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Assessment of Rainwater Harvesting Potential for Non-Potable Use: A Case Study in Debre Tabor University, Ethiopia

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Abstract

Freshwater is expected to become increasingly scarce as temperature and sea levels rise due to Global Climate Change. Water reuse and conservation at different levels is so essential to meet the current water demands. One of the best ways to conserve water at a university level is installing small scale rainwater harvesting system for the demands of the shower, laundry, plant growth, and construction requirement within the campus. The purpose of this study was to determine the rainwater harvesting potential and analyze the significance of a rainwater harvesting system for non-potable use in the university and urban areas. The evaluation of rainwater harvesting was done through surveying and analysis of roof catchment, channel networks, and rainfall data. The evaluation of rainwater potential was followed by the design and characterization of the rainwater harvesting system components. The investment required for rainwater harvesting in the campus was very small since it only requires the construction of storage tank, treatment of water by providing sedimentation tank, alum, and chlorination, and pump cost for lifting the water from the final treatment tank to the distribution system. The results of this study indicated that installing a rainwater harvesting system is economical to address the water scarcity problem in the university. In Debre Tabor University, the available water to be collected from 13 dormitory buildings and the open surface area was 10372.35 m^3, 24,671.43 m^3, 41510.99 m^3 values of minimum, the average and maximum volume of water respectively. This revealed that there is a huge amount of water which is sufficient enough to meet the demand for non-potable uses. Hence, as climate change continues to threaten parts of the world; individuals and organizations must take micro steps to overcome the effect of climate change on water scarcity. Therefore, the adoption of rainwater harvesting technologies in the university will play a great role in reducing water scarcity and making a conducive environment.

Keywords: Rainwater harvesting; Water scarcity; Non-potable uses; Thomas and Fiering model

Introduction

The amount of water present on the earth is almost constant. This is due to the transformation of one form of water to another in a specified manner. Though two-thirds of the earth is filled with water, the usable water for irrigation and drinking purpose is only two percent of the total available. So, proper management of the available water is very important for the sustainable utilization of water for different purposes. The major share of usable water is found underground in the aquifers. An increase of groundwater storage in the aquifers has been detected as a direct measure of water richness. Nowadays rainwater harvesting plays a major role for reducing surface and underground water scarcity problem in tropical and dry land areas [1].

A technology of collecting and storing rainwater from land surface catchments, and rooftops using different and simple techniques such as jars and pots and complex techniques as underground check dams have been termed as rainwater harvesting [2]. The harvested water from rain serves as a major source of drinking water supply, irrigation, gardening, construction purpose, and recharging groundwater. The commonly used rainwater harvesting system has three main components namely the catchment area, conveyance and the collection system [3]. Rainwater harvesting is a technique is used to effectively trap the surface runoff. In technical terms, water harvesting is a system that collects rainwater from where it falls around its periphery rather than allowing it to go as runoff. By constructing water harvesting structures in appropriate sites it is possible to increase the groundwater recharge and level of the water table so that we can effectively use the water for irrigation and drinking purpose in the off-monsoon season. Also, these structures act as a barrier to soil erosion and prevent flooding. Percolation Ponds, Subsurface Dykes, Farm Ponds, Check Dams, Bunds, etc. are some of the types of water harvesting structures that are widely in use [4].

Research Methodology

Location of study area

The project area is located in Debre Tabor University, Debre Tabor, Ethiopia male technology faculty student's dormitory and it lies between 110 51' 15.71" to 110 51' 29.52" North latitude & 380 02' 21.1" to 380 02' 35.31" East longitude. It covers a total area of 39819.51 m^2 from this 10177.74 m^2 area is covered by buildings and the rest 29641.77 m2 is space grassland. So, this project will propose and design to collect and treat the rainwater from the Technology faculty dormitory and office area. That means enclosed with 2-channels, and the area is consists of the dormitory and other blocks (B-53, B-54, B-55, B-56, B-57, B-58, B-61, B-62, B-63, B-64, B-67, B-68, and B-144) and the spacing with them. From this area total of 10372.35 m^3, 24,671.43 m^3, 41510.99 m^3 minimum, the average and maximum volume of water flow respectively will be collected. Then to collect,

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treat and use this huge amount of water resource rainwater harvesting is very essential technique (Figure 1).

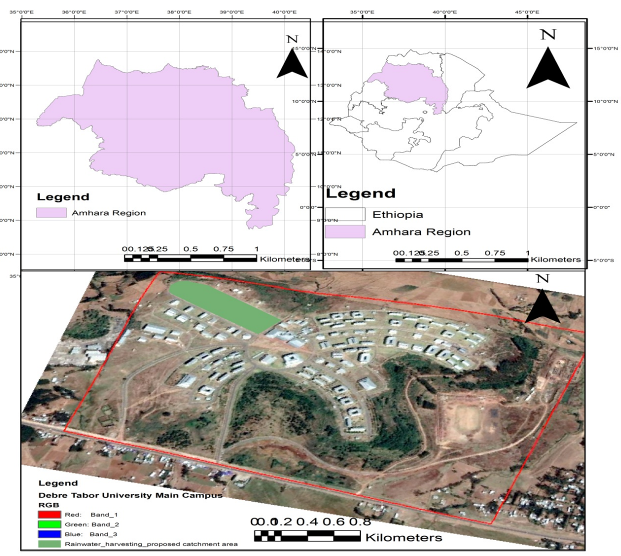

Figure 1: Location map of Debre Tabor University, Ethiopia.

Description of Thomas and Fiering model

Stochastic simulation of hydrologic time series has been widely used for solving various problems associated with the planning and management of water resources systems for several decades [5]. Stochastic monthly stream flow models are often used in simulation studies to evaluate the likely future performance of water resource systems [6]. Synthetically generated flows have many uses to the water resources planner. They are of equal importance as historic flows in simulation and optimization schemes used to study several feasible alternatives of planning, design, and operation of water resources projects [7]. The role of stochastic methods in water resources was first explored by Thomas and Fiering in the context of system design and operational studies through the generation of synthetic sequences of stream flow through Monte Carlo simulation. They developed a stochastic data generation model incorporating the serial correlation behavior of hydrologic data. This serial correlation model was an example of Markovian type models; that is a lag-one Markov model.

For the first type of models, the Thomas Fiering (TF) model can be regarded as a typical stochastic approach for forecasting in hydrology [8-11]. Harms and Campbell extended the TF model to preserve the normal distribution of annual flows, the lognormal distribution of monthly flows, and the autocorrelation of both annual and monthly flows. Modelers later disaggregated the annual flow requirement, usually data from a terminal reservoir, into the monthly flow requirements by establishing the correlation between annual and monthly flows [12].

The generated data sequences, particularly monthly time series such as stream flow or rainfall are widely used in water resources planning and management to understand the variability of future system performance. Stochastic data generation aimed at generating synthetic data sequences that are statistically similar to the observed data sequences. Therefore, the generated data is important for more accurate solutions of various complex planning, design and operational problems in water resources development (Figures 2-5).

Input for the model

To carry out this study a historical rainfall depth data of adjacent meteorological station is required then after the computation of the projected or forecasted rainfall depth values the per capita demand and number of people which uses the water harvesting project is needed.

Thomas and Fiering used the Markov Chain model for generating monthly flows (by serial correlation of monthly flows) by using the following recursion equation.

$$q_{i+1} = \overline{q_{j+1}} + b_j\left(q_i - \overline{q_j}\right) + \varepsilon_i \delta_{j+1} \sqrt{1 - r_j^2} \qquad (1)$$

Where:

- q, q=discharges (RF depth) in the i and i+1 months, respectively
- , =mean monthly discharges in the j and j+1 months of the annual cycle
- bj = regression coefficient for estimating the discharge (RF depth) in the j+1 month from that in the j month.
- εi=a random normal deviate at time i with a zero mean and unit variance.
- σj+1 = standard deviation of discharges in the j+1 month
- rj = correlation coefficient between the discharges (RF depth) in the j and j+1 months.

The above Equation is called 'Lag-one single period Markov Chain Model', where the period may be the day, month or year.

Results and Discussion

Statistical comparison of historical and generated rainfall depth

By using the above equation of Thomas and Fiering and the historical daily rainfall depth values which are collected from Debre Tabor meteorological station for 25 years from (1992-2016) rainfall depth was generated. The generated average rainfall depth in millimetre for each month for the next 34 years which is from (2017-2050) is as follows in Table 1.

	Historic (1992-2016)			Generated (2017-2050)		
Month (j)	Mean (μ)	std. deviation (σ)	correlation (ρ)	Mean (μ)	std. deviation (σ)	correlation (ρ)
Jan	8.86	17.52	-0.12	11.15	11.75	0.14
Feb	4.40	8.24	0.05	6.74	5.24	0.37

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Mar	30.67	22.53	0.03	23.71	22.22	-0.15
Apr	47.04	31.43	-0.08	42.41	27.00	-0.21
May	108.74	64.96	0.10	88.25	69.40	-0.06
June	164.41	50.97	0.24	143.33	51.56	0.31
July	406.72	68.27	0.54	359.85	75.07	0.65
Aug	411.15	91.70	0.09	369.67	93.63	0.07
Sept	195.33	40.73	-0.08	188.44	39.88	-0.17
Oct	73.14	75.66	-0.14	66.80	59.13	0.07
Nov	28.14	26.22	0.01	28.65	22.70	0.08
Dec	14.55	17.85	0.06	11.64	15.90	0.25

Table 1: Statistics of observed and generated inflow using Thomas-Fiering model.

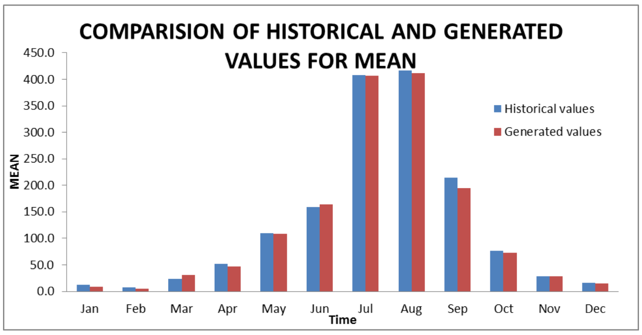

Figure 2: Comparison between mean monthly observed and generated Rainfall depth using T-F model.

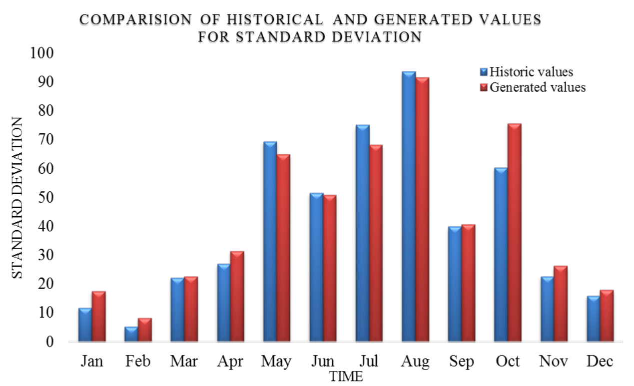

Figure 3: Comparison between standard-deviation of observed and generated Rainfall depth using T-F model.

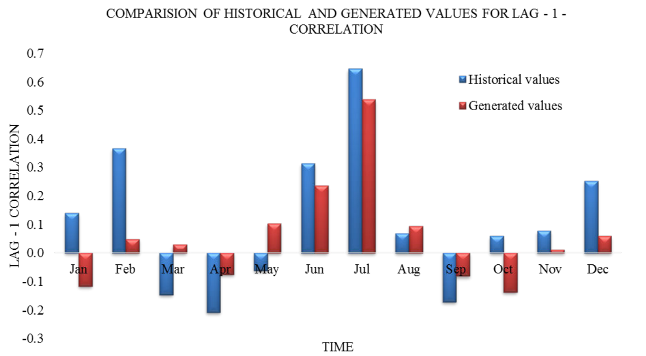

Figure 4: Comparison between correlations of observed and generated rainfall depth using T-F model.

As it can be seen above Thomas Fiering model between observed and predicted data in the validation period has been calculated. Results of Thomas Fiering model showed that the model is performed well for generating the synthetic rainfall depth for the project area. Because as seen in the above figures of statically value comparisons there is no big difference between the historic and the generated rainfall depth.

Computation of volume of water to be collected

In order to determine the proposed system capacity, designed and utilized a custom rainwater-harvesting computation of inflow volume to the collection and treatment plant and the demand of the users will be computed (Table 2). Then after computing the inflow and demand the treatment plant also designed to balance them. As follows:

Net harvesting potentia=Catchement area (m^2) × rainfall depth (m) × runoff coefficient

Where:

- The catchment area is in m which is collected by direct measurement and from Google Earth.
- Rainfall depth is in the meter which is the average value of generated depth by Thomas Fiering model.

- Runoff coefficient is taken as 0.85, 0.95 and 0.75 for channels, building a roof and free space enclosed the buildings respectively.

Month	Average Rainfall depth (m)	Area (m^2)			Water to be collected (m^3)	Water demand (m^3)
		channels	building roof	free space		
January	0.012	53.29	11013	27144.84	190.14	2081.4
February	0.007				112.04	2081.4
March	0.023				377.23	2081.4
April	0.052				834.34	2081.4
May	0.110				1775.06	2081.4
June	0.159				2580.41	2081.4
July	0.407				6595.05	693.8
August	0.417				6752.67	693.8
September	0.215				3474.10	693.8
October	0.078				1257.42	2081.4
November	0.028				461.26	2081.4
December	0.016				261.45	2081.4
Total Volume (m^3)					24,671	20,814

Table 2: Computation of volume of water to be collected averagely in between (2017-2050).

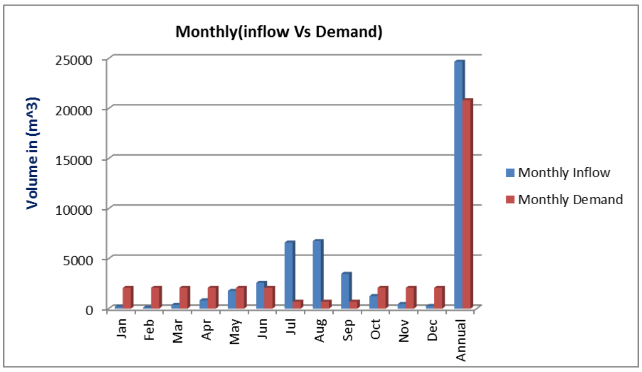

Figure 5: Monthly inflow vs. demand graph.

In the above table for computation of the Volume of water to be collected each year and the water demand computation the demand is calculated by considering the following:

- The water to be collected is used for non-portable use only not for drinking purpose.
- It is assumed that the average water requirement is 55 l/p/d for students and 35 l/p/d for office staff members.
- And the population to be supplied is 3064 students with 55 l/p/d and 1620 staffs and floating population in offices with 35 l/p/d demand.

Then to supply the demand of these populations throughout the year without water scarcity we need to collect the excess water in the rainy season by preparing a suitable tank. The tank capacity was constructed is computed by using sequent peak volume of tank analysis method without considering evaporation because it is very small i.e., evaporation is negligible in amount. The required tank volume is 379 m^3 capacities and is divided into three tanks as collection or sedimentation, coagulation tank, and chlorination tank so the sedimentation tank volume is fixed as 353.4 m^3 and the coagulation, as well as the chlorination tank, is 10 m^3 capacity synthetic tank capacity.

Cost and benefit comparison

The total cost of this specific project is 579,649.7 ETH Birr for material, equipment and labor costs. And the benefit of this project in terms of money is computed the total volume of water utilized each year multiplied by the cost of water per m^3 is 172,698 ETH Birr by taking 7 ETH-birr/m^3. The graph below in Figure 6 is comparison of cost and benefit for 10 years of utilization time of the Rainwater Harvesting project by considering 10% of initial cost of the project for maintenance and operation of the project for the next years and 20% of initial cost of the project in the 5th year of the project as an assumption (Table 3).

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Total Cost for the Construction of Rainwater Harvesting Project					
Sl. No	**Description of work**	**Unit**	**Quantity**	**Cost (birr)**	**Amount (birr)**
1	Quantity of earthwork with specified before	m^3	537	205	110,085
2	Site clearance	m^2	208	21	4,368
3	Quantity of RR masonry work	m^3	75	262.5	19,688
4	Quantity of cement bags	Bags	651	145	94,395
5	Quantity of sand	m^3	74	875	64,750.0
6	Quantity of aggregates	m^3	20	562.5	11,250
7	Steel bar 8 mm Dia.	Berga	158	250	39,500
8	Purchasing of 10,000 L tank from Bahir Dar	No	2	30000	60,000
9	Purchasing of 0.5 HP capacity pump from Bahir Dar	No	1	5000	5,000
10	Transportation cost for the above-said items 8 and 9 from Bahir Dar				5,000
	Adding above all the items				414,035.5
	Adding 15% VAT on above-said items			62,105.33	
	Adding 25% for miscellaneous items			103,508.9	
	Total cost			579,649.70	

Table 3: Quantity and cost of the rainwater harvesting project.

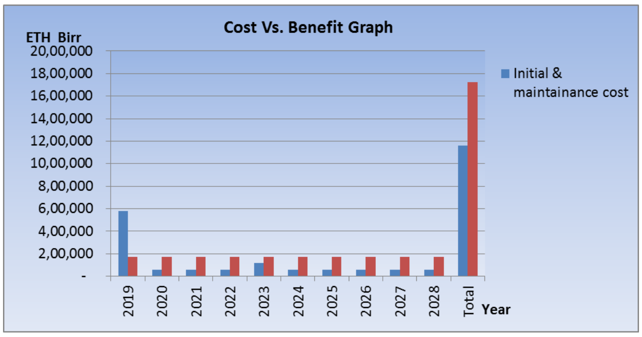

Figure 6: Cost and benefit comparison graph.

Conclusion

Water shortage is one of the critical problems in Debre Tabor University. This problem is not a new one, and it cannot be solved immediately. Therefore, rainwater harvesting is an effective option to provide adequate storage of water for future use by collecting summer rooftop catchment water for showering and plant growth by providing simple treatment. This paper tried to focus on the sustainability and effectiveness of rainwater harvesting system in terms of quantity and quality. Additionally, it assesses the cost-effectiveness as large amounts of money can be saved per year. Also, the project is used as a field practical learning resource for the students.

Generally, Rainwater harvesting is an essential technique to solve the water scarcity in every place for drinking, washing, plant growth by using the simple collection and treating method without requiring a huge investment. In universities, most of the time clean water with drinking standard is used for plants and washing purposes. But if Universities have their own small-scale rainwater harvesting it covers the demand for washing and plant growth by using simple treatment i.e., the rest demand is water demand for drinking and cooking purpose which is supplied from groundwater or surface water with full treatment.

References

1. Naseef TAU, Thomas R (2016) Identification of suitable sites for water harvesting structures in Kecheri River Basin. Procedia Technology 24: 7-14.
2. Sivanappan RK (2006) Rain water harvesting, conservation and management strategies for urban and rural sectors. In National Seminar on Rainwater Harvesting and Water Management 11: 1.
3. Fewkes A (2006) The technology, design and utility of rainwater catchment systems. Water Demand Management pp. 27-61.
4. Rao KHVD, Rao VV, Roy PS (2005) Water resources development–Role of Remote sensing and Geographical information system. In 12th International Rainwater Catchment Systems Conference. Main steaming Rainwater Harvesting, New Delhi, India.
5. Kim BS, Kim HS, Seoh BH (2004) Streamflow simulation and skewness preservation based on the bootstrapped stochastic models. Stoch Env Res Risk A 18: 386-400.
6. Stedinger JR, Taylor MR (1982) Synthetic stream flow generation: 1. Model verification and validation. Water Resour Res 18: 909-918.
7. Wijayaratne LH, Chan PC (1987) Synthetic flow generation with stochastic models. In Flood Hydrology Springer, Dordrecht. pp. 175-185.

8. Harms AA, Campbell TH (1967) An extension to the Thomas-Fiering Model for the sequential generation of streamflow. Water Resour Res 3: 653-661.
9. Joshi GS, Gupta K (2009) A simulation model for the operation of multipurpose multireservoir system for River Narmada, India. J Hydro-Environ Res 3: 96-108.
10. McMahon TA, Miller AJ (1971) Application of the Thomas and Fiering model to skewed hydrologic data. Water Resour Res 7: 1338-1340.
11. Thomas HA (1962) Mathematical synthesis of streamflow sequences for the analysis of river basin by simulation. Int J Water Res 459-493.
12. Kurunç A, Yürekli K, Cevik O (2005) Performance of two stochastic approaches for forecasting water quality and streamflow data from Yeşilırmak River, Turkey. Environ Model Softw 20: 1195-1200.