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Climatic Water Availability and Rainwater Harvesting in Imphal City, Manipur

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Abstract
Opportune utilisation of water can help protect the environment and minimise energy used to process and pump water for daily use. Rainwater is considered a renewable resource and the system of harvesting is sustainable, which can help in reducing vulnerability to climate change. Due to water scarcity, domestic rooftop rainwater harvesting (DRWH) is being practiced in Imphal as an alternative source of water for the urban water supply. However, not all households are aware of the potential of rainwater harvesting. This indicates that the climatic water availability to be quantified determines rainwater potential. DRWH also minimises water bills and lowers water demand. Regardless of its benefits, this resource is wasted, especially in the city of Imphal, where demand is high. This article finds out the potential climatic water availability adjusted with the water losses through evapotranspiration; analyses the characteristics of annual and monthly rainfall; DRWH maximum potential; and a plan for using rainwater by finding out potential water reserves.

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I. Introduction

Climate change is altering weather patterns, which causes extreme weather conditions, unpredictable water availability, a worsening of water scarcity, and contaminated water supplies. This has a significant impact on the quantity and quality of water that humans require to survive. As a consequence of both natural and anthropogenic causes, many areas throughout the world are experiencing what is known as "water scarcity," or an insufficient quantity of water to meet local demands. Water isn't spread out evenly over the Earth's surface, and a lot of it is wasted, polluted, or mismanaged. The main causes of the water shortage are the growing demand for freshwater and the diminishing supply of freshwater sources. Physical water shortage and economic water scarcity are two forms of scarcity. When a region's natural water supply is inadequate, it faces a physical water shortage. The economic water shortage is caused by the wrong way water resources are being used.

Water scarcity is an acute problem in many densely populated regions. Rainwater harvesting systems can be a solution to this issue, providing households and businesses with water for use during dry seasons and relieving pressure on municipal systems. Rainwater harvesting usually involves large cisterns or multi-barrel systems that can store enough water to help sustain us through our long, dry summers. It provides distributed containment of rainwater while storing water that can be used for irrigation, toilet flushing, washing clothes, car washing, pressure washing, or treated for daily use as drinking water. Rainwater harvesting can reduce the load on combined sewer systems during rainy periods, helping to reduce the risk of system overflows entering streams, lakes, or seawater directly. In order to solve the problem of not having enough water, we need to know how much water could come from rain by figuring out the seasonal and annual patterns.

The two physical factors that have the greatest influence on a region's water availability are rainfall and temperature. In the past, people did not think that rainfall was the main source of water that aided in the recharge of groundwater and the rivers. The first person to state that all stream flow was caused by precipitation and infiltration was the potter, Bernard Palissy. In his book Admirable Discourses (1957), Palissy stated that "all fountains come only from springs fed by rain" (Deming D, 2021).

The availability of water in a region's climate is not, however, solely based on rainfall. Rain that falls on the earth evaporates back into the atmosphere, and plants release water vapour from their leaves during transpiration. Together, these actions are referred to as evapotranspiration. Temperature, humidity, wind speed, and solar radiation are just a few of the variables that affect how much water evaporates. Heat, or temperature, is the primary force behind evapotranspiration. Actual and potential evapotranspiration are the two types of evapotranspiration. The quantity of water that transpires and evaporates from plants and soil is known as actual evapotranspiration. The volume of water that would evaporate and transpire in the absence of atmospheric factors like humidity, wind, and temperature is known as potential evapotranspiration. Understanding the pattern of rainfall and water loss due to evapotranspiration in a given area can provide information about climatic water availability. A potential estimate of rainwater harvesting could then be examined.

The population of Imphal has increased by a great deal over the past few years, and there has been an increase in industries as well. This leads to more demand for water, and it is not being met. Water scarcity in Imphal is a major issue. A lot of people are forced to drink unclean water because they can't afford it. This is a problem that needs to be solved as soon as possible before the situation becomes worse. The water supply in Imphal is not reliable due to the lack of infrastructure and the high demand for water. The population of this city is about 2.6 million (census, 2011), which is a huge number when it comes to water consumption.

Rainwater harvesting is considered to be an effective alternative water source strategy to increase water supply capacity (Motsi, Chuma and Mukamuri, 2004). Collection systems not only provide water during difficult times but also constantly replenish aquifers, ensuring that groundwater does not sink too low. The fact that rainwater harvesting could be a possible source of water supply was recognized through samples from roofing systems. Harvesting rainwater from rooftops could help authorities deal with this water shortage crisis, as studies have shown that rainwater collected from rooftops is potable and should only be used for secondary purposes. If all households collected rainwater, the number would be impressive. This can relieve huge pressure on the current water supply.

Hence, the objective of this study is to quantify Climatic Water Availability and analyse the potential and prospects of Rainwater Harvesting in Imphal City by using rainfall and temperature data from Imphal (Tulihal) meteorological station.

Study Area

Imphal City, the capital of Manipur, is situated in north-eastern India between 24°46'60"N and 24°51'0"N latitude and 93°52'30"E and 93°58'30"E longitude (figure 1). The valley is situated in the state's centre, surrounded by hills on all sides. It is 1,200 meters above sea level on average (3,900 feet). According to the Ministry of Housing and Urban Affairs, the number of households in Imphal City is 55,657. Imphal city has 264 986 population, according to the 2011 census. The city has a semi-humid (Cwg) monsoon type characterized by cool, dry winters and hot, humid summers. Throughout the year, the region has mild temperatures that are neither very hot nor too cold.

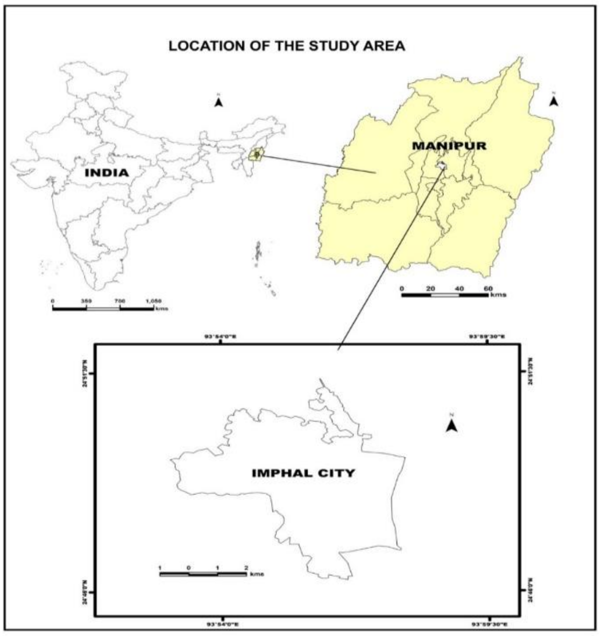


Fig. 1: Study area location

The average temperature of Imphal is 21.7°C. According to CAU, Imphal, the average maximum temperature in Imphal is 29.4°C in the month of June, while the average minimum temperature is 4.3°C in the month of January. The average annual rainfall is 1518.36 mm. The wettest month is July, with a total rainfall of 253 mm. The least rainy months are January and February (12.8 mm and 13 mm, respectively), which are the driest.

II. Materials and Methods

Rainfall and temperature data: Rainfall and temperature data of Imphal City from the year 2008 to 2018 were collected from the Indian Meteorological Department (IMD), Imphal. TMRF i.e., Total Rainfall in the Month (in mm) data were utilised in analysing average monthly rainfall, annual rainfall, climatic water availability and the potential rainwater collection.

Tab. 1: Distribution characteristics of monthly rainfall in IMF (mm)

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Month Max	256 (vii)	203 (viii)	300 (vii)	333 (vi)	200 (ix)	348 (vii)	300 (vi)	308 (vii)	310 (v)	358 (vii)	319 (vi)
Month Average	105	84	133	111	96	129	87	114	133	168	95
Rainfall 3-10	1197	973	1527	1306	1064	1547	1026	1314	1504	1883	1123

Source: Indian Meteorological Department (IMD), Imphal

Estimation of potential climatic water availability: Climatic water availability depends on two main factors, rainfall and temperature. Rainfall represents the amount of water an area gains while temperature by providing the energy that drives the process of potential evapotranspiration determines the amount of water loss (Mangalleima, 2011). The water availability of Imphal has been calculated as follows:

Total rainwater falling over the city

The total area of Imphal = 34.48 sq. km or 34,480,000 sq. m

Annual average rainfall = 1373 mm or 1.37 m (height of rainfall)

Therefore, 34,480,000 × 1.37

= 4,72,37,600 cubic metres or 4,72,37,600,000 litres

= 12, 94, 18,082 million litres per day (MLD)

The gained water through rainfall has to be adjusted with the loss factor which is evapotranspiration. There are two types of evapotranspiration. Actual and potential evapotranspiration. For this study, potential evapotranspiration is used to determine the loss. There are many methods and formulas for finding potential evapotranspiration. The present study, however, uses Thornthwaite's method for 25° N latitude from (January to December). Imphal is located at 24°N latitude and 93°E longitude in extreme eastern India. The formula for determining Thornthwaite's potential evapotranspiration is given below.

To calculate Potential Evapotranspiration (PET) using the Thornthwaite method, first, the Monthly Thorthwaite Heat Index (i) calculation is required, using the following formula:

$$\text{i} = \left(\frac{t}{5}\right)^{1.514}$$

where *t* is the mean monthly temperature.

The Annual Heat Index (I) is calculated, as the sum of the Monthly Heat Indices (i):

$$\sum i$$

A Potential Evapotranspiration (PET) estimation is obtained for each month, considering a month is 30 days long and there are 12 theoretical sunshine hours per day, applying the following equation:

$$\text{PET } (\textit{unadjusted}) = 16\left(\frac{10t}{I}\right)^{\alpha}$$

Where α is

$$\alpha = 6.75 \cdot 10^{-7} \cdot I^3 - 7.71 \cdot 10^{-5} \cdot I^2 + 1.792 \cdot 10^{-2} \cdot I + 0.49239$$

Obtained values are later corrected according to the real length of the month and the theoretical sunshine hours for the latitude of interest, with the formula:

$$\text{PET} = \text{PET } (\textit{unadjusted}) \cdot \text{adjustment factor}$$

Tab.2: Monthly variation in Potential Evapotranspiration (PET)

Months	Mean Temperature(*t*) °C	Heat Index (i)	PET (*unadjusted*)	Adjustment Factor	PET (mm/month)
January	14.4	4.96044	29.61	0.93	27.54
February	16.7	6.208006	42.85	0.89	38.13
March	20.2	8.280592	68.86	1.03	70.93
April	22.8	9.946557	93.14	1.06	98.73
May	24.4	11.02218	110.30	1.15	126.85
June	26	12.1347	129.23	1.14	147.32
July	26.2	12.2763	131.73	1.17	154.12
August	26.2	12.2763	131.73	1.12	147.53
September	25.7	11.92335	125.55	1.02	128.06
October	23.6	10.47968	101.50	0.99	100.49
November	19.2	7.667918	60.67	0.91	55.21
December	15.1	5.330041	33.33	0.91	30.33
		I =112.5061			

Tab.3: Monthly Variation in Water Balance

Months	PET	Rainfall (mm)	Water Balance
January	27.54	12.85	-14.68
February	38.13	13.16	-24.97
March	70.93	64.94	-5.99
April	98.73	138.82	40.09
May	126.85	181.91	55.06
June	147.32	231.51	84.18
July	154.12	253.28	99.16
August	147.53	180.29	32.76
September	128.06	151.98	23.92
October	100.49	112.59	12.10
November	55.21	16.06	-39.15
December	30.33	15.16	-15.17

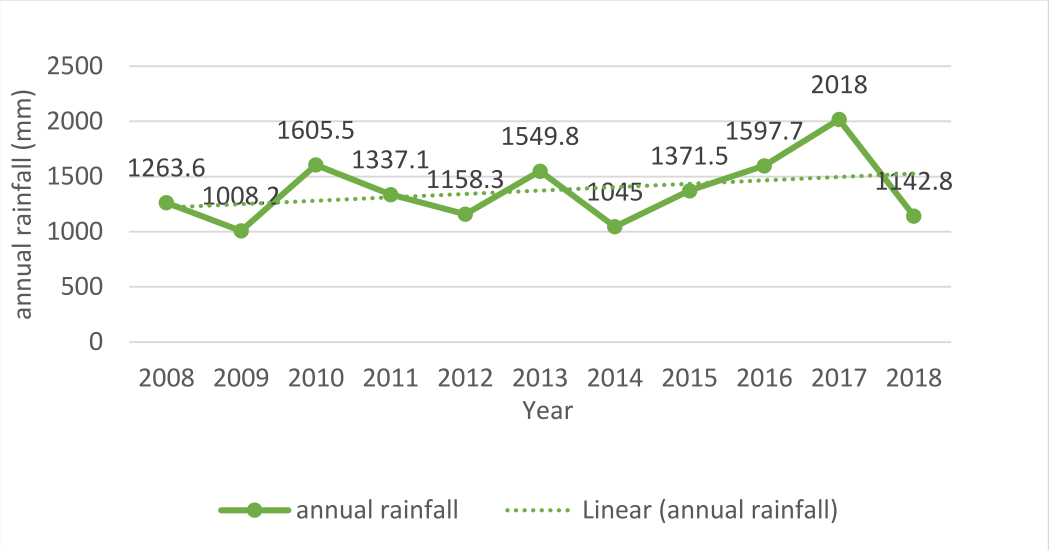
The plan for using rainwater for Imphal City: For calculating the amount of rainwater that can be harvested, the annual mean precipitation data is commonly used. Mean annual rainfall is the statistical average derived from multiple years of rainfall measurements.

If every home in Imphal could collect rainwater, the total capacity would be substantial.Imphal has approximately 0.05 million households; the average roof area is 120 m^2. With an average annual rainfall of 1373 mm, water reserves are 120 m^2 × 1.373 m (1373 mm) × 0.05 million = 8.238 million m^3. In other words, a sizable water reservoir will result from the combination of numerous "small tanks." If each individual house has 4.4 people and often uses about 790 litres of water per day, the rainfall that would be lost can be recovered for use against the total amount of water per day: (120 m^2 × 1.373 m): (790 litres × 365 days) × 100 = 57%. It is possible to use rainwater collected for this demand because a family's total water consumption for sanitation accounts for 22% of the total water used by a family.The Remaining could be used in other domestic chores.

III. Result and discussion

Annual and monthly Rainfall: Imphal lies in the climatic zone of Tropical Monsoon climate. The southwest monsoon is the main factor for its abundant rainfall. The total amount of rainfall reached 15098 mm and the average annual rainfall in the period of (2008 – 2018) reached about 54 inches (1373 mm) which are higher than the annual national average (1182.8mm) by 13%. In 2017, annual rainfall passed the level of 2000 mm. The minimum rainfall of 1008 mm occurred in 2009.

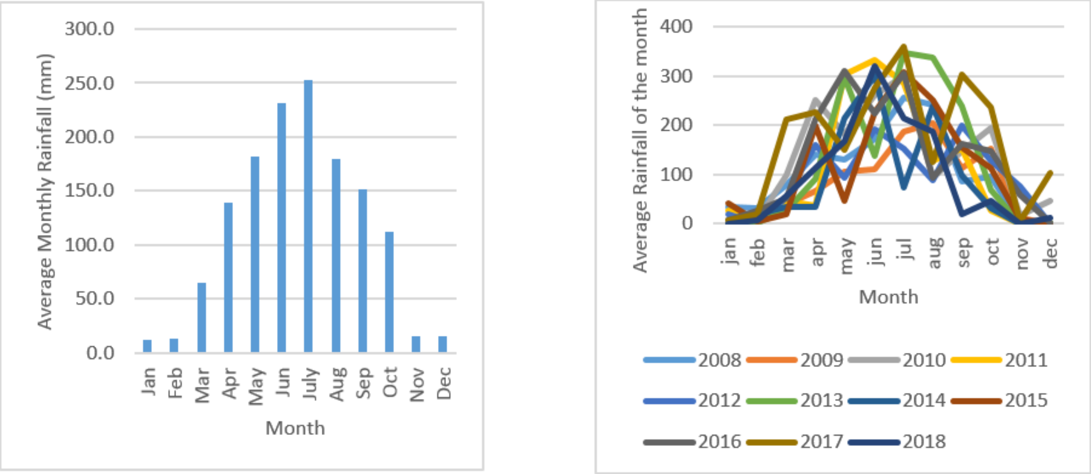
Fig. 2: Annual rainfall in the period (2008-2018) in Imphal City



The graph of annual rainfall shows fluctuation initially until 2014, where continuous increment occurred till 2017 thereafter followed by large drop in rainfall in 2018 (Fig: 2). Nevertheless, the linear trend line indicates steady increase in rainfall.

Fig. 3:(a) Average Monthly Rainfall (2008 – 2018) (b) Distribution of Rainfall in Imphal (2008 - 2018)

(a) (b)



Analysing monthly rainfall clearly depicts the monsoonal characteristics where the concentration of rainfall occurs during the summer season and decreases during the winter. Imphal starts receiving a good amount of rainfall from the month of April till October. July is the wettest month (with the highest average rainfall) with 253 mm. January and February are the driest months with the least rainfall (12.8 mm and 13 mm, respectively).

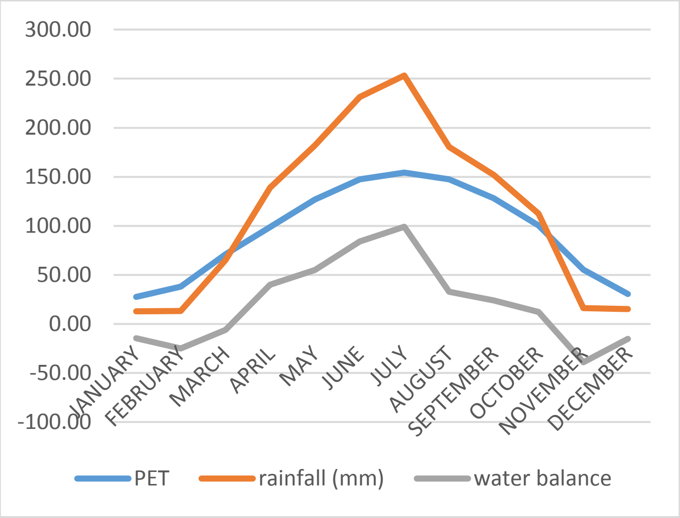
In the Koppen climate classification, wet months are defined as months with an average precipitation of 60 millimetres (2.4 inches) or more for tropical climates. The rainy season in Imphal is relatively long, almost evenly distributed from March to October during the period of 2008–2018. These months receive 60 mm or more of rainfall. The maximum monthly rainfall reached 200–358 mm in the period from 2008–2018. The average monthly rainfall during the rainy season was between 64 and 253 mm.

Rainfall patterns are fairly distributed as described above, which is very convenient for the design of tanks with an appropriate storage capacity. For every community to build a sustainable water resource path, the practice of rainwater harvesting is crucial and significant. Due to a variety of problems, including increased infrastructure costs, uncertain weather patterns, and rising national consumption, water costs are rising. These technologies must be viewed as prudent investments by all households. However, some rainwater harvesting incorporates less expensive containers and collects a sizable amount of water, making it a viable substitute for urban water supplies for a variety of needs.

Potential Climatic Water Availability: Rainfall that contributes to springs, rivers, stream flow, ponds, aquifers and other water bodies determines how much water is available in a region. Therefore, the theoretical water availability of a region can be estimated by considering the amount of rainfall a region receives. Imphal city covers an area of about 34.48 km2 and receives an average annual rainfall of 1373 mm. Therefore, the potential water availability according to rainfall is 472,37,600,000 litres and 12, 94, 18,082 million litres per day.

Thornthwaite's Potential Evapotranspiration (1948): PET value of January, February, March, November and December is greater than the value of rainfall (Tab.2). This results in negative water balance during these months. The analysis of the water balance showed water surpluses in April-October and water deficit in November-march (Fig. 4). The highest surplus was in July with 99.16 mm while the highest deficit was in February with -24.97 mm. The southwest monsoon winds weaken and start to leave the area in the months of October and November. Water availability during this period is very low. Hence, the study area experienced a water deficit in these months. This phenomenon suggests improvement and enhancement in water storage tanks.

Fig. 4: Water Balance Graph of Imphal City



Total capacity of rainwater: Calculating the total capacity of rainwater that could be collected in the study area, shows that about 8.238 million m3 is available for reserve. The average household size in the country is 4.4 people. It is calculated by dividing the household population by the total number of households. Assuming that a person uses about 790 litres of water per day, 57% of the total could be derived from available rainwater. Sanitation accounts for about 22% and other remaining could be used in gardening, car washing and other general household cleanings. This can give relief during water shortages and to the urban water supply. Many urban households in Imphal purchase drinking water tankers whose prices are very high.

IV. Conclusion

The amount of rainwater available in Imphal City is quite sufficient to use for household requirements or as an alternative to the urban water supply maintained by the PHED department. The climatic water availability can be categorised as good enough to assist in the deficit period with improvement in storage. Hence, the potential of rainwater harvesting as an alternative to the urban water supply is real. Although adjusting water loss shows a negative water balance in some months, such rainwater harvesting systems, if well-designed, may be able to meet a considerable demand for domestic water supply. More awareness of this resource is urgently needed as many urban dwellers suffer during water cuts. Even the households that are already collecting rainwater do not reach the maximum potential. Decentralized rainwater management, including retention, storage, and reuse strategies that are integrated into spatial planning and urban design, can reduce flood risks while simultaneously enhancing freshwater availability.

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