GIS-Based Analysis of a Rainwater Harvesting System in the Multipurpose Hall of Quaid-e-Awam University of Engineering, Science, and Technology

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Abstract-Drinking water availability has become a major issue. Rainwater Harvesting Systems (RHSs) amass and store rainwater for future use. In Pakistan, drinking water availability has become a major issue. Rainwater can be used as a constant alternative to clean water resources. Google Earth Pro (GEP) is utilized in this paper to select suitable locations for the installation of RHSs. The decision must not be too excessive, must fit in buildings that have small available space, and must cover the needs of bigger buildings. The required capacity for an RHS to cope with an unusually high water shortage in the study area was calculated using GEP and ArcGIS. The total estimated amount of rainwater harvesting potential during the average annual monsoon period from 2012 to 2021 is 1064.056 m^3 from the 13452.05 m^2 available area from rooftops and plain surfaces. The capacity of storage containers is primarily based on day-to-day spills and breadth.

Keyword-rainwater harvesting system; ArGIS; Pakistan Meteorological Department (PMD); Google Earth Pro; potential demand of water

I. INTRODUCTION

A Rainwater Harvesting System (RHS) is an adaptation to climate change that helps improving local livelihoods and conserve water that can be used for future use [1]. In Nawabshah, there is a frightening decline of the available drinking water, making the saving of water essential in order to overcome the present and forthcoming water crisis [2]. A large number of countries rely on RHSs for conserving water due to urbanization and imprudent extraction of drinking water from aquifers [3].

Rainwater Harvesting (RWH) can be defined as catching and storing the excess seasonal runoff and diverting it for domestic and agricultural purposes. This activity has been developed for use in arid and semi-arid regions, in rural or urban settings, and can be used as a primary or secondary water supply [4]. RWH is not a new technique. Humans have been harvesting rainwater for drinking and non-drinking purposes for more than 4000 years [5]. In many places, rooftop rainwater collection is still used to supply water demands. Rainwater can

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be captured as a means of preventing flooding roadways, recharging aquifers, increasing water tables, and meeting the requirements of the growing population [6, 7]. Compared with most unprotected ordinary water sources, drinking rainwater from well-maintained roof catchment typically represents a substantial enchantment [8]. RHSs add safety to the city water supply system in the event of unexpected failures [2, 9].

The main purpose of this study is to determine the possibility of rainwater collection for storage and use at household level. This strategy is advantageous for minimizing groundwater overuse and conserving it, particularly in Nawabshah, where there will be a water-scarcity in the coming years. Therefore, this research study entails a thorough examination of the necessity for and application of rainwater collection in the QUEST Nawabshah multipurpose hall. For the RWH analysis, the Geographical Information System (ArcGIS) and Google Earth Pro (GEP) tools were used. This research work suggests steps to be taken at a local level to deal with the issue of water shortage in communities and at the individual level.

A. General Aspects of Rainwater Harvesting

The RHS mounted to collect rainwater from the roof areas of the three dormitories would be ample for the flushing consumption as 2831m^3 of water that can be amassed annually with a reliability of 93% [9]. The volume of rainwater that can be gathered from a roof, is based on its measurement and texture. The catchment floor will have an effect on the rainwater via the contaminants that might be present on the surface [10, 11]. Furthermore, the groundwater will be recharged with the aid of RWH [8]. Some details about filters used in RHSs, calculations, and the set up price are discussed in [11, 12], where, additionally, the calculation and format of the RWH device was introduced and price analysis was given. Rainfall of high quality via water treatment technologies, such as photovoltaic collector disinfection, is needed to minimize health risks. The manageable of RWH structures on lowering runoff goes with the flow height for households in southern Italy, and simulation outcomes exhibit that, with the aid of the usage of tank-based RHSs, there is a top-notch discount in runoff peak, between 30% and 65%, depending on the dimensions of rainwater tanks [13]. A linear programming method for a single residential housing unit to decide the top-quality rainwater storage tank volume for RWH and storage was established in [14]. A lifecycle cost-benefit model and a nonlinear metaheuristic algorithm to optimize RHSs was presented in [15]. Furthermore, an optimization-based model for the utilization, storage, and distribution of rainwater aiming for cost-efficiency and water saving was proposed in [16]. An analyzed model was used in [17]. This model can analyze the most useful graph variables, price, and overall environmental performance of RHSs, and make comparisons with other models, such as the Aqua Cycle and the Rain Cycle.

B. Potential of Rainwater Harvesting

RWH is the collection of rainwater which can be used for irrigation or to replenish groundwater supplies [12, 15, 18, 19, 22]. As the demand for water for industrial and household usage continues to rise, RWH is becoming increasingly important [19]. It is considered to be a low-cost and a better option than other strategies for increasing water supply in the near future. Due to the frightening decline of the water table in Nawabshah, conserving water is essential to deal with the existing and upcoming water crisis [15, 18]. It is possible to define RWH as capturing and storing seasonal excess runoff and diverting it for domestic and agricultural use. Creating a rainwater collection system is a simple method for conserving rainwater for future use. The majority of global population will be affected by the global water crisis by 2025 [18]. RWH has become a necessity in the current arid climate. Currently, RWH is an easy solution to unregulated urbanization and rising water demand. RWH is a concept for conserving fresh water and using it for potable and nonpotable applications that has been proven practicable and practical all over the world. It can also be used in Nawabshah to replace the city's diminishing water table, which is quickly dwindling.

C. Treatment Techniques for Rainwater Harvesting

The fundamental categories are heat and UV-based methods, chemical treatment procedures, and bodily elimination operations [19]. Moreover, RWH structures intended for potable use must be screened, settled, filtered, and disinfected before use [20]. The utilization of satellite images and GIS data for particular land-cover classification of rooftops is extremely important for superior city runoff simulation and estimation of the feasibility of rainwater storage and harvesting systems [21]. The reliability of RWH structures for exclusive situations below the local weather conditions is primarily based on the water balance model to find out the most effective rainwater storage tank extent of the RWH structures serving a common six-member family [22, 23]. A daily water stability model of the overall performance of RWH structures under climate change was established in [18]. The set-up of RWH structures comes collectively with a number of direct and indirect fees and benefits [24]. Mass stability methodology, Ripple sketch method, analytical approach, and the sequent height algorithm were used to determine the extent of water. The Analytical Hierarchy Process (AHP) was utilized to determine which RWH technique was the best for the considered area. AHP can be an effective tool for assessing RWH procedures and structures [25]. Microfinance institutions may play an important role in the spread of domestic RHSs.

II. METHODOLOGY

A. Description of the Study Area

The study area, as shown in Figure 1, using an ArcGIS map of the rooftop and the plain surface area surrounding the multipurpose hall building of the Quaid-e-Awam University of Engineering, Science, and Technology (QUEST), Nawabshah, is located on the outskirts of the city, near the airport road, at latitude 26°14′9.38″N and longitude 68°23′24.24″E. The total area of the multipurpose hall building is 11,453.403ft^2, while the total area of the university is 457 acres on both sides of the main Sakrand Road.

B. Rainfall Data Collection

The Pakistan Meteorological Department (PMD) in Nawabshah collected precipitation data for the city of Nawabshah for 10 years (2012-2021) [26, 27]. In our study area there is not a particular rain gauge station. So, precipitation data from the PMD station at the airplane terminal of Nawabshah (OPNH-417490) were utilized to assess the water volume. Only the monsoon period is considered in this study. As presented in Table I, the annual monsoon rainfall data (2012 to 2021) and the minimum to maximum total monsoon rainfall data for the last 10 years are noted as 179.07, 277.3, 284.61, and 389.43mm in the months of June, September, July, and August respectively. Minimum to maximum average rainfall data are 17.90, 27.73, 28.46, and 38.9mm in June, September, July, and August respectively as shown in Figure 2. The maximum annual monsoon precipitation occurred in 2019, which was 274.90mm. The average annual monsoon precipitation within the period of 2012 to 2021 was 277.3mm. The minimum annual monsoon precipitation happened in 2018 and was 4.42mm.

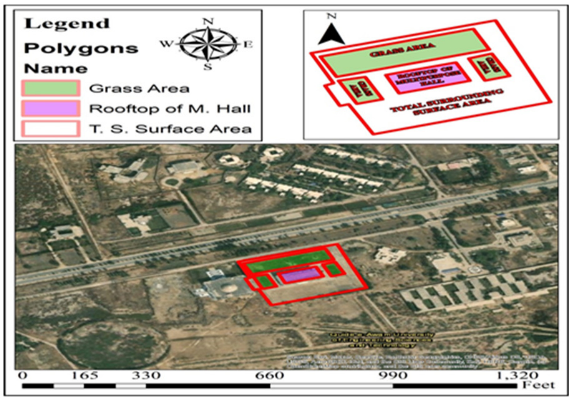


Fig. 1. Study area (ArcGIS map).

TABLE I. ANNUAL MONSOON RAINFALL DATA OF NAWABSHAH (2012 TO 2021)

Year	Monthly data				Total (mm)
	June	July	August	September	
2012	0.00	0.00	15.20	163.50	178.70
2013	19.00	7.50	39.00	3.50	69.00
2014	0.00	0.00	11.20	0.00	11.20
2015	37.20	69.00	0.00	0.00	106.20
2016	58.00	4.00	63.20	0.00	125.20
2017	58.86	33.17	65.71	4.40	162.15
2018	0.01	1.71	2.70	0.00	4.42
2019	0.00	152.20	41.70	81.00	274.90
2020	0.00	1.03	150.72	12.90	164.65
2021	6.00	16.00	0.00	12.00	34.00
Average (mm)	17.90	28.46	38.9	27.73	
Total (mm)	179.07	284.61	389.43	277.3	

C. *Catchment Area*

A catchment area is a surface, of any kind, where rainwater can be collected. The rooftop surface and plain surface area are catchment regions that get precipitation. The catchment area of the Multipurpose Hall Building and its surroundings is estimated. This estimation was done physically with the assistance of a measuring tape. The equation for spillover catchment region estimations is :

$$\text{Plain surface area} = \text{Total surrounding surface area} - \text{Area of Multipurpose hall and total grass area} \quad (1)$$

D. *Runoff Coefficient C_r*

The runoff coefficient is a proportion of the amount of precipitation and the rate of spillover. There are certain factors that are determined by taking into account that not all rainwater can be collected. In some cases, there is a constant loss of overflow from the catchment area due to vanishing or holding at a superficial level. The runoff coefficient is calculated using:

$$C_r = \frac{V_r}{V_t} \quad (2)$$

where V_r and V_t are the runoff volume and the total precipitation volume on a superficial level. The calculated factors of runoff coefficients for several forms of catchments are given in Table II.

TABLE II. RUNOFF COEFFICIENTS FOR DIFFERENT CATCHMENT AREA TYPES

***Cr* factor**	**Catchment type**
0.7 to 0.9	Corrugated-metal sheets
0.8 to 0.9	Tiles
0.5 to 0.6	Brick concrete
0.6 to 0.8	Concrete
0.2 to 0.5	Rocky natural catchments
0.0 to 0.3	Soil on slopes less than 10%
0.05 to 0.10	Green area

E. *Rainwater Harvesting Potential*

In a particular area, the whole amount of water that was mainly received as rainfall is the rainwater endowment. The amount of rainwater that is commendably harvestable is the RWH potential. The RWH potential for the study area is estimated with (3):

$$S = R \times A \times C_r \quad (3)$$

where S, R, A, and C_r are the runoff potential of rainwater harvesting (m^3), the average annual rainfall (m), the area of the catchment (m^2), and the runoff coefficient (%) respectively.

F. *Weekly Discharge and Volume of Storage Tank Calculation*

The volume of the storage tank is calculated based on the expected discharge. Catchment area and weekly rainfall are used to calculate weekly discharge. Monsoon weekly rainfall will be calculated by multiplying the daily monsoon rainfall with 7. The daily monsoon rainfall is calculated by dividing the maximum average annual monsoon rainfall by 122 as there are 122 days in the monsoon period every year (June, July, August, and September). The maximum average monsoon rainfall is 274.90mm which occurred in 2019. As a safety precaution, the tank should be built larger than the storage volume required.

G. Specifications of the Rainwater Harvesting Treatment System

Rainwater is collected in drain pipes on the roofs of buildings. After that, the rainwater is filtered to make it safe to drink. A first rain separator, or first flush, can be used to remove most pollutants from the rain water before it enters the filter. Rainwater can be collected and stored in one or more connected tanks, either below or above the ground. Rainwater is either pumped to an internal holding tank or delivered directly where it is needed on demand. Figure 2 shows the diagram of the Multipurpse Hall Building's rooftop RHS.

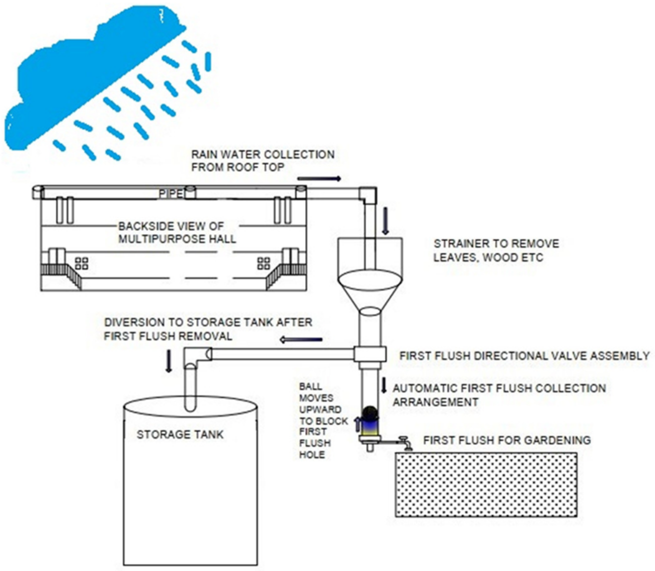


Fig. 2. Diagram of the rooftop RHS.

III. RESULTS AND DISCUSSION

A. Digitization of Rooftop and Plain Surface Area with Google Earth Pro

The rooftop and the plain surface area of the surroundings of the multipurpose hall building were digitized in Google Earth Pro (GEP) using the available polygon tool. RWH is an attractive source of drinking water in urban areas due to the scarcity of conventional sources and their limited capacity [9]. In water-scarce areas, the system could be used to secure water demand locally and commercially. When the water quality parameters are met, rainwater harvested from rooftops could be used as supply water [10, 11]. The surface areas of rooftops (1642.130m^2) and the total plain surface (11788.989m^2) were digitized in GEP, they were saved as KML files and are shown in Figures 3 and 4.

B. Calculation of the the Rooftop and Plain Surface Area using ArcGIS

The saved KML files were imported into ArcGIS as layers. The KML layers have been converted to shape files because each shape file coordinate system has been changed to a projected coordinate system that is actually separate for each country (EPSG: 32644-WGS 84/UTM zone 43N) to calculate the areas of digitized rooftops and plains with the help of an available geometry calculation tool (Figure 5). Figure 5 shows the projected shape file in ArcGIS, as well as the digitized rooftop and plain surface area catchment shape files.

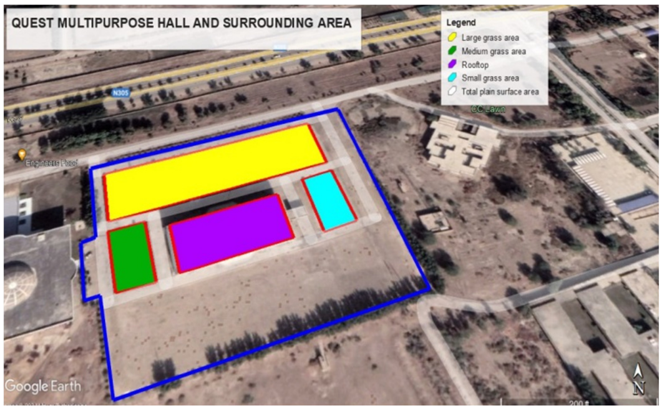


Fig. 3. Rooftop and plain surface area digitized with (GEP).

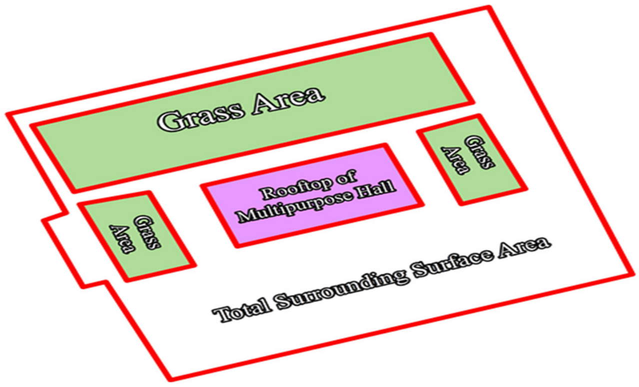
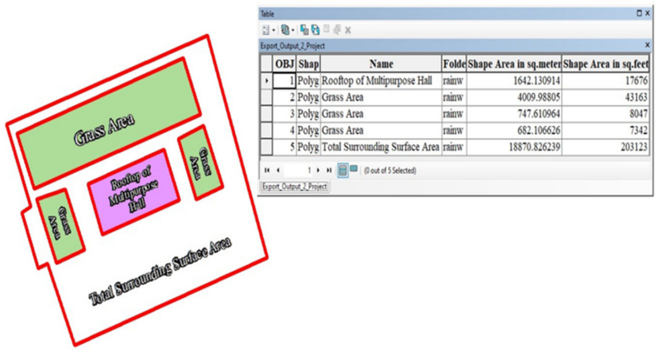


Fig. 4. The shape files of the projected coordinates in ArcGIS.



OBJ	Shap	Name	Folde	Shape Area in sq.meter	Shape Area in sq.feet
1	Polyg	Rooftop of Multipurpose Hall	rainw	1642.130914	17676
2	Polyg	Grass Area	rainw	4009.98805	43163
3	Polyg	Grass Area	rainw	747.610964	8047
4	Polyg	Grass Area	rainw	682.106626	7342
5	Polyg	Total Surrounding Surface Area	rainw	18870.826239	203123

Fig. 5. Calculation of the areas of digitized rooftop and plain surface catchments using ArcGIS.

C. Estimated Rooftop and Plain Surface RWH Potential

Table III shows the estimated average monsoon annual runoff from 2012 to 2021 from the rooftop of the multipurpose hall and the plain surface area surroundings. The maximum average annual monsoon runoff was 932.509m^3, collected from the plain surface area surroundings of the multipurpose hall. The minimum average monsoon runoff was 129.892m^3, collected from the rooftop of the multipurpose hall building.

TABLE III. ESTIMATED RAINWATER HARVESTING POTENTIAL OF THE STUDY AREA (2012 TO 2021)

Catchment type	Runoff (m^3/year)	Average annual monsoon rainfall (m)	C_r	Area (m^2)
Rooftop	129.892	0.113	0.7	1642.130
Plain surface	932.509	0.113	0.7	11788.989
Total	1062.401			13431.119

D. Estimated RWH Potential (Runoff) on a Yearly Basis

Figure 6 shows the results of the estimated RWH potential (runoff) from the study area on a yearly basis. The maximum estimated amount of runoff water that could be collected from the rooftop and the plain surface area is 2584.550m^3 during 2019 and the minimum estimated amount of runoff water was 41.367m^3 during the year 2018. ArcMap 10.4.1 was used to calculate the RWH potential for the roofs of buildings. It is also proposed to use the RWH model at the household level with its utilities. Uncontrolled urban sprawl, rapid population growth, and uncontrolled immigration contributed to extensive groundwater extraction. Therefore, in addition to other sources such as rooftops, roadways provide a significant opportunity for rainwater harvesting as a viable solution to urban flooding.

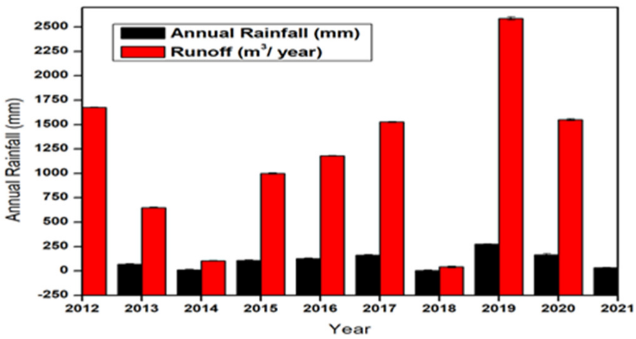


Fig. 6. Comparison of the estimated annual monsoon runoff from the study area.

E. Estimated Weekly Discharge and Volume of Storage Tank

Table IV shows that a weekly monsoon discharge of 210.868m^3 from the rooftop and the plain surface area can be obtained. A tank size of 330m^3 per week is required for this discharge.

TABLE IV. ESTIMATED MONSOON WEEKLY DISCHARGE AND THE REQUIRED VOLUME OF THE STORAGE TANK

Catchment type	Weekly discharge (m^3)	Volume of storage tank per week (m^3)
Rooftop	25.781	40
Plain surface	185.087	288
Total	210.868	330

IV. CONCLUSION

An analysis was made in this study to determine whether rooftop and plain surface RWH can meet the general water demands in the study area. GEP was used for digitizing and ArcGIS was used to calculate the rooftop and the plain surface areas surrounding the multipurpose hall. The total estimated amount of RWH potential during an average annual monsoon period (2012 to 2021) is 1062.401m^3 for the 13431.119m^2 considered area. The results proved the abundant potential for exploitation of RWH from the rooftop and the plain surface area surrounding the Multipurpose Hall is possible in QUEST. Rooftop RWH is a good alternative for educational institutions because these buildings usually have extensive roof surfaces and the amount of water stored will provide a viable solution to the water requirements.

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