located at the foothills of Marudhamalai at Westernghats, at a distance of 18 kilometers west of Coimbatore city, covering a vast area of 880 acres. The entire campus is separated into north campus (Academic) and south campus (Residential). It is placed between11° 2' 46.1004" and 11° 1' 48.5904" N and 76° 52' 14.8944" and 76° 52' 57.378" E longitude with an elevation of 411 m above MSL Geographical location and satellite map of Bharathiar University are shown in Figure. 1 and 2.

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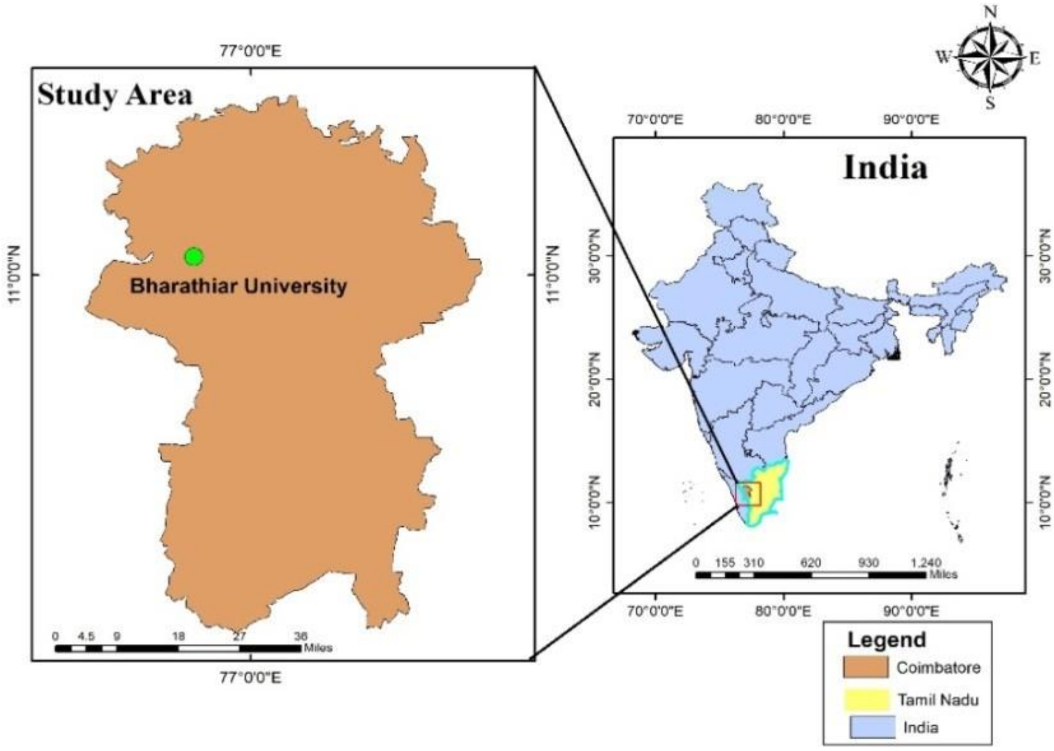

Figure 1: Geographical Location of Coimbatore

Figure 2: Map of Bharathiar University campus (Source: Google earth, 2024).

2.1.a Climate

The climate of the region is semi-arid with an annual average temperature ranging between 18°C to 35°C. The study area is located in the rain shadow of the Western Ghats and experiences pleasant weather conditions throughout the year. Southwest monsoon is from June to September and northeast monsoon is from October-December contributing 28% and 47% respectively to the total rainfall.

2.1.b Catchment area

The rooftops of various buildings across the campus serve as the catchment areas for rainwater harvesting. The north campus comprises administrative buildings, academic departments, research centers, men's hostels, the Bharathiar University-Defence Research and Development Organization (DRDO- Industry Academia-Centre of Excellence (DIA-CoE)), and a guesthouse. The south campus includes women's hostels, staff residences, guesthouses, and health centers. Figure 1 illustrates the locations of these buildings, accompanied by satellite imagery of the campus. The rooftop areas of all buildings were obtained from the Office of the University Engineer.

2.1.c Water supply

The entire campus receives a water supply of 7,08,08,000 liters annually from the Siruvani water source, provided by the Coimbatore Corporation. The additional water demand for all campus buildings is fulfilled through the extraction of groundwater via borewells located on the premises.

2.1.d Demography

Demographic data of the campus was collected from the office of the university administration. The total population encompassed boarding students, teaching and non-teaching faculty, family members residing in the campus, the day scholars, visitors and employees working in banks, post office, stationery shop, food court and health center located within the campus.

2.1.e Water Demand

The campus water demand was calculated based on the norms specified by the Bureau of Indian Standard (BIS, 1993) as detailed below:

Hostel/Residence : 135 L per person per day
Day scholar/office : 45 L per person per day

2.1.f Estimation of Rainwater harvesting potential

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The total rainwater harvesting potential from the proposed rooftops area was determined using the following equation (Lancaster, 2019):

$$Q = A * R * Cr$$

where,

Q = Rainwater harvesting potential in liters

A = Area of rooftop catchment in m^2

R = Rainfall intensity in mm

Cr = Runoff coefficient

The runoff coefficient (Cr) in any catchment is the ratio of the volume of rainwater that flows off the surface to the total volume of rainwater that falls onto it (Hari et al., 2018). The runoff coefficient for rainwater harvesting potential varies depending on the type of catchment surface. Table 1 provides the runoff coefficients for various common surface types (CGWB, 2007).

Sl. No	Roof Type	Runoff Coefficient
1	Galvanized Iron sheets	0.9
2	Asbestos sheet	0.8
3	Tiles roof	0.75
4	Concrete roof	0.7

3. Results and Discussion

Rainwater harvesting system is the collection and storage of rainwater from the rooftop areas during rainy days. Bharathiar University receives rainfall during southwest monsoon (SWM: June - September) and northeast monsoon (NEM: October – December). For the rest of the months, some slight showers are being experienced, otherwise, it remains a dry period.

The rainfall data from Agro Climate Research Centre (ACRC), Tamilnadu Agricultural University (TNAU), for a long-term average period of 50 years (1970 – 2020) revealed that the district has received the highest precipitation of 1299 mm in 1979 and the lowest of 285.4 mm in 1974. In 2019 and 2020, it was found to be 859.5 mm and 638 mm respectively against 50 year's average of 674 mm (THE HINDU 08.01.2020 and 01.01.2021) as shown in Figure 3.

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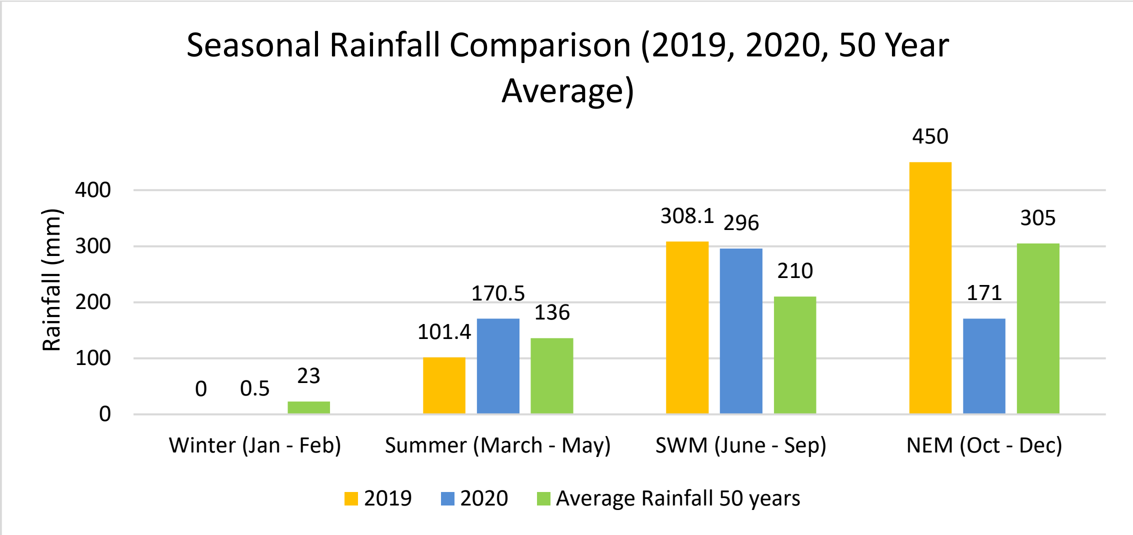

Figure 3: Seasonal Rainfall Comparison for the Year 2019, 2020, and the 50-year Average.

The United Nations Environment Programme (UNEP) recommends that before storing the rainwater, it is essential to subtract “the first flush” of 0.50 mm of rainfall (UNEP, 2015). Accordingly, in our study, the first flush of 4 mm of rainfall was subtracted from the total annual rainfall of 674 mm and the remaining 670 mm rainfall has been taken for calculating the potential rainwater harvesting so as to maintain the improved quality of the harvested rainwater. Table 2- 4 depicts the number of buildings in north and south campuses, the dimensions of the roof area, types of rooftops and the annual rainwater harvesting potential of the individual buildings. It is noticed that buildings of Controller of Examinations (COE) office followed by administrative building with the highest roof area of 4278 m^2 and 3287 m^2 have a greater potential of harvesting **21,45,695** liters and **16,51,718** liters respectively of rainwater. There are 69 buildings with different types of rooftops present in the entire campus.

Table 2. Rooftop Area of Buildings and Rainwater Potential in North (Academic)

Sl.No	Name of the Building	Rooftop area (m^2)	Rainwater Potential (Litres)
1	Administrative Building	3287	16,51,717.5
2	Estate Office	520	2,61,300.0
3	Office of COE	4278	21,45,695.0

4	Dept.of Env. Science	962	4,83,405.0
5	BSMED	1573	7,90,432.5
6	Dept. of Physics	1385	6,95,962.5
7	Dept. of Nanotechnology	1392	6,99,480.0
8	Dept. of Chemistry	2649	13,31,122.5
9	Dept. of Zoology	1649	8,28,622.5
10	Dept. of Information Technology	422	2,12,055.0
11	Dept. of Education Technology	536	2,69,340.0
12	Dept. of Comp. Science	1269	6,37,672.5
13	Dept. of Electronics	286	1,43,715.0
14	Dept. of Economics	411	2,06,527.5
15	Dept. of Sociology	411	2,06,527.5
16	Dept. of Media Studies	1341	6,73,852.5
17	Dept. of Physical Education	2432	12,22,080.0
18	Dept. of Biotechnology	1258	6,32,145.0
19	Dept. of Bioinformatics	1269	6,37,672.5
20	Dept. of Tamil	1269	6,37,672.5
21	Dept. of Mathematics	1269	6,37,672.5
22	Dept. of Human Genetics	1663	8,35,657.5
23	Advance Science Lab	1582	7,94,955.0
24	Central Instrumentation Centre	1526	7,66,815.0
25	Dept. of Botany	2790	14,01,975.0
26	Dept. of Psychology	2790	14,01,975.0

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27	Dept. of Social Work	2790	14,01,975.0
28	Dept. of Textiles	2790	14,01,975.0
29	Dept. of History	2790	14,01,975.0
30	Dept. of Population Studies	2790	14,01,975.0
31	BU-DRDO Centre for Life Sciences	1745	8,76,862.5
32	Library	1860	9,34,650.0
33	Nachimuthu Seminar Hall	1203	6,04,507.5
34	Multipurpose Hall*	366	1,96,176.0
35	Usha Kirtilal Mehta Convention Centre**	1766	10,64,898.0
36	BU-DRDO Guest House	2369	11,90,422.5
37	School of Distance Education	1819	9,14,047.5
38	Book Storage Godown	377	1,89,442.5
39	Outdoor Stadium Building	252	1,26,630.0
40	Indoor Stadium**	1765	10,64,295.0
41	Animal House	340	1,70,850.0
42	Panel Room	214	1,07,535.0
43	Bus Service Station	388	1,94,970.0
44	Food Court, Stationary and Amenities	434	2,18,085.0
45	Power House 1&2	469	2,35,672.5
46	Swimming Pool Complex	1051	5,28,127.5
47	Canteen	1131	5,68,327.5
48	Over Head Tank Office	225	1,13,400.0

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49	Thiruvalluvar Hostel	705	3,54,262.5
50	Elango Hostel	1585	7,96,462.5
51	Kambar Hostel	1441	7,24,102.5
52	Sekhizhar Hostel	1071	5,38,177.5
53	Gents/Sports Hostel	2501	12,56,752.5
	Total	**76456**	**3,87,86,266.5**

* RWHP = Area (m^2) x Rainfall (mm) x Runoff Coefficient (Cr)
Cr: Tiles (0.75), Asbestos* (0.8), Metal sheet** (0.9)
Annual Rainfall - 670mm.

Table 3. Rooftop Area of Buildings and Rainwater Potential in South (Academic) Campus

Sl. No	Name of the Building	Rooftop Area (m^2)	Rainwater Potential (Litres)
1	Residence of the Vice Chancellor	936	4,70,340.0
2	Type A Residence (9)	1755	8,81,887.5
3	Type B Residence (14)	2018	10,14,045.0
4	Type C Residence (20)	2324	11,67,810.0
5	Type E Residence (10)	595	2,98,987.5
6	Type F Residence (10)	644	3,23,610.0
7	Common Dining Hall	380	1,83,312.0
8	Periyar Hostel	1250	6,28,125.0
9	Kannamma Hostel	1557	7,82,392.5
10	Kasthuribai Hostel	1820	9,14,550.0
11	Vasuki Hostel	2501	12,56,752.5
12	Chellammal Hostel	1071	5,38,177.5

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13	Health Centre	264	1,32,660.0
14	International-Students Hostel	1905	9,57,262.5
15	Academic Staff College Guest House	1153	5,79,382.5
16	University Guest House	210	1,05,525.0
	Total	**20383**	**1,02,42,457.5**
	Grand Total(South + North Campus)	**96839**	**4,90,28,274.0**

* RWHP = Area (m^2) x Rainfall (mm) x Runoff Coefficient (Cr)
Cr: Tiles = 0.75
Annual Rainfall - 670 mm.

The campus comprises 69 buildings with varied rooftop types, as detailed in Table 4. Among these, one building features an asbestos roof, two buildings have galvanized iron (GI) rooftops, and the remaining 66 buildings are equipped with tiled roofs over reinforced concrete. The rooftop areas range from 214 m^2 to 4,278 m^2 in the north campus and from 210 m^2 to 2,501 m^2 in the south campus. Runoff coefficients of 0.8, 0.9, and 0.75 were applied for asbestos, GI, and tiled roofs, respectively. The total annual rainwater harvesting potential of the campus was estimated at **49,028,274 l**iters. The north campus, with a total catchment rooftop area of 76,456 m^2, accounted for **3,87,86,266.5** liters, contributing to 80% of the total harvest. In comparison, the south campus, with a catchment rooftop area of 20,383 m^2, contributed **1,02,42,457.5** liters, making up 20% of the total. Notably, over 90% of the harvested roof water originated from tiled surfaces, while the remaining portion was collected from GI and asbestos rooftops.

Table 4. Rooftop type and Rainwater Harvesting Potential

Sl. No	Type of Roof	No. of Buildings	Area (m^2)	Run of Coefficient (Cr)	Annual Rainfall (mm)	Rainwater Potential (Liters)
1	Asbestos sheet	1	366	0.8	670	1,96,176.0
2	Galvanized Iron sheet	2	3531	0.9	670	21,29,193.0
3	Tiles roof (North Campus)	50	72559	0.75	670	3,6460897.5
4	Tiles roof (South Campus)	16	20383	0.75	670	1,02,42,457.5

Total	69	94839	4,90,28,724.0

Annual Water Demand (Liters) : 13,36,91,625
Annual Siruvani Water Supply (Liters) : 7,08,08,000
Groundwater Supply : 6,28,83,625
RTRWH Potential : 4,90,28,724
Domestic requirement : 8,43,87,750
Flush requirement : 4,60,18,875
Laboratory requirement : 32,85,000

The current demographic data indicates that 2,270 students reside in the hostel, while 315 members reside in the university staff quarters. Additionally, approximately 1,700 day scholars frequent the campus, comprising teaching and non-teaching faculty, students, university employees, and personnel from the bank, post office, stationery shops, food court, health center, and visitors. According to BIS (1993) guidelines for educational institutions, 135 liters of water per person per day is recommended for boarding and domestic members, whereas non-boarding members require 45 liters per person per day.

Furthermore, the campus houses 30 laboratories, each utilizing an average of 300 liters of water daily for experiments. Students typically take a two-month vacation and observe government-declared national holidays. For calculations, 365 days were considered for campus residents and 300 days for other categories. Analysis revealed an annual water requirement of 9,19,35,000 liters for hostel residents, 1,55,21,625 liters for residential members, and 2,22,75,000 liters for day scholars. Employees of essential services and visitors consume an estimated 6,75,000 liters, while laboratories require 32,85,000 liters annually. The domestic water demand (hostel and residence) was found to be five times higher than the demand for day scholars. The total annual water demand for the campus was calculated at a staggering 13,36,91,625 liters (refer to Table 5).

Table 5. Annual Water Requirement of the campus

Sl. No	Category	No: of Persons	Water Supply CGWA Norms L/H/D	Domestic	Flushing	Water Required l/d Domestic	Water Required l/d Flush	Water Demand Lpd (D+F)	Ann. Domestic. Demand (Litres)	Ann. Flush Demand (Litres)	Total Annual Demand (D+F) (Litres)
1	Hostel members (300 days)	2270	135	90	45	204300	102150	3,06,450	61290000	30645000	9,19,35,000
2	Resident	315	135	90	45	28350	14175	42,525	103477	517387	1.,55,21

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	members (365 days)								50	5	,625
3	Day scholars (Teaching Staff , Non-teaching Staff, Students,Visitors - 300 days)	1650	45	25	20	41250	33000	74,250	12375000	9900000	2,22,75,000
4	Employees of Bank, Post-Office, Stationary, Food Court and Health Service (300 days)	50	45	25	20	1250	1000	2,250	375000	300000	6,75,000
5	Laboratories.	30	300					9000			32,85,000
	Total					**275150**	**150325**	**4,34,475**	**84387750**	**46018875**	**13,36,91,625**

Currently, this demand is partially met through Corporation (Siruvani) water, which supplies 7,08,08,000 liters, while the remaining 6,28,83,625 liters is sourced from borewells. Groundwater is either pumped to overhead tanks for supply or used directly for gardening. An analysis of rooftop rainwater harvesting (RTRWH) potential revealed that rainwater harvesting alone cannot fully meet the campus's water demand but can contribute significantly. The study estimated that 30% of the campus's water requirement could be met through effective implementation of RTRWH, particularly for flushing and laboratory utilities, while also reducing groundwater extraction by 75%. This conservation effort would provide ecosystem benefits, mitigate global warming to an extent, and enhance sustainable water management.

A perusal of literature reveals the successful implementation of rooftop rainwater harvesting (RTRWH) systems worldwide. In Sweden, despite an annual precipitation as low as 508 mm, rainwater harvesting from rooftops has proven effective, with substantial volumes being utilized at the household level, conserving significant amounts of drinking water (Villarreal and Dixon, 2005). Similarly, the United Nations Development Programme (UNDP, 2013) successfully installed 2.5 m^3 storage tanks in homes with 74 m^2 rooftops in Guanajuato, Central Mexico, where the average annual rainfall is 455.3 mm.

In India, RTRWH systems have been widely recommended and implemented to address growing water demand in Vardaman College of Engineering, Hyderabad, thereby completely satisfying the drinking water requirement and reducing the pressure on groundwater (Hari, 2019). At Anna University, Chennai, RTRWH achieved self-sufficiency, even under conditions of 50% dependable rainfall (Krishnaveni and

Rajkumar, 2016). An investigation at Bansal Institute of Engineering and Technology (BIET) campus, Lucknow, revealed that 50,171.94 m^3 of rainwater could be harvested annually, sufficient to meet campus requirements (Kumar et al., 2023).

Similarly, studies at Dr. Babasaheb Ambedkar Marathwada University Sub-campus in Osmanabad, Maharashtra, found that 3,714,450 liters of harvested rainwater could meet the drinking water needs of faculty and students (Patel, 2023). At RK University, Rajkot, Gujarat, a RTRWH system could collect 3,230,525 liters of rainwater annually, satisfying the institution's drinking water demands (Gohel et al., 2020). Anchan and Shiva Prasad (2021) demonstrated that South India University (SIU), Mangalagangothri, Mysuru, harvested 113,678.9 m^3 of rainwater annually from 19 selected rooftops, which was utilized for washing, flushing, cleaning, and gardening. Furthermore, at Mangalayatan University in Aligarh, Uttar Pradesh, an annual harvest of 1,03,97,025 liters of rainwater supplemented the existing water system (Priyadarshini et al., 2018).

Seasonal rainfall data analysis (Figure 3) indicates that the maximum quantity of rainwater can be collected during the months of October, November, and December, when the northeast monsoon is at its peak. This period provides an opportunity to harvest significant amounts of water for use during the dry season (January to April) when precipitation is minimal. Mishra et al. (2020) demonstrated that 6,109.42 m^3 of RTRW harvested during the monsoon months could meet non-monsoon water requirements at Amity University, Mumbai. Similarly, Revelo-Garcia et al. (2023) showed that 5,718 m^3 of water collected from the rooftops of two buildings at FCITEC, Autonomous University of Baja, California, helped meet campus water consumption, offering both environmental and economic benefits such as conservation of water resources, energy savings, savings and return investment.

In Rajiv Gandhi University of Knowledge Technologies, Srikakulam Campus, Kiren and PremKumar (2023) recommended RTRWH as the best solution to meet 13% of the university's total water demand. Analysis of historical rainfall data reveals significant variation, ranging from a minimum of 285.4 mm in 1974 to a maximum of 1,299 mm in 1979, with normal annual rainfall in Coimbatore ranging from 600 mm to 900 mm. This variability, coupled with unusually heavy rainfall due to climate change, presents an opportunity to implement extensive rainwater harvesting activities at the university campus. This approach would improve water management practices, reduce pressure on the Coimbatore city corporation's water supply, and limit groundwater extraction in the campus area thereby reducing the gap between water demand and supply.

Currently, rainwater runoff from rooftops flows through sewage channels into canals or rivulets. Yannopoulos et al. (2017) stated, "Worldwide, rainwater harvesting has regained importance as a valuable water resource, either as an alternative or supplementary source in conjunction with more conventional water supply technologies." Our study confirms that implementing rooftop rainwater harvesting is highly relevant to the university campus both now and in the future. With the expected increase in population and water demand due to the expansion of the university, RTRWH offers a promising solution to meet future water needs and support self-sustainability.

4. Conclusion

The rooftop rainwater harvesting potential (RTRWHP) of all buildings within the Bharathiar University campus was assessed based on rooftop area, annual rainfall, and the runoff coefficient. The findings reveal that rooftop rainwater harvesting is a practical and sustainable solution, given the campus's average annual rainfall of 674 mm. If rainwater is systematically collected from all building rooftops, it could fulfill nearly one-fourth of the campus's water demand, significantly reducing reliance on municipal water supply by over 50% and alleviating pressure on groundwater resources by almost two-thirds. When properly implemented, a rooftop rainwater harvesting system (RTRWHS) can serve as a reliable source of water conservation. By treating and disinfecting the stored rainwater and employing effective management practices in the conveyance system, this high-quality, soft water can become a cost-effective alternative to traditional water sources, addressing the campus's water stress effectively. Future studies should explore the potential for harvesting additional water sources, such as surface runoff and upland flow, across the entire campus. Planning and constructing suitable storage structures like ponds and reservoirs at strategic locations will be essential to enhance both surface and groundwater resources. Furthermore, the impact of rainwater harvesting on groundwater recharge, campus gardening, and sustainable development should be thoroughly investigated to establish a long-term solution to the university's water demand.

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