INNSPUB

Journal of Biodiversity and Environmental Sciences (JBES)
ISSN: 2220-6663 (Print) 2222-3045 (Online)
Vol. 23, No. 6, p. 92-101, 2023
http://www.innspub.net

RESEARCH PAPER | OPEN ACCESS

Evaluation of rainwater harvesting potential from rooftop and paved areas for the water saving using application of Google Earth Pro and ArcGIS

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Article published on December 12, 2023

Key words: Rainwater harvesting, Water demand, Storage tank, Potential water saving

Abstract

In the current situation of global warming, the availability of fresh water is a blessing. Due to the uncontrolled extraction of groundwater, the water table is decreasing at a rapid pace. This reduction and water scarcity dilemma could be resolved through better management of available water resources. Rainwater harvesting is the most applicable and demanding way for the conservation of water, which includes localized storage of rainwater for different future uses. In this paper, a case study of Capital University of Science and Technology (CUST) Islamabad Pakistan has been taken to assess the rainwater harvesting potential. Google Earth Pro (GEP) was used for marking out the boundaries of the study area. Digitization of the campus was worked out by using ArcGIS. The overall demand for water in the CUST was calculated by considering the total population. The selection of suitable sites for the storage of rainwater harvesting (RWH) was identified. Quantity of rainwater ware calculated by using rational method. Storage tank size and location were suggested in three different places based on the natural ground slope. The result of this study shows that 100% of the water will be saved by rainwater harvesting. This saved water can be used for other purposes like landscape irrigation. This will help in decreasing the usage of groundwater resources.

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Introduction

Water is a valuable gift of nature and life exists where water is available. It has many usages in human life. With the increase in population, the demand for this natural resource is increasing day by day. Nowadays, water scarcity is a big challenge in many developing countries, like Pakistan, for the use of future generations (Ali and Jain, 2014; Prinz, 2000). Fresh water resources are limited, and because of increased demand in comparison to an increasingly growing world population, industrialization, urbanization, and global climate change, water is becoming a scarce resource. Water conservation is essential, and the rainwater harvesting technique is an effective way to conservation (Aklan *et al.*, 2023). With the use of a rainwater collection system, water savings have risen from 30% to 60% according to the region of the study (Herrmann and Schmida, 2000). (Ghisi *et al.*, 2006) analyzed over 62 cities in southern Brazil for the potential of drinking water saving by using rainwater harvesting." The results indicate that the average drinking water savings capacity is from 34% to 92% based on the need for drinking water. Such a capacity is very useful, as rainwater may be used for both potable and non-potable purposes. Hari (2019) examines the calculation of the capacity of rooftop rainwater harvesting (RWH) using Google Earth Pro and ArcGIS. The results showed that 11653860 liters of potable water are saved through RHW which is 38% of the total demand for water on the campus. (Ghisi and Ferreira, 2007) investigate the potential for saving water in a high-rise residential building in southern Brazil, using rainwater and greywater. The result showed potable water savings range from 36.7% to 42.0% with the use of rainwater and greywater in combination. Karim *et al.* (2021) investigated the Potential of Rainwater harvesting in different commercial buildings in Dhaka: reliability and economic analysis. The result showed that for a water demand of 30 liters per capita per day (lpcd), roughly 11 to 19% and 16 to 26.80 % of the annual need for water can be improved by rainwater harvesting under the normal year and wet year climate situations, respectively. Hassan (2016) investigated the Rainwater Harvesting alternative water supply in the Future of Pakistan. The results showed that 45% of potable water was saved by using rainwater harvesting. Rainwater harvesting has many benefits, water is free of charge; the direct harvesting and storing of the water near its use removes the need for a delivery system and its repair costs; high quality for many applications; leads to the elimination of street-surrounding runoffs; decreases the need for fresh drinking water for purposes other than drinking. There are six key components of the rainwater collection system, including the catchment area, rainwater spout gutter, filtration structure, storage system, treatment, and distribution system (Che-Ani *et al.*, 2009). Morey *et al.* (2016) researched the rainwater harvesting scheme in India, and they discovered that rainwater harvesting is useful for multiple purposes such as washing clothes, washing vehicles, and planting and one of the key benefits is to cut the water bill by 50 percent to 60 percent. They also note that surplus rainwater can also be used through artificial recharging methods to restore underground aquifers. Mishra *et al.* (2020) design rooftop rainwater harvesting structure at the University Campus in India. During the non-monsoon season, rainwater harvesting can resolve water shortage issues by storing a massive amount of water 6109.42 m3 each year on the university campus. This system will improve the water availability for development projects, and planting and also encourage the artificial recharge of the groundwater table. Hari *et al.* (2018) determine rainwater harvesting potential by using ArcGIS in the Almasguda region of India. They obtained 436708288.17 liters of water from both runoff and rooftop rainwater harvesting. The obtained water is more than adequate for at least 46398800 liters of domestic demand and sufficient. They conclude that rainwater harvesting is a convincing method. Rahman *et al.* (2014) analyzed the sustainability of rainwater harvesting systems in Dhaka city in terms of water quantity and quality. RWH system is reliable and economical for a residential building with a catchment area of 170m2 and a daily water demand of 135 liters/capita/day in addition to controlling many water quality parameters. The diversity and productivity of rainwater harvest is a sustainable solution that has become increasingly successful both in rural and urban environments in the developing world and is an important means of resolving global water problems (Cain, 2014). Ward *et al.* (2012) studied the efficiency of the rainwater harvesting system for a large building. The study indicated that for an office-based rainwater harvesting system, about 87% water-saving capacity could be obtained over eight months. Harvested rainwater is an alternate source of water in arid and semi-arid areas for different uses when traditional supplies such as lakes, wells, and rivers fail (Frasier, 1980). The use of rainwater in private homes, public buildings, and heavy industry through pipeline systems is quite a recent tradition. Rainwater is used in schools, vehicle washing centers, and challenging factories for water supply (Herrmann and Schmida, 2000). Olaruntande and Oguntunde (2009) investigated that rainwater collection is a good solution and a backup in the long dry season or when water levels fall and wells are dry, excluding in the most arid or semi-arid regions. Domènech and Saurí (2011) investigated that rainwater harvesting can address many requirements for domestic interior and exterior water demand, but due to heavy financial resources, it also had extremely long payback periods.

Various researchers around the world recommend that rainwater harvesting is an alternate source for managing the challenges related to water shortage for human use and supporting the environment. These researches have been carried out in Chania (Shiguang and Yu, 2021). Evaluation of the capacity and economic feasibility of the rainwater harvest mechanism for four various climate regions of China. The results indicated that the reliability of rainwater availability ranges dramatically across four cities 3.85%–20.55%. Multi-criteria analysis of device configurations for the harvest of rainwater in UK building results shows that rainwater best of reduction of capital costs, maximum efficiency in water saving, minimization of operational (Melville-Shreeve *et al.*, 2016). Water energy consumption, minimization of stormwater releases, and annual stormwater releases the effect of the roof surface area on the rainwater runoff quality and quantity in the method of rainwater harvesting (Faza and Suwartha, 2021). They conclude that roof catchment has a substantial effect on the quantity and efficiency of rainwater harvesting and can be used by a basic water treatment unit as a safe water source.

Table 1. List of factors that can be done to encourage the use of RWHs

Type	Factor	Reference	Explanation
Institutional	Awareness about RWH	Jones and Hunt, 2010	Subjective understanding of the advantages of using RWH technology.
	Perceived ease of use	Liu *et al.*, 2022	It indicates the extent to which a person believes that using RWH technologies doesn't require any effort.
	Availability of skilled workforce	Andersen, 2014	RWH systems require specific skills to be installed. This is an indication of the availability of qualified staff.
	Subjective norms	Shanmugavel and Rajendran, 2022	It is generally accepted that an individual's choice is contingent upon the presence of influential individuals.
	Intention to use	Aliabadi *et al.*, 2020	It refers to an individual's ability to explain whether they complete a task or act in a certain way.
Finances	Subsidy	Woltersdorf *et al.*, 2014	Giving money back in the form of grants and loans makes it easier to take care of your finances.
	Tax incentives to companies	Gonela *et al.*, 2020	State or central government policies to encourage industrial involvement to make RWH systems' parts.
	Regulation and guidelines	Campisano *et al.*, 2017	In addition to existing laws, a set of regulations are established for residential units to promote the adoption of RWH technologies.
Technology	Ease of installation	Villarreal and Dixon, 2005	It's all about how easy it is to install the RWH technology.
	Technology innovation	Xu *et al.*, 2018	The need of the hour is a broad array of research and development activities to develop innovative designs for RWH and technologies to monitor the quality of the collected water.

RWH workshops and training courses on the importance and implementation of RWH technologies can help create a positive mindset. Decentralized RWH technologies make the household accountable for operation and maintenance (Domènech *et al.*, 2012). By raising awareness among participants in community-based workshops, RWH technologies can be adopted more widely, resulting in lower installation costs due to economies of scale (Akuffobea-Essilfie *et al.*, 2020). When it comes to RWH technology, one of the biggest factors that can affect its adoption is people's perception of how useful it is, which can be improved by emphasizing the benefits (Liu *et al.*, 2022). Table 1 gives an overview of each factor that affects the use of RWH technologies.

In Pakistan, drinking water availability is becoming a big problem. The present 141 million in Pakistan population is projected to cross approximately 221 million by 2025. This development would directly affect the water demand to serve various purposes. The supply per capita of water has declined from 5,000 m3 in 1951 to 1100 m3 which is only above the globally recognized point of scarcity. By 2025, the supply of water was estimated to be less than 700 cubic meters per capita (Pak-SCEA, 2006). This study aims to suggest the effectiveness of rainwater harvesting in institutes where vast areas and populations of more than 5,000 no. exist in Pakistan. This will help in the reduction of groundwater pump age and also help in recharging the groundwater.

Materials and methods

The main source of water supply in the research area is groundwater. The water demand is growing exponentially on the campus mostly for drinking, lab work, washrooms, kitchens, canteens, floor cleaning, irrigation, etc. Rainwater harvesting is the most widespread alternative source for the current water requirement and to meet the future water demands in the research area. This study includes the estimation of potential rainwater availability at campus.

Study area

The selected area for this research is the Capital University of Science & Technology (CUST) Islamabad as shown in Fig. 1. CUST is located in Islamabad having 33'32'54.24N 73'113.83E coordinates. CUST is located on the left bank of the Soan River. It spreads over an area of approximately 177 kanals (23.13 acres or 93603.789 m²) and provides quality education facilities to thousands of students. The university campus is a state-of-the-art facility under the private sector and has almost 12 main blocks, canteens, parking spaces, green lawns, and playgrounds. The campus is composed of alluvial soil, which is fairly level.

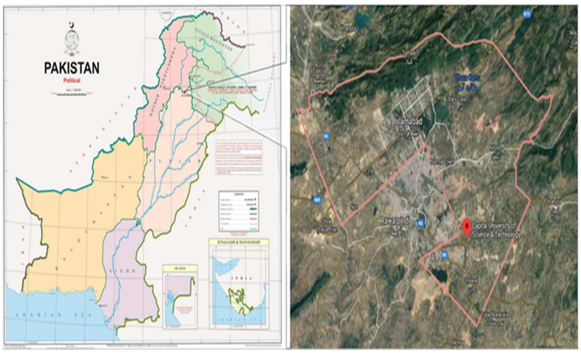

Fig. 1. Study area location

Rainfall data

Monthly ground station rainfall data for Islamabad is taken from the Pakistan Meteorological Department from 1954 to 2020 and the time series trends of precipitation are studied for the period of last 30 years (Figs 2, 3). The Global Precipitation Climatological Center (GPCC) (Becker, Klein, & Wetzels, 2012) and Climate Research Unit (CRU; TS 4.04) (Ahmed, Kurnitski, & Olesen, 2017), gridded datasets were used to evaluate precipitation data at a resolution of 0.5° x 0.5° (https://climexp.knmi.nl/start.cgi).

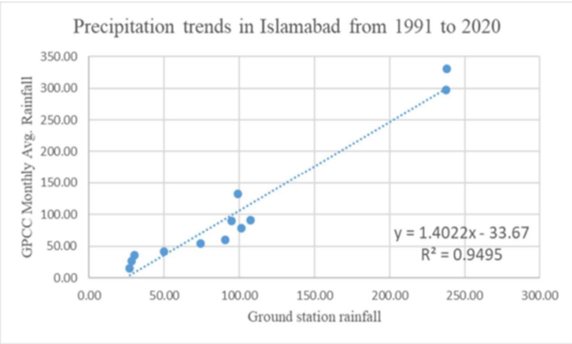

Fig. 2. Precipitation trend in Islamabad from 1991 to 2020.

From the correlation analysis, it is observed that the value of the root mean square is 0.95 which indicates that the GPCC dataset has a greater association with *in-situ* station rainfall data due to its high resolution.

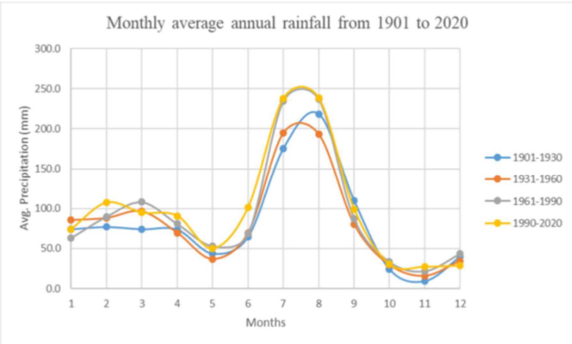

Fig. 3. Monthly average rainfall from 1901 to 2020

Time series analysis of GPCC rainfall data

Keeping in view the previously discussed strong relation between ground observed precipitation data and that of the GPCC gridded data set. Precipitation data is taken from 1901 to 2020 and a time series trend is tried to observe for 4-time steps of 30 years. It can be seen clearly that there are two major episodes of rainfall seasons since 1901 till now shown by peaks.

Data collection

The population data of students, faculty, and staff were obtained from the university administration. Google Earth Pro (GEP) and ArcMap software play are used to do research related to geo-space. Both are freely available and user-friendly. ArcMap was used to note the elevation of the study area. Area was measured with the help of the polygon tool which is available in GEP. The average annual rainfall data obtained from the Metrological Department of Pakistan is 1.25m/year.

Methodology

The campus master plan was digitized by using GEP and verified through a reconnaissance survey of campus. The following steps carried out included the followings (Fig. 4).

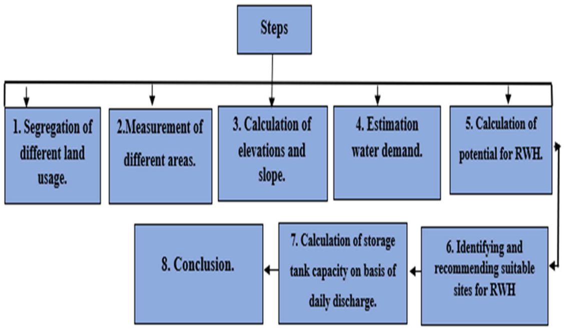

Fig. 4. Steps carried out included with the study

Fig. 5. Area identification using GEP

Fig. 5 shows 12 main blocks, canteens, parking spaces, green lawns, and playgrounds. The campus is composed of alluvial soil, which is fairly level.

Results and discussion

Segregation of different land usage

The area is divided into impervious (parking and sidewalks) different-sized rooftops in the GEP) and pervious areas. Then the file is saved as KMZ (Keyhole Markup language Zipped). This file was imported into ArcMap and converted into the shapefile as shown in Fig. 6.

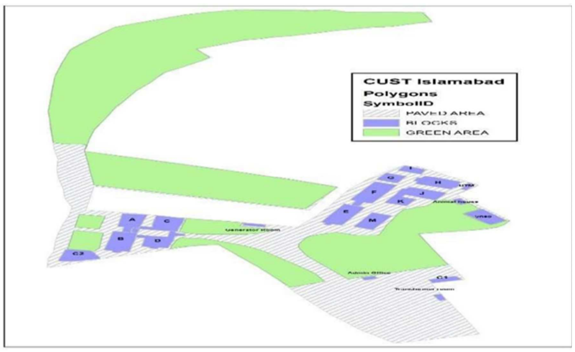

Fig. 6. Shapefile by using ArcMap

Measurement of different areas

The Polygon method was used to measure the impervious areas (sidewalk and parking) and different rooftops. Table 2 and 3 show the measured impervious area and rooftop area.

Table 2. The impervious area

SN	Impervious areas	Avg. annual rainfall (R) m/year	Area (m^2)
1	Area 1	1.25	13340
2	Area 2	1.25	4069.75
3	Area 3	1.25	1002.64
4	Area 4	1.25	432.02
5	Area 5	1.25	1134.56
6	Area 6	1.25	238.42
7	Area 7	1.25	233.95
8	Area 8	1.25	100.59
9	Area 9	1.25	162.72
10	Area 10	1.25	250.25
11	Area 11	1.25	268.3
12	Area 12	1.25	583.33
	Total		22326.33

Table 3. The rooftop area of all blocks

SN	Blocks	Avg. annual rainfall (R) m/year	Area(m^2)
1	Block A	1.25	377.11
2	Block B	1.25	621.62
3	Block C	1.25	372.6
4	Block D	1.25	359.13
5	Block E	1.25	726
6	Block F	1.25	790.65
7	Block G	1.25	349.32
8	Block H	1.25	543.43
9	Block I	1.25	167.74
10	Block J	1.25	563.43
11	Block K	1.25	298.44
12	Block M	1.25	598.91
13	Adman office	1.25	55.87
14	Shed(Iron sheet)	1.25	464.15
15	Transformer room	1.25	134.02
16	Canteen 1	1.25	127.3
17	Canteen 2	1.25	390.02
18	Generator room	1.25	93.28
19	Animal House	1.25	70
	Total		7103.02

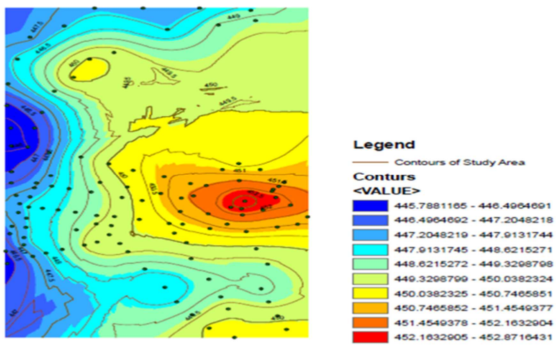

Fig. 7. Contours map of study area by using ArcMap

Calculation of elevations and slope

The contour plan of the study area is developed by ArcMap. The elevation points of the area range from a minimum of 445.788m to a maximum elevation of 452.871m which shows that the natural terrain of the study area is flat. Fig. 7 shows the contour map of the study area.

Estimation of water demand

As per data gained from the university, the estimated population of students on the campus is 5000, the number of faculty and staff is 300 and workers are 35 which take residence in the campus. The students and faculty/staff attend the institute for 261 days (working days) except the residents who remain available for 365 days. According to the standards, the water requirement for universities is 23 lpcd is sufficient. The calculated water requirement of the campus is shown in Table 4.

Calculation of potential for rainwater harvesting

The potential for rainwater harvesting on the campus has been calculated by using Gould and Nissen formula (1999) which is provided below as equation 1.

$S = R*A*C_r$ (1)

Where: S = Potential of rainwater harvesting (m^3) Cr = Co-efficient of runoff.

R = Average annual rainfall (m) A = Area in (m^2).

The coefficient of runoff for rainwater harvesting has different values for different types of material. Different values of runoff coefficient show in Table 5 and RWH potential of study areas shows in Table 6.

The above calculations show that rainwater harvesting potential is 32,185.58 m^3 against the water demand of 32109.73 m^3. This shows that 100% demand for water will be fulfilled through this harvesting technique.

Water available for one person = 32185580/5335 = 6032.9 liters/year.

Water available for one student or faculty member = 6032.9/261 = 23.11 liters/day.

From the above calculation, it is clear that rainwater that could be harvested makes up 100% of water demand (23lpcd).

Table 4. Water requirement of campus

SN	Population		No. of working days	Per capita demand. Liters/day	Total water requirement per annual. Liters	m^3
1	Students	5000	261	23	3,0015,000	30015
2	Faculty and staff	300	261	23	1800900	1800.9
3	Workers	35	365	23	2,93,825	293.825
Total		5335			3,21,09725	32109.73

Table 5. Shows values of C based on different materials.

Materials	Runoff coefficient (Cr)	Reference
Asbestos	0.85	
PVC	0.98	Hari, 2019
Concrete	0.95	
Brick/Clay tiles	0.75	
Concrete	0.7	Temizkan *et al.*, 2021
Metal	0.9	
Corrugated metal Sheet	0.7-0.9	
Galvanized sheet	0.9-0.95	
Soil	0.0-0.3	Biswas *et al.*, 2014
Green cover	0.05-0.1	
Tile	0.8-0.9	
Brick/Clay tiles	0.5-0.6	
Concrete	0.6-0.8	

Identification of catchments

Based on the slope, drainage path, and elevations of overall rainwater harvesting capacity, the study area is divided into three catchments as shown in Fig. 8. The capacity of rainwater harvesting for each catchment is estimated and shown in Table 7.

Identifying and recommending suitable sites for rainwater harvesting

According to the measured elevations, the direction of drainage, slope, and observed runoff of each catchment, rainwater harvesting storage tank sites are identified, recommended, and shown as ST1, ST2, and ST3 in Fig. 9.

Table 6. Shoes discharge calculation of rooftops and impervious area.

SN	Name of area	Types of material	Avg. annual rainfall (R)	Value of "Cr"	Area (m^2)	S =R*A*Cr m^3/year
1	Surface area	Paver tiles	1.25	0.85	22326.33	23,721.73
2	Rooftops	Concrete	1.25	0.95	6638.87	7,883.66
3	Shed	Iron sheet	1.25	1.00	464.15	580.19
	Total					32,185.58

Table 7. Shows the capacity of catchments.

SN	Catchment	Blocks and areas	Capacity (m^3/year)
1	Catchment 1	E, F, G, H, I, J, K, M, UTM, Shed, Animal house, Area 3 to Area 12	10,518.14
2	Catchment 2	Area 1, Area 2, Canteen 1, Admin office and Transformer room	18,874.53
3	Catchment 3	A, B, C, D Area 13 and Canteen 2	2,792.91

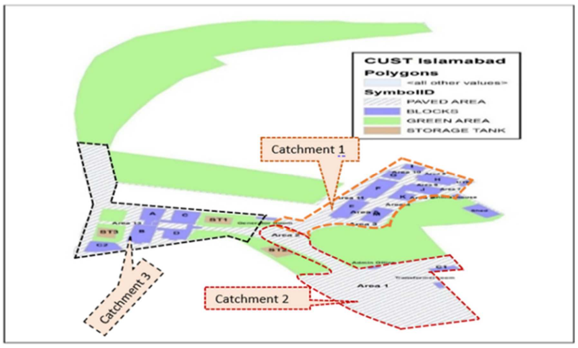

Fig. 8. The catchments

Calculation of storage tank capacity using samsam water rainwater harvesting tool

Samsam water tool is used to calculate the storage tank size for the catchment. Samsam works out user precipitation data and a weighted C value of 0.70 for a defined area. The capacities of RWH tanks are given in Table 8.

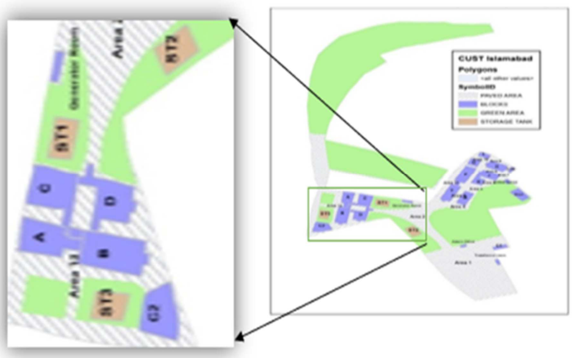

Fig. 9. Location of storage tanks (ST)

Table 8. Shows storage tank size and capacity

SN	Length m	Width m	Depth m	Total m^3
Catchment 1	44	22	2.70	2614
Catchment 2	58	29	2.70	4541
Catchment 3	24	12	2.70	778

Conclusion

The above study thus concludes that rainwater harvesting is the best technique for water saving on campus rainwater harvesting plays an important role in resolving many water issues such as water shortage, flooding, and pressure on underground water, etc. We should promote and adapt rainwater harvesting for the sake of our country because our country facing a big challenge of water shortage.

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