Research article

Analyzing Water Harvesting Potentials in Zoned Areas in Qargha Reservoir Watershed

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Received 22 January 2019 Accepted 8 April 2019 (*Corresponding Author)

Abstract In recent years surface runoff water harvesting is gaining more popularity in arid and semi-arid regions such as Afghanistan due to the increasing demand for scarce water resources. In Paghman District growing season starts in March and ends in October; however, in the latter half from June to October, it hardly rains, which causes crop failure and low productivity. So, collecting and stocking a certain amount of runoff water in the wet season and using it as irrigation water during the latter half of the growing season can reduce water shortage problems. Therefore, this study aimed to analyze water harvesting potentials through identifying suitable water harvesting sites and estimating the potential volume of surface runoff based on the rational method and the sorptivity method in the Qargha Watershed of Paghman District, Afghanistan. In this study, weighted overlay in GIS was used to determine suitable water harvesting sites. Sorptivity method and rational methods were used to estimate the volume of surface runoff. Based on the results of suitability analysis only 27.67% of the land was suitable for water harvesting. The estimated potential volume of surface runoff applied the rational method, and the sorptivity method was at 509.4 m^3 and 478.3 m^3. Therefore, it was concluded that water harvesting is possible in the study area. However, these estimated potential volumes of surface runoff needed to be calibrated with the observed data.

Keywords water harvesting, suitability analysis, rational method, sorptivity method, GIS

INTRODUCTION

Accessibility of water is the main preventive factor of agriculture in arid and semi-arid regions, due to low and an equally divide rainfall throughout the growing season (Watanabe et al., 2012). Harvesting surface runoff water from rainfall is getting popularity due to the increasing demand for scarce water resources in arid and semi-arid regions (Amu-Mensah et al., 2013). Afghanistan is often characterized as arid to semi-arid regions. Although water utilization in Afghanistan is mostly for agricultural purposes, hence 75% of agricultural production is based on irrigation activities. Recently, the country is suffering from a serious drought due to climate change, and the magnitude of the drought reached an emergency level in some part of the country. Cropping season starts in March and ends in October. Though, in the latter half of cropping season from June to October, it hardly rains. So, collecting and stocking a certain amount of runoff water in the wet season and using it as irrigation water during the latter half of the growing season can reduce water shortage. Therefore, surface runoff potential was analyzed in the study area. Many methods such SCS-CN method, rational method, sorptivity method, GIS and remote sensing etc. are used for estimating surface runoff volume. This study focused on the rational and the sorptivity method for estimating surface runoff.

OBJECTIVES

This study aimed to analyze water harvesting potentials through identifying suitable water harvesting sites and estimating the potential volume of surface runoff based on the rational method and the sorptivity method in the Qargha Watershed of Paghman District, Afghanistan.

METHODOLOGY

Study Area

Qargha Reservoir watershed located in Paghman District of Kabul Province, Afghanistan. Average annual precipitation is 280 mm, and the average annual temperature is 11 °C. Most of the farmers are small scale producers with less than 1 ha of land. Irrigation water shortage in the study area is in worse condition, especially in the latter half of the growing season. So, in this study attention have been focused on collecting a certain amount of water in the first half and to used collected water in the dry latter half of the growing season. Location map of the study is shown in Fig. 1.

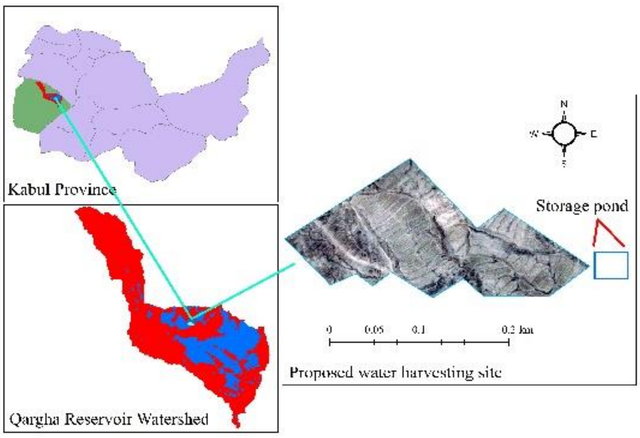

Fig. 1 Location map of proposed water harvesting site in the study area

Table 1 Weightage and ranking for layers and features

Layer	Weight	Feature class	Runoff generation rank
Land use	75	Waterbody	0
		Agriculture	0
		Rangeland	0
		Bare land	1
Soil	10	Rocky land	0
		Haplocambides	1
		Xerorthents	1
DEM	15	< 2000m	0
		2000-2200	1
		➢ 2200	0

Suitable Site Selection

The shortage of water resources for irrigation has resulted in the need to identify suitable water harvesting sites. Several factors influence the selection of suitable water harvesting sites. Land slope, digital elevation model (DEM), land use, soil type, annual rainfall, geology, and drainage are the factors used for suitable site selection (Buraihi and Shariff, 2015 and Miana and Raude, 2016).In this study, weighted overlay among land use, digital elevation model (DEM) and soil type maps in GIS was used to determine suitable water harvesting sites. The necessary data such as digital elevation model (DEM) and soil type maps were collected from the Ministry of Agriculture Irrigation and Livestock (MAIL) (2016). Also, a Landsat image was acquired from an online source and was used to make land use map of the study area using unsupervised classification in ArcGIS. Table 1 shows the different weights and ranks assigned to layer and features and of the layers. The layers were assigned different weights and ranks according to their importance in the suitability analysis. The higher the weight, the more the influence on the results of the suitability map, and the same applies for assigning rank values.

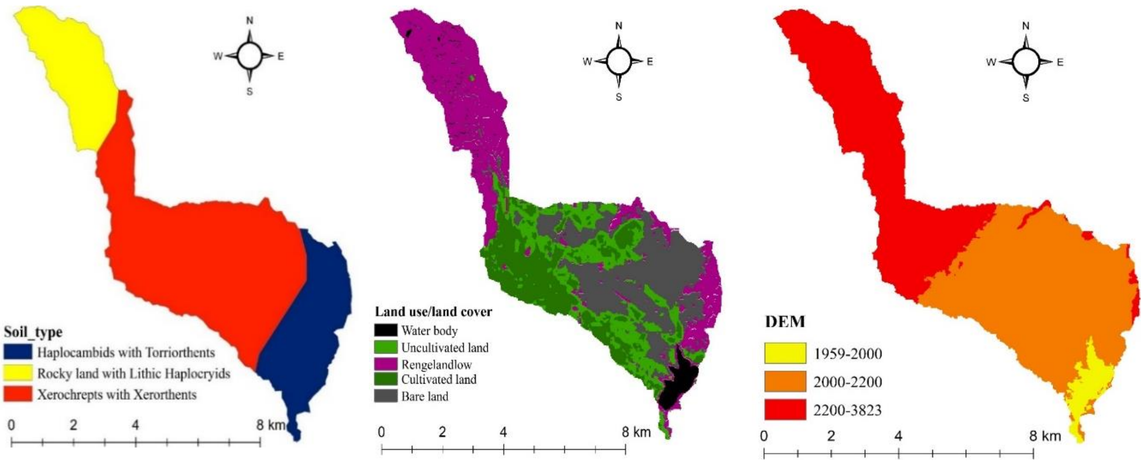

Fig. 2 Layers used in suitability analysis

Surface Runoff Estimation Using the Rational Method

Rational method is a simple and effective method used to estimate surface runoff from a small watershed with scarce hydrological data (Thompson, 2006). Rational runoff coefficient C is part the rational equation relates the amount of runoff to the amount of rainfall. The value getting larger for areas with low permeability and high runoff such as paved, and steep lands, and low value for highly permeable and well-vegetated areas such as forest, flat land (WRCB, 2001). Rational runoff coefficient (C) of this study was based on ODOT (2014) manual, the calculated value for rational runoff coefficient was 0.15. Total 16 rainfall events observed from 18 November 2017 to 6 May 2018 for 170 days were also selected for runoff volume estimation. Rational runoff equation is expressed below:

$$Q = C \times P \times A \tag{1}$$

Where Q is direct runoff (m^3), C is the rational runoff coefficient, and P is the rainfall amount (m) and A is area (m^2). The rational equation has been modified, I rainfall intensity (m/h) has been replaced with rainfall (m). The modification was carried out for making the equation simpler for calculating surface runoff volume.

Surface Runoff Estimation Using Sorptivity Method

Unite State Department of Agriculture (USDA)-Soil conservation service (SCS) (1972), developed a method (SCS-CN method) for measuring the volume of surface runoff from rainfall. However, the SCS-CN method doesn't consider rainfall intensity, so there were doubts if it is applicable in other areas outside of the United States (Yamashita et al., 2006). Chong and Green, (1983), developed a method which is the combination of SCS rainfall runoff equation and potential maximum retention to estimates surface runoff volume of a watershed. The difference between the SCS-CN method and sorptivity method is in calculating maximum retention potential (S). Chong and Green introduced an equation based on soil sorptivity, saturated hydraulic conductivity, and rainfall intensity to calculate maximum retention potential (S) values. Philip (1957), introduced the term sorptivity and define it as a measure of the capacity of a soil to absorb and desorb water by capillary. Also, Hall and William (2012), describe it as the tendency of soil to absorb and transmit water by capillary. The Chong equation is shown below:

$$S = 1/2 \times R_i^{-1/2} \times K_{sat}^{-1/2} \times [Sp(\theta)]^2 \tag{2}$$

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S} \tag{3}$$

Where, S is the maximum potential retention, Sp (θ) is soil sorptivity, K_{sat} is saturated hydraulic conductivity, R_i is rainfall intensity and θ is initial moisture content. And surface runoff was calculated using equation (2) or (SCS rainfall runoff equation), where Q is surface runoff in (m^3), P is rainfall in (mm).

Sp (θ) and K_{sat} were measured in the Laboratory and rainfall intensity data was collected from installed rain gauge in the study area. Mini-Desk infiltrometer was used to measures the soil sorptivity of control and clayey dressed soils. Since different soil types infiltrate water at different rates, measuring the change of volume in Mini-Desk infiltrometer vs time can often be difficult. According to Decagon Device, Inc. (2016), for most type of soils a suction rate of 2 cm is adequate, so the suction rate was adjusted to 2 cm. Soils collected from various locations in the study area were used for sorptivity measurements. Soils from Deh Arbab, Hakim Khel and Doda Mast was used. Soil moisture contents of the soil used in soil sorptivity tests were adjusted to 0, 0.05, 0.10 and 0.15 cm^3 cm^{-3} for control conditions. The average soil moisture content at 0.125 cm^3 cm^{-3} calculated from average moisture content was used as initial soil moisture content (θ) in surface runoff estimation using the sorptivity method.

RESULTS AND DISCUSSION

Suitability Map

Based on the results of suitability analysis only 27.67% and 11.16 km^2 of the land was suitable for water harvesting and the remaining 72.33% and 29.17 km^2 of the land was not suitable for water harvesting as shown in Table 2. Fig. 3 shows the water harvesting suitability map (zoning map) of the Qargha Reservoir Watershed.

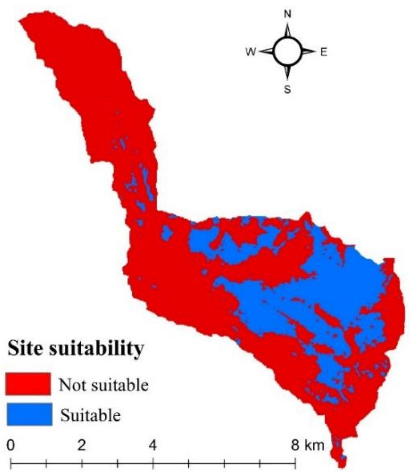

Fig. 3 Suitable water harvesting map

Table 2 Water harvesting suitability categories

Category	Area (%)	Area (km^2)
Not suitable	72.33	29.17
Suitable	27.67	11.16
Total	100.00	40.33

Suitability analysis or suitable water harvesting site selection can be used to facilitate and make water conservation scheme management and planning easy and simple engineers and planners. According to Buraihi et al., (2015), suitable site selection using GIS and remote sensing is a cost-effective and environmentally friendly way of recovering rainfall water.

Relationship between Soil Moisture Content and Soil Sorptivity

Based on the results of sorptivity analysis sorptivity values decreased with an increase in soil moisture content. Fig. 4 shows the relationship between soil sorptivity values and soil moisture contents. The following equation (3) can be used to determine values of sorptivity when rainfall event occurs in control conditions.

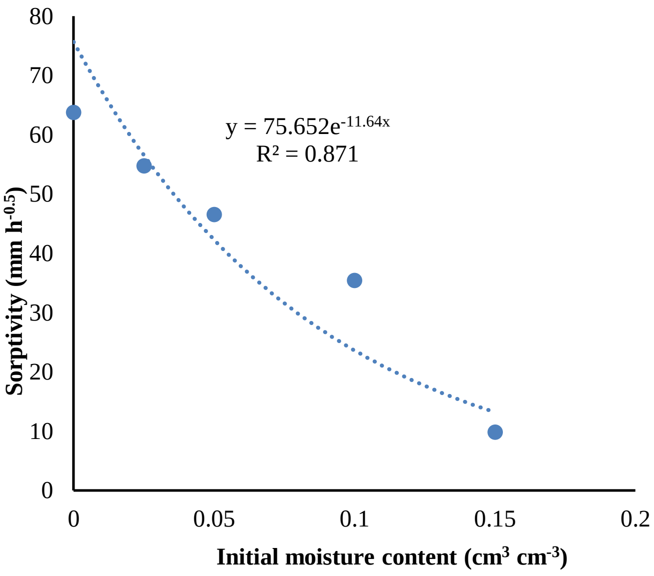

Fig. 4 Relationship between soil moisture content and soil sorptivity

Figure 4 shows the relationship between soil sorptivity values and initial moisture contents which was measured in the laboratory. Soil sorptivity values decrease with increasing soil initial moisture content. The following regression equation (3) can be used to determine the values of sorptivity when rainfall occurs.

$$Sp(\theta) = 75.625e^{-11.64(\theta)} \quad (3)$$

Where Sp(θ) is o soil sorptivity and (θ) is the volumetric initial moisture content.

Potential Surface Runoff Volume

Based on the results of suitable water harvesting site map, a land of 20,000 m^2 was proposed inside suitable areas for estimating potential surface runoff volume. Based on the results of surface runoff volume estimated using the rational method and sorptivity method was at 509.4 m^3 and 478.3 m^3, respectively. Surface runoff estimated based on the rational method was comparatively higher than that the sorptivity method as shown in Table 3.

Table 3 Surface runoff volume estimated using the rational method and sorptivity method

Rainfall event	P (10^{-2}*m)	S	Area (m^2)	C	Qsp (10^{-2}*m)	Qsp (m^3)	Qra (m^3)
1	14.8	20.2	20000	0.15	3.7	74.6	44.4
2	12.8	18.1	20000	0.15	3.1	62.0	38.4
3	8.0	31.7	20000	0.15	0.1	1.7	24
4	14.2	25.9	20000	0.15	2.3	46.5	42.6
5	11.4	22.2	20000	0.15	1.7	33.3	34.2
6	16.8	26.9	20000	0.15	3.4	68.2	50.4
7	3.2	0.0	20000	0.15	0.0	0.0	0.0
8	15.6	27.7	20000	0.15	2.7	53.6	46.8
9	11.2	46.2	20000	0.15	0.1	1.6	33.6
10	22.6	35.7	20000	0.15	4.7	93.4	67.8
11	6.8	23.9	20000	0.15	0.2	3.2	20.4
12	17.4	42.8	20000	0.15	1.5	30.3	52.2
13	8.0	28.4	20000	0.15	0.2	3.5	24
14	10.2	33.4	20000	0.15	0.3	6.7	30.6
15	3.8	0.0	20000	0.15	0.0	0.0	0.0
16	2.2	0.0	20000	0.15	0.0	0.0	0.0
Total						478.34	509.40

Qsp= Surface runoff volume based on sorptivity method Qra= Surface runoff volume based on the rational method
P= rainfall S= maximum retention potential C=runoff coefficient

The viability of the estimated volume of runoff cannot be confirmed. Accordingly, Watanabe et al. (2012), reported that the surface runoff estimated using sorptivity method overestimate surface runoff compare to observed values. Chong and Green, (1983), Watanabe et al., (2012), Chong and Teng (1986) and Gan (2002), reported that the equation could be adjusted in accordance with the observed value of a given soil. Based on their method, the maximum retention potential can be recalculated using optimized parameters. Therefore, necessary adjustments are needed to clarify the accuracy of estimated surface runoff volume in the field. The recalculation of maximum retention potential using the optimized parameters is only possible if we access to observed surface runoff values in the study area.

Table 3 shows the comparison between the sorptivity method and rational method estimated potential surface runoff volume. There is a tendency between the sorptivity and the rational method estimated potential surface runoff volume using sorptivity values. However, the rational method overestimated the values of surface runoff, but the difference was not very big.

CONCLUSION

Collecting and stocking a certain amount of runoff water in the wet season and using it as irrigation water during the latter half of the growing season or dry season can reduce water shortage problems. Based on the suitability analysis only 27.67% of land in Qargha Reservoir Watershed was suitable for water harvesting. So, a small area at 20,000 m^2 was proposed inside suitable areas in Qargha Reservoir Watershed. The estimated volume of surface runoff applied the rational method was at 509.4 m^3 was larger than that applied the sorptivity method at 478.3 m^3 from the 16 rainfall events observed from 18 November 2017 to 6 May 2018 for 170 days. It was recognized that there was a relationship between soil sorptivity and initial moisture content in the catchment area. The volume of each rainfall event could be estimated using sorptivity values measured in the laboratory. The rational method can also be used to estimate valume of surface runoff in case of scarce data conditions. It was concluded that water harvesting is possible in Qargha Reservoir Watershed, means that there is enough amount of rainfall for water collecting and stocking a certain amount of water. However, these estimated volumes of surface runoff should be calibrated with the observed data. According to the finding of this study, the application of water harvesting strategies is highly recommended. So, the government should design and apply certain projects to reduce irrigation water shortage in the study area.

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