Assessment of Rain Water Harvesting System

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Abstract— **The life of the inhabitants of the globe is greatly dependant on water. Providing portable water to communities is of prime interest. Scarcity of water will be a serious threat in near future in Pakistan. There is a need to search alternate sources of water to fulfil the community water requirements. Rainwater Harvesting (RWH) system could be a better alternative due to its vast applications. Therefore, in this research study this system is applied as an alternative source of water in a small village of Abbottabad city having scarcity of water. According to PHED, the currently available gravity system and three tube wells are not sufficient to supply water to all the population of study area. Therefore, in this study, principle of rainwater harvesting system is used to quantify the water available from rainwater. Runoff was calculated using SCS curve number method for mean monthly rainfall depth. Calculations were made with predicted rainfall depth using frequency analysis as well as applying current rainfall depth fir future as well. It was found that this alternate source can overcome the water shortage in study area for both the cases, not only for current population but for future 20 years as well. Even after 20 years there will be surplus water of 299194.2 gallons per day for case 1 and 116042.18 gallons per day for case 2 will be available if stored properly. Therefore, on the basis of this study, it is recommended to the PHED of Abbottabad city for adopting RWH system for study area as well as all far flange areas where there is shortage of water.**

Index Terms— **Water Resources, Shortfall of Water, Curve Number, Water Requirements, Population Projection, Catchment Area, Runoff.**

I. INTRODUCTION

Water is the firmest need of the humans for surviving on this planet. Although most part of the Earth is covered with water but still there are certain countries where there is shortage of portable water. The shortage of water occurs mainly because of over population and its wastages. Due to uncontrolled population, water is diminishing day by day specially in under developed countries like Pakistan. The population of Pakistan is approximately 20 crores [1].

Many of the areas of Pakistan are self-sufficient for water but still there are some area that could not meet the water requirement of people living there. Abbottabad is one of the well-developed and most beautiful cities of Pakistan but there is shortage of water and needs to be mitigated to fulfill needs of people. Different government departments are working for the provision of adequate supply of water to the people of Abbottabad. They have managed well the available water resources and utilizes them in a systemic way to provide palatable water to the community for drinking purposes. Still some areas are facing shortage of water. According to data collected by the Public Health Engineering Department (PHED), the total water demand of water in whole Abbottabad city is 357 liters/second (6.78MGD) out of which 140 liters/second (2.66 MGD) is provided by tube wells. To overcome the remaining demand of water gravity system is there but it not fulfilling the whole demand and resulting in some shortfall.

Although maximum of population of Abbottabad is facilitated by the gravity system to convey water to its inhabitants but still there are some far fling areas where people are still facing shortage of water. The government departments are making efforts to fulfill this shortage but still not successful.

Therefore, main objective of this research study is to identify an alternate technique (Rainwater Harvesting (RWH) system) of water that can reduce this water shortfall and the community can be supplied with sufficient quantity of water. For this purpose, after consultation with PHED a village named Sheikh ul Bandi was selected where there is shortage of water. As first step, the shortage of water is calculated and then using the available rainfall data and catchment area characteristics, the water available from rain is calculated using SCS curve number method which will be collected through RWH system. The collected water from rainfall and the water short fall for present and future population will be compared and discussed.

II. LITERATURE REVIEW

Many researchers have performed studies on adopting innovative systems to cope the demand of water supply to the community. The previous research mainly focuses on the gravity system, pumping system and rainwater harvesting system. A detailed and inclusive literature review on classical methods of water supply system is given below.

The potential application of rainwater harvesting for crop production was discussed [2]. About 170 articles were published in between 1970 and 1980 and these articles emphasize on the increase in awareness for rainwater harvesting and recognition of its potential. Based on three common characteristics of it, the definition of rainwater is presented: small-scale operation, local water and semi-arid climate. The water quality from RHW systems in Ontario, Canada was assessed in [3]. The generated results pointed out that with the change of environmental conditions, the quality varies expectedly. Through the selection of storage material, adequate catchment and application of post cistern treatment, the water obtained from RHW system can be of high quality. The past and future water harvesting were correlated in [4] and according to it, the backbone of agriculture in semi-arid and arid zones in the past was water harvesting. After decline,

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during the past decades, it gained attention again. The link between soil and water conservation, rain fed agriculture and irrigated agriculture will be its future role. It will alleviate slightly the tension on draught-ridden farmers and communities. The data about previous paleoclimatical evidence for climate change during the Holocene was reviewed and collected to test the climate change rainwater-harvesting hypothesis [5]. This study compared this data with historical and archaeological records. The results revealed that in response to sudden climate fluctuation, there is correlation among human activities for the construction of rainwater harvesting structures across the whole region. The reason of microbial contamination present in drinking water between the source and point of use in developing countries was discussed in [6]. They also discussed the process of accessing these microbial contaminants. The capability of saving potable drinking water through the rain water in residential estates of brazil was studied and it was concluded that on the dependency of geographic location this ranges from 48% to 100%. [7]. A study [8] discussed that one of the targets of 7th Millennium Development G
oals (MDGs), is the amount of people who are living without accessing to safe potable drinking water and adequate sanitation system. In South Africa about 9.7 million (20%) people do not have access to potable safe drinking water and 16 million (33%) do not have proper sanitation system. Domestic rainwater harvesting system (DRWH) system provides water directly to households enable them to do small productive activities. Through this system, water can easily be supplied to the rural and pre-urban areas where there is problem of installing conventional technical water supply system. The capability of rainwater harvesting system was assessed in [9]. It was concluded that excess rainfall normally occurs in September and October and if adequate storage facility is available then this stored water is sufficient to supplement the shortfall in dry months. The highest capability of water saving is in June and September which is the two rainfall peak periods in south Nigeria. The implementation of rainwater harvesting system in Malaysia to avoid water crisis in future was discussed in [10].

A study in Abbottabad [11] discussed that the gravity system installed by the Japan International Cooperation Association cope just 60% of the total demand while remaining 40% is cope with the help of tube well system. But since according to (PHED) the tube well system is not properly working there so it is causing a deficiency of 140 liters/s.

III. MATERIALS AND METHODS

A. Precipitation Data

The rainfall data was collected from Kakul precipitation gauge. Daily data for 12 years (2004-2015) was collected. From this daily data total monthly rainfall data was calculated. Total monthly rainfall data is shown in Table I below. From this, we compute average runoff depth.

B. Population forecasting and Required water of study area (Sheikh-ul-bandi)

The data about present and future forecasted population of the study area was collected from PHED, Abbottabad office and is shown in Table II below.

There are presently 3243 houses in the study area. As per PHED standard of 7 persons per house resulted in total present population of 22701. The future population is projected using geometric mean method with 3% growth rate (PHED). After calculation, the population in 2028 and 2038 was found to be 29511 and 38364 persons respectively.

C. Catchment Area Calculation for (RWH) system

The area of village under study was calculated using Google earth pro. After locating the area its boundaries were marked as shown in Fig. 1 and then the area was calculated using scale command.

By selecting polygon in option and draw a line exactly on the boundary line it gives value 1.12km².

Fig. 1: The Aerial Image of Sheikh-ul-Bandi Showing Its Boundaries For Area Calculation

D. Description of Study Area

The study area can be broadly classified into two categories including urban area and Non-urban area. Urban areas include constructed area like streets, roads, buildings small shops and markets while non-urban area include undeveloped area like barren land, agricultural land etc. Area for each category is calculated by dividing the area into number of polygons and then using ruler command in Google earth as shown in Fig. 2 below. Area for both categories was calculated separately using the same method.

Fig. 2: The Area distribution into different land use

Fig. 3: Detailed Area Calculation

(USDA) Soil Conservation Service (SCS) and is a method of estimating rainfall excess from rainfall [15] and documented by [16]. The initial abstraction used in SCS method was examined by [17] and was documented by [18]. For calculating the runoff for small or medium sized watershed, this method is widely used. Rainfall amount and curve number are the essential requirements for this method. The equation that is used for calculating depth of direct runoff by SCS from storm rainfall is:

$$Q = \frac{[(P - I_a)]^2}{(P - I_a + S)} \tag{1}$$

Table I: (Twelve Years (2004-2015) Rainfall Data for Abbottabad City (values are in 'mm')

Year/Mon	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
2004	108.3	45.9	13.4	133.4	65.4	89.6	209.7	221.5	71.7	124.1	40.5	47.2
2005	117	196.1	186.5	64.7	68.4	45.3	198.1	146.3	41.4	79.3	21.5	0
2006	115.8	78.5	61.5	65.3	61.7	67.2	329.7	191.5	60.8	37	84.6	121.6
2007	2.1	85.8	179.2	41.1	65.6	135.1	294.6	180.4	155.2	0	19.3	35.7
2008	400	133.5	40.6	241.7	90.2	495.8	538.2	278.5	77.3	72.2	154	223
2009	74.2	99.5	85.6	178	34.5	75.7	152	174.9	42	23.8	34.7	8.2
2010	20.2	214.1	33.5	49.6	82.7	59.1	384.2	139.3	120	15.9	2	24.4
2011	23.9	218.3	132.7	116.6	16.5	83	176	266.5	88	63.3	16.4	9
2012	26	77.3	107.2	214.3	42.8	45.7	146.4	272.6	173	33	5.3	74
2013	7.6	180.2	105.1	90.8	91.2	165.3	228.7	411.7	161.9	21.5	10.9	0.1
2014	21.4	85.2	313.4	76.5	152.4	79	186.5	137.8	189.2	48.2	19	0
2015	24	104.8	175.6	170.1	87	116.1	343.6	135.4	94	187	50.4	45.2

Table II: Present and Future Population Of Study Area (PHED-2018)

Number of Houses in Year 2018	Population in 2018 @ 7 Person Per House	Population in 2028 @ 3% Increased.	Population in 2038 @ 3% Increased.
3243	22701	29511	38364

E. Runoff calculation using SCS-Curve Number Method for RWH system

For the estimation of runoff from the rainfall data, universally applied method SCS curve number method is used [12], [13] and [14]. The SCS Runoff Curve Number method is developed by the United States Department of Agriculture

Where P shows precipitation in millimeters or inches

Q= runoff in millimeters or inches and
S= potential maximum retention in millimeters or inches
Ia=initial abstraction (i.e., Ia= 0.2S)

Now using equation (1) and putting value of Ia gives us
Q =(P-0.2S)^2/((P+0.8S)) (p>0.2S)---------- (2)
For the condition of Pakistan, the potential maximum retention is given by,

S= (25400/CN)-254 ----------- (3)
Here CN is dimensionless number ranging from 0-100 and S is in mm.

F. Curve Number (CN)

The empirical parameters which are used to predict the direct runoff is runoff curve number. It usually ranges from 0 to 100and is based on hydrological soil group, land use/land cover, and hydrological condition. In our case the curve number came to be 84.5. Average condition of moisture is assumed and antecedent moisture condition ⟦AMC⟧_ii is taken. The equation that is used for cumulative or normalized curve number for different land use and hydrological soil group condition is:

$$CN = \sum Ai * CNi \ / \sum Ai \text{-------}(4)$$

Where, CN represents weighted curve number
Ai= area of each individual curve number.
From curve number and rainfall data using SCS method, runoff Volume is calculated.

IV. RESULTS AND ANALYSIS

After all the data is collected from the concerned departments and calculations, results were obtained. The analysis was started from calculation of the water demand required by the community in the study area followed by the water calculations from rainfall data.

V. WATER REQUIREMENTS CALCULATION

Before calculating the runoff from rainfall, the total population and their water requirement is calculated. As discussed above current population is calculated by assuming seven people per house and then population is projected using Geometric mean method. After the population forecasting, the water demand for this population was calculated using PHED criteria of 20 gallons per person per day as shown in Table III below. Table III also shows the current water availability from gravity system as well as already installed tube wells and the expected shortfall.

Table III: Water Requirements / Demand in Study Area

Year	Forecasted Population	Water Requirement @ 20 Gallon per day	Discharge Available from an Existing Tube Well (3 No's) with 12 Hours Pump in Gallons per day.	Water Available from Gravity System	Water Deficit
2018	22701	454020	192000	110000	152020
2028	29511	590220	192000	110000	288220
2038	38364	767280	192000	110000	465280

A. Land Use and Land Cover (LULC)

The categorization of Sheikh-ul-Bandi is done in three LULC classes, including Residential Houses, Streets and Roads, and Agricultural land. The percentage distribution of each category is shown in Table IV below:

Table IV: Categorization of Land Use Land Cover and its Distribution

Land use/Land cover	Area(Km²)	Area (%)
Residential Houses	0.578	51.61
Streets and roads	0.102	9.11
Agricultural Land	0.44	39.29
Total	1.12	100

B. Calculation of Curve Number

After land use classification, the next step is to calculate the weighted curve number for each classification. For this purpose, the soil types were determined and classified into hydrological soil groups A, B, C and D. curve number for each individual area is obtained from SCS curve number tables available in literature. After all these steps the weighted curve number is calculated using equation 4. These calculations are shown in Table V below. The weighted curve number after calculation was 84.83.

Table V: Curve Number Calculation Table

Land Use Type	Soil Group	Curve Number (SCS table)	Area(Km²)	Area*CN
Residential Houses	D	92	0.3179	29.2468
	C	90	0.1156	10.404
	B	85	0.1445	12.2825
Streets And Roads	D	98	0.0459	4.4982
	C	98	0.0306	2.9988
	B	98	0.0255	2.499
Agricultural Land	A	65	0.176	11.44
	C	82	0.264	21.648
Total			1.12	95.0173
Weighted Curve Number			84.83	

C. Runoff calculations

Following all the above calculations, runoff depth is calculated from the collected rainfall using SCS curve number method. Daily rainfall data of Kakul Gauging station was collected for 12 years (2004-2015) and then mean monthly data was sued for the analysis. Since in this study future water demand is also predicted therefore frequency analysis was also carried out to forecast the rainfall depth for 2028 and 2038. Log Pearson type-III distribution was used for future rainfall depth prediction. Therefore, the calculations were made for two different cases. 1). Taking into account the frequency analysis and predicting runoff depth for 2028 and 2038, and 2). Using current mean monthly rainfall depth for current as well as future runoff depth calculations. Results for runoff depth and comparison of water shortage and water collected from RWH system for case 1 is shown in Table-VI while the same results for case 2 are shown in Table VII.

Table VI: Comparison of Water Shortage and Runoff Volume Collected From Rainfall Using RWH System for Case-1

Year	Rainfall Depth (mm)	Runoff Depth (mm)	Runoff Volume (m^3)	Runoff Volume (Gallons/day)	Water Deficit (Gallons per day)	Balance (Gallons per day)
2018	113.13	72.31	80987.2	564764.30	152020	412744.30
2028	125.56	83.8	93856	654504.88	288220	366284.88
2038	140.74	97.88	109626	764474.20	465280	299194.20

Table VII: Comparison of Water Shortage and Runoff Volume Collected From Rainfall Using RWH System for Case-2

Year	Rainfall Depth (mm)	Runoff Depth (mm)	Runoff Volume (m^3)	Runoff Volume (Gallons/day)	Water Deficit (Gallons per day)	Balance (Gallons per day)
2018	113.13	74.43	83361.6	581322.18	152020	429302.18
2028	113.13	74.43	83361.6	581322.18	288220	293102.18
2038	113.13	74.43	83361.6	581322.18	465280	116042.18

Results in presented in Table-VI and Table-VII summarizes all the results. These tables show the shows runoff depth obtained from SCS curve number method for mean monthly rainfall. The runoff depth is then converted into Runoff volume in cubic meter by multiplying the runoff depth with area. Volume is then converted into gallons per day units and then it is compared with the shortage of water obtained for each current and predicted years population as mentioned in table III above. The results obtained showed that for both cases the water obtained from Rainfall is sufficient to overcome the shortage for present as well as future population for the next 20 years or even more. This is possible if the water obtained from rainfall and collected through RWH system is properly stored in single or multiple reservoirs. Table VI and VII shows that if the rainwater can be properly stored then it can not only be sufficient for population after 20 years but also there will be extra water available amounting upto 299194 gallons per day in case 1 and 116042.18 gallons per day in case 2. So if this system can be installed and effectively utilized each and every person of the study area will get sufficient amount of water and there will be no shortage.

VI. CONCLUSIONS

From the analysis of water requirements and possible availability of water from the rainwater harvesting it is concluded that:

- If the water from rainfall can be stored through RWH system in the reservoir, there will be no shortage of water not only for current for future population as well.
- This water can be stored in a single larger reservoir or number of small reservoirs depending on the topography of the area.
- Keeping in view the importance of water and possible shortage in near future, it is recommended that the government department should promote this system to save water.

REFERENCES

[1] PSLM / HIES, “Population Census Report, “Pakistan Bureau of Statistics, 2018.

[2] T. M. Boers, and J. Ben-Asher, “A review of rainwater harvesting,” Agric. J. Water Manage, Vol. 5, 1982, pp. 145--158.

[3] C. Despines, K. Farah bakhsh, and C. Ledil, “Assessment of rainwater quality from rainwater harvesting systems in Ontario, Canada,” J. Water Supply Res. Technol. AQUA, Vol.58(2), 2009, pp. 117-134.

[4] D. Prinz, “Water harvesting - past and future,” University Karlsruhe (TH) Institute for Wasserbau und Kulturtechnik 76128 Karlsruhe, 1994.

[5] D. N. Pandey, A. K. Gupta, and D.M. Anderson, “Rainwater harvesting as an adaptation to climate change,” J. current sci., Vol. 85(1), 2003, pp. 46-59.

[6] J. Wright, S. Gundry, and R. Conroy, “Household drinking water in developing countries: a systematic review of microbiological contamination between source and point-of-use,” J. Trop. Med. Int. Health, Vol. 9(1), 2004, pp.106-117.

[7] E. Ghisi, “Potential for potable water savings by using rainwater in the residential sector of Brazil,” J. Build. Environ, Vol. 41, 2006, pp.1544-1550.

[8] J. M. Kahinda, A. E. Taigbenu, and J. R. Boroto,, “Domestic rainwater harvesting to improve water supply in rural South Africa,” J. Phys. Chem. Earth, Vol. 32, 2007, pp.1050-1057.

[9] O. O. Aladenola, and A. O. Adebayo (2010) “Assessing the Potential for Rainwater Harvesting,” Proc. Inst. Civ. Eng. Water Manage. Proceedings of the Institution of Civil Engineers, Vol. 24, 2010, pp. 2129-2137.

[10] A.I. Che-Ani, N. Shaari, A. Sairi, M.F. M. Zain, and M. M. Tahir, “Rainwater Harvesting as an Alternative Water Supply in the Future” Eur. J. Sci. Res., Vol. 34 (1), 2014, pp. 132-140.

[11] S. Ali, “Final PC-1 for Rehabilitation of Gravity Flow Water Supply Scheme Abbottabad”, Public Health Engineering Department Abbottabad, 29 July 2015.

[12] R. E. Rallison, and N. Miller, “Past, present, and future SCS runoff procedure. In V.P. Singh (ed.) Rainfall-Runoff Relationships,” Proceedings, International Symposium on Rainfall-Runoff Modelling. Mississippi State University. pp: 353-364, 1985.

[13] J. Rajbanshi, “Estimation of Runoff Depth and Volume Using NRCS-CN Method in Konar Catchment (Jharkhand, India),” J. Civ. & Environ. Eng, Vol. 6(4), pp.01-06.

[14] Z. Ara and M. Zakwan, “Estimating Runoff Using SCS Curve Number Method”, J. Emerging Techno. & Adv. Eng, Vol. 8(5), 2018, pp. 195-200.

[15] A. T. Hjelmfelt, Jr, “Investigation of Curve Number Procedure”, J. Hydraul. Eng. Vol. 117 (6), 1991, pp. 01-10.

[16] S. K. Mishra and V.P. Singh, “SCS-CN Method. In: Soil Conservation Service Curve Number (SCS-CN) Methodology”, Water Sci. Technol. Lib., Vol. 42, 2003, pp. 84-146, Springer, Dordrecht

[17] R. H. Hawkins, R. Jiang, D. E. Woodward, A. T. Hjelmfelt,, J. A. Van Mullem,, "Runoff Curve Number Method: Examination of the Initial Abstraction Ratio,". Proceedings of the Second Federal Interagency Hydrologic Modelling Conference, Las Vegas, Nevada, 2002.

[18] S. K. Mishra and V.P. Singh, “Determination of ‘S’ Using Volumetric Concept. In: Soil Conservation Service Curve Number (SCS-CN) Methodology”, Water Sci. Technol. Lib., Vol. 42, pp. 205-243, Springer, Dordrecht.