Research article

Water Harvesting Potential and its Maximization by the Application of Clayey Dressing in Qargha Reservoir Watershed, Kabul, Afghanistan

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Abstract The unfavorable impacts of climate change are experienced all over the world. Afghanistan is among the countries that are severely affected by the impacts of climate change. The adverse effect on water resources constitutes one of the most negative effects. Currently, water management authorities and researchers look for improved water management techniques that will reduce the pressure on the already stressed water resources. Surface runoff harvesting is becoming more popular in regions with an arid-semi-arid climate, such as Afghanistan because of the increasing demand for scarce water resources. Therefore, a study was carried out to analyze the water harvesting potential in Qargha Reservoir Watershed, and to evaluate the effectiveness of clayey dressing application in maximizing surface runoff compared to control conditions. Rational method and sorptivity method were used to estimate the potential surface runoff and clayey dressing (silty clay loam and clay loam) was applied as a conservation strategy. A small area of 2 ha was selected in suitable areas of Qargha Reservoir Watershed. Based on 16 rainfall events, the volume of surface runoff estimated by the rational method was 509.40 m^3, which was larger than the 478.34 m^3, estimated by the sorptivity method. After clayey dressing application, the estimated volume of surface runoff based on the rational method increased to 1392.36 m^3. Furthermore, the estimated volume of surface runoff after clayey dressing calculated with the sorptivity method increase to 1608.46 m^3 based on 16 rainfall events. Proper soil surface treatment such as application of clayey dressing is highly recommended for achieving sustainable agriculture.

Keywords water harvesting, Qargha Reservoir, clayey dressing application, silty clay loam, clay loam and sorptivity method

INTRODUCTION

In recent years, the adverse impacts of climate change occur more consistently, and the sector most severely hit by climate change is agriculture sector. The adverse effect of climate crises on water resources constitutes one of the most negative effects. Moreover, excessive use of available irrigation water in the field aggravates the consequences. The most common irrigation method used in the study area is surface irrigation (flood irrigation). Thus, intensive aridity has altered the yield pattern negatively (Parvizi and Sepaskhah, 2015). According to Oweis and Hachum, (2006), rain water harvesting can considerably boost productivity in the drier marginal environments. Water harvesting is among the most promising ways of supplementing the scarce surface water resources in areas to meet demand (Aladenola and Adeboye, 2010). Maximizing surface runoff can be used to provide partial water requirement of rain-fed and irrigation based agriculture (Parvizi and Sepaskhah, 2015). Currently, water management authorities and researchers look for improved water management techniques that will reduce the pressure on the already stressed water resources. Climate induced changes in precipitation, surface runoff, and soil moisture will possibly have intense impacts on living creatures (Hardy, 2005). Survey conducted by Rahmani and Mihara, (2017) reported that water shortage was the main problem in the study area farmers face during crop production. Growing season in Qargha Reservoir Watershed of Paghman District, Kabul Province 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 (Rahmani et al., 2019 and). Wide range of techniques such as soil compaction, gravel removal, bitumen emulsion and tall oil, less permeable soil, wax and plastic and Sodium dispersants such as sodium carbonate and sodium chloride (Yazar et al., 2014, Parvizi et al., 2015, Short and Lantzke, 2006, Amu-Mensah et al., 2013, Fink et al., 1980 and Frasier et al., 1987) used worldwide for surface runoff maximization. This study aimed to evaluate the effectiveness of clayey dressing application in surface runoff maximization compared to control conditions in the laboratory and in the field.

OBJECTIVE

To analyze the water harvesting potential in Qargha Reservoir Watershed, and to evaluate the effectiveness of clayey dressing application in maximizing surface runoff compared to control conditions.

METHODOLOGY

Study Area

The research area lies between longitudes E 68° 49' 44" and E 68° 40' 54" and latitudes N 34° 25' 14" and N 34° 40' 19.2". The research was carried out in Qargha Reservoir Watershed, Paghman District, Kabul Province, Afghanistan. The total area of Paghman District is 361 km^2, and Qargha Reservoir catchment area is 40.33 km^2. According to Rahmani et al, (2018), average precipitation in the watershed is around 280 mm annually and average annual temperature is 11.01 ^{o}C. Majority of the people living in Paghman District is small subsistence farmers with small plots of agricultural land.

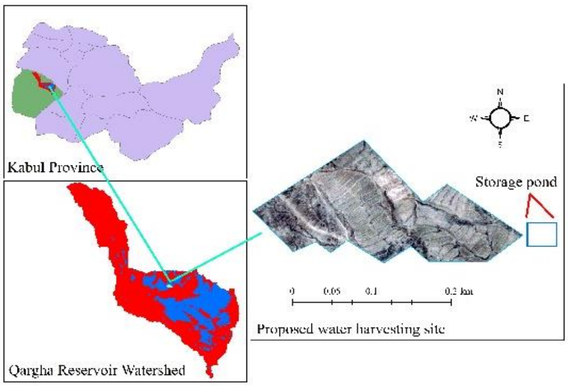

Fig. 1 Location map of proposed water harvesting site (Rahmani et al., 2019)

Surface runoff experiments were conducted in the field and laboratory. Sorptivity method and rational method were used to calculate surface runoff. Soil sorptivity experiments were carried out in the laboratory; several samples from local soil were used in the experiment. The dominant soil particle size distribution (soil texture) in the study area is loam. Thus, surface runoff was calculated with and without clayey dressing application. Clayey dressing application is an economical and environmental friendly runoff enhancement technique. Clayey dressing (less permeable soil) was extracted using sieve sieving and cloth sieving. A clothing was placed on the bucked to remove larger particles from diluted soil (Rahmani, et al., 2018). Cloth sieving was used for clayey dressing extraction in the field and soil sieved (clayey dressing) using sieves of 38 μm and 75 μm were used in the surface runoff experiment in the laboratory. Runoff experiment was conducted in the laboratory of Land and Water Use Engineering, Tokyo University of Agriculture using runoff plots with 0.90 m long, 0.052 m wide and 0.035 m deep. Marriott bottle was used to provide constant water flow rate of 20 cm^3 s^{-1} at constant pressure for a concentrated surface scenario and 8% slope.

The rational runoff coefficient for treated condition was calculated based on the runoff plot experiment in the laboratory and in the field. The change in rational coefficient was recorded and then added to rational runoff coefficient for control condition based on ODOT (2014). And then the average runoff coefficient was calculated. The average runoff coefficient for treated conditions calculated was 0.41. Total 16 rainfall events observed from 18 November 2017 to 6 May 2018 for 170 days were selected for runoff volume estimation. Additionally, silty clay loam (SiCL) dressing and clay loam (CL) dressing were used as a surface runoff maximization strategy. For further information refer to the calculation of surface runoff using sorptivity method and rational method in Qargha Reservoir Watershed control condition (Rahmani et al., 2019).

RESULTS AND DISCUSSION

Surface Runoff Estimation

The amounts of surface runoff generated under different treatments compared to control in the laboratory are shown in Table 1. Silty clay loam dressing with 57%, 53% and 47% concentration increased runoff 1.30 x, 1.28 x and 1.16 x, respectively. While, clay loam dressing with 65%, 60% and 53% concentration increased runoff 1.43 x 1.41 x and 1.27 x, respectively. The result shows that, the clay dressing application is highly effective in increasing surface runoff, and the influence of sieve size was not obvious. Shirazi et al., (2010) stated that permeability noticeably decreasing by the increasing rate of clay in the clay-sand mixture. For instance, application of clayey dressing on the soil surface is highly recommended as a runoff maximizer. Thus, it is very economical and easy to use, and extraction does not need expensive and difficult equipment and tools to use. Availability and generation of extra rainfall runoff water can help to revive agriculture in the study area and cultivate large dry uncultivated lands. Statistical analysis showed that there are significant differences between control and clayey dressing applied conditions.

Table 1 Surface runoff water under different treatments

Clayey dressing	Dry density ($g\ cm^{-3}$)	Treatment ($cg\ g^{-1}$)	Water applied (dm^3)	Runoff ($dm^3\ m^{-2}$)	Infiltration ($dm^3\ m^{-2}$)	Runoff (C)	Increase from control (x)
SiCL	1.3	Control	12.96	9.70 ^{a**}	3.20	0.75	
		46.4	12.96	11.24 ^{b**}	1.68	0.87	**1.16**
		52.3	12.96	12.45 ^{b**}	0.50	0.96	**1.28**
		56.9	12.96	12.62 ^{b**}	0.00	0.97	**1.30**
CL	1.5	Control	12.96	8.68 ^{a**}	3.82	0.67	
		52.1	12.96	11.04 ^{c**}	1.55	0.85	**1.27**
		60.1	12.96	12.20 ^{b**}	0.00	0.94	**1.41**
		64.9	12.96	12.38 ^{b**}	0.00	0.95	**1.42**

*CL = Clay loam dressing, SiCL = Silty clay loam dressing, **denotes significance difference level at P<0.01*

The result of surface runoff experiment conducted in the field showed that, Deh Ponba soil treated with clayey dressing at 57.7 and 64.9 cg g^{-1} increased runoff by 1.41 x and 1.42 x, and Doda Mast soil increased runoff by 1.55x and 1.58x compared to control shown in Table 2. Statistical analysis also showed that the result of control and treated conditions had signification differences. Parvizi and Sepaskhah, (2016), examined the effect of gravel removal, rill construction across to slope and applying of baking soda on surface runoff. According to the results, gravel removal technique is nearly as effective in the runoff enhancement as rill construction across to slope and baking soda technique.

Table 2 Surface runoff estimation in the field

Site	Treatment ($cg\ g^{-1}$)	Water applied (dm^3)	Runoff ($dm^3\ m^{-2}$)	Runoff (C)	Increase from control (x)
Deh Ponba	Control	45.0	27.7 ^{a**}	0.62	
	SiCL 57.7	45.0	39.2 ^{b**}	0.87	**1.41**
	SiCL 64.9	45.0	39.5 ^{b**}	0.88	**1.42**
Doda Mast	Control	45.0	25.3 ^{a**}	0.56	
	SiCL 57.7	45.0	39.2 ^{b**}	0.87	**1.55**
	SiCL 64.9	45.0	39.5 ^{b**}	0.88	**1.58**

*SiCL = Silty clay loam dressing. **denotes significance difference level at P<0.01*

Results of runoff volume calculation showed that with clayey dressing application of either silty clay loam or clay loam, the runoff volume increased from 509.40 m^3 to 1392.36 m^3 compared to control conditions, which shows 2.73 x increase in surface runoff. Similarly, the runoff coefficient value was increased from 0.15 to 0.41. The results of surface runoff calculated based on sorptivity method with clayey dressing application showed that surface runoff volume can be increase to 1608.46 m^3 from 478.34 m^3 control condition, which shows 3.36 x increase. Accordingly, both methods confirm that clayey dressing application onto the soil surface can effectively increase surface runoff. The results of surface runoff volume in treated conditions estimated using sorptivity method is shown in Table 3. For the result of surface runoff calculated using rational and Sorptivity method in control conditions please refer to Rahmani et al., (2019). Comparison result of rational and Sorptivity method calculated surface runoff is shown in Table 4.

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

Rainfall even	P (mm)	S	Area (m^{-2})	C	Qsp (mm)	Qsp (m^3)	Qra (m^3)
1	14.80	6.70	20000	0.41	9.00	179.70	121.36
2	12.80	6.00	20000	0.41	7.70	153.20	104.96
3	8.00	10.50	20000	0.41	2.10	42.50	65.60
4	14.20	8.60	20000	0.41	7.40	147.90	116.44
5	11.40	7.30	20000	0.41	5.70	114.20	93.48
6	16.80	8.90	20000	0.41	9.40	188.70	137.76
7	3.20	10.80	20000	0.41	0.00	0.00	0.00
8	15.60	9.20	20000	0.41	8.30	165.20	127.92
9	11.20	15.30	20000	0.41	2.80	56.60	91.84
10	22.60	11.80	20000	0.41	12.80	255.50	185.32
11	6.80	7.90	20000	0.41	2.10	41.60	55.76
12	17.40	14.20	20000	0.41	7.40	147.80	142.68
13	8.00	9.40	20000	0.41	2.40	48.30	65.60
14	10.20	11.10	20000	0.41	3.40	67.10	83.64
15	3.80	3.90	20000	0.41	0.00	0.00	0.00
16	2.20	8.90	20000	0.41	0.00	0.00	0.00
			Total			**1608.46**	**1392.36**

Amu-Mensah et al., (2013), reported that, possibility of water harvesting to can be created in soils with high infiltration rate by less permeable soil application onto the soils surface. In accordance with the results, it was assumed that the higher effectiveness of clayey dressing in surface runoff inducement (maximization) and reducing infiltration rate of the soil is due to its characteristic of clogging and sealing surface which leads to lower infiltration rate and high runoff production. A study conducted by Rahmani et al., (2018), indicated that, application of less permeable soil (clayey dressing) on soil surface lower the infiltration rate because of clogging soil pores and cracks. It is to be concluded that, the increase observed in surface runoff by clayey dressing application compared to control was due to clogging the soil pores and sealing the surface. Pore clogging and surface sealing take place when the plug flow radius of the soil suspension was bigger than the radius of soil pores. Mihara et al. (1993), also confirm that pore radius smaller than radius of plug flow causes clogging of soil pores, which leads to increased runoff. Mihara and Yasutomi (1992) also reported that clayey suspension flow causes pore clogging.

Table 4 Surface runoff volume change after clayey dressing compared to control

Treatment	Method	Rainfall events	Area (m^2)	Runoff (m^3)	Increase in runoff volume (x)
Control*	Sorptivity method	16	20,000	478.3	
Clayey dressing		16	20,000	1,608.5	**3.36 x**
Control*	Rational method	16	20,000	509.4	
Clayey dressing		16	20,000	1,392.4	**2.73 x**

Rational method and sorptivity method (control condition) by Rahmani et al.,(2019).

This idea is confirmed and backed by Mihara and Yasutomi (1993) and Mihara et al., (1992), which conclude that clay suspension caused pore clogging and surface sealing. According to Robert (1974), infiltration decreases with increased number of suspended solids in the water. Further, he stated that sediment deposition caused surface sealing.

CONCLUSION

Water harvesting is one of the promising ways of supplementing the surface and underground scarce water resources in areas where existing water supply system is inadequate to meet demand. Water harvesting can substantially increase rainwater productivity in the drier marginal environments. The results of both laboratory and field runoff experiment showed that clayey dressing application (less permeable soil) was highly effective in maximizing surface runoff and to lower infiltration rate even in rainfall events with depth and intensity. Thus, the result of surface runoff calculated using rational method and sorptivity method also indicated that surface runoff can be increased with clayey dressing application onto the soil surface. The statistical analysis also showed that there were significant differences between control and soil treated with clayey dressing. So, maximizing surface runoff can be used to provide water requirement of rain-fed and irrigation based agriculture.

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