Research article

Development of Water Harvesting Technique in Qargha Reservoir Watershed of Paghman District, Afghanistan

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Abstract Harvesting surface runoff water from rainfall rather than allowing these waters to run into the streams and rivers and eventually lost into sea is attaining popularity due to the increasing demand for scarce water resources. In semi-arid countries such as Afghanistan crops in need regular irrigation due to low and unequally divided annual rainfall throughout the growing season. Therefore, this study aimed to develop water harvesting technique with clayey dressing application as a water harvesting strategy for surface runoff inducement to reduce water shortage problems in Qargha Reservoir Watershed of Paghman District, Afghanistan. The results of laboratory and field experiments showed that, application of clayey dressing on the soil surface was highly effective in surface runoff inducement. The application of clayey dressing with silty clay loam and clay loam textures in the laboratory and in the field and at various concentrations increased surface runoff considerably. The plug radius of both silty clay loam dressing with 37.16% or lower concentration and clay loam dressing with 46.96% or lower concentration can effectively clog pores and seal soil surface. Therefore, development of proper water harvesting strategies such as clayey dressing application is indispensable to achieve sustainable agriculture.

Keywords water harvesting, irrigation, clayey dressing, water resource management, conservation strategies

INTRODUCTION

Water is the most essential input for successful farming. Afghanistan is often characterized as a dry or arid to semi-arid country. Water utilization in Afghanistan is mostly for agricultural purposes. Majority of the population lives in rural areas and are small subsistence farmers who live on small plots of land (Qureshi, 2002). Recently, all the country is moaning from a serious drought due to climate change. Recently National Disaster Management Authority (NDMA) (2018) stated in a report that, drought has reached to an emergency level in several parts of the country. According to FAO (2018) report, drought impacted agricultural seasons of 2017 and 2018 in some part of the country of to a level in which the harvest was considered completely lost. As a semi arid region, crops in the study area need regular irrigation due to low and unequally divided annual rainfall throughout the growing season. Growing season starts in the march and ends in the month of October. Hence, from June to October, Qargha Reservoir Watershed receives hardly any precipitation. Therefore, irrigation water shortage during the latter half of the growing season is a serious problem causing crop failure and low productivity in the study area. Karezes (Karez is a tunnel system used to extract shallow groundwater) and tube wells are the main irrigation sources in the study area. Mack et al., (2010) reported that, the water table has been continually dropping. Rahmani and Mihara (2017) reported that 83% of the farmers in the Qargha Reservoir Watershed have an irrigation water shortage, and 66% of the farmers severely face it, especially in the latter half of the growing season. Rain water management through water harvesting and inducement of surface runoff by clayey dressing application onto soil surface can help in reducing water shortage problems in the study area. Water harvesting techniques such as compaction by (Yazar et al., 2014), gravel removel by (Parvizi et al., 2015), bitumen emulsion and tall oil, (Short and Lantzke, 2006), less permeable soil (Amu-Mensah et al., 2013), wax and plastic cover by (Fink et al., 1980), Sodium dispersants such as sodium carbonate and sodium chloride (Frasier et al., 1987 and Parvizi et al., 2015) are widely used in the world for runoff inducement. In this study clayey dressing was focused as a water harvesting techinque because it is an economical and environmental friendly strategy.

OBJECTIVE

This study aimed to develop water harvesting technique with clayey dressing for runoff inducement in order to reduce water shortage problems in Qargha Reservoir Watershed.

METHODOLOGY

Study Area

Qargha Reservoir Watershed is located within semi-arid region. Water utilization in Afghanistan is mostly for agricultural purposes. The study 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 conducted 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. Average annual precipitation in the watershed is 280 mm and average annual temperature is 11.01 ^oC. The majority of the rural population is small subsistence farmers with small plots of land.

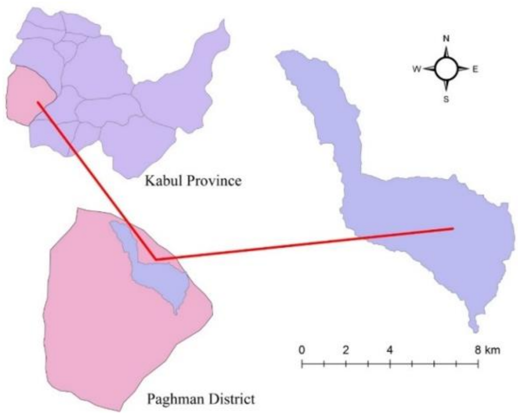

Fig. 1 Location of Qargha Reservoir Paghman District, Kabul, Afghanistan

Rheological Analysis and Pore Size Distribution

Soil from Qala e Jan Big and Qala e Khwaja area of Qargha reservoir watershed was used for clayey dressing extraction in the laboratory. Sieves of 38 µm and 75 µm were used for the clayey dressing extraction. Soil was diluted in the water and then passed it through sieves. Particles larger than 38 µm and 75 µm were removed. Water content was reduced in room temperature. Cloth sieving was used for clayey dressing extraction in the field. The extracted clayey dressing was analyzed for its soil particle size distribution. Rheological analysis of the clayey suspension was carried out using MacMicheal rotational viscometer in the laboratory.

Rotational rheometer tests have been used to determine the flow behaviors and shear strength properties of very soft clays and muds with high moisture contents (Mahajan et al., 2008; Fakher et al., 1999). Standard wire number 26, and 10, 20, 30, 40, 50 rpm (revolutions per minute) were used. Clayey suspension of silty clay loam (SiCL) and clay loam (CL) with 56.90%, 52.28%, 46.41%, 37.16% and 37.16% and 64.86%, 60.05%, 55.35%, 52.06 and 46.96% concentration were used, respectiveley. Shear stress and shear rate values of the clayey suspension were measured and were used to estimate Bingham yield values of the clayey suspension. Estimated Binghm yield values were used to calculate plug flow radius of the suspension using equation below:

$$r_o = 2L / \Delta P \qquad \text{Eq. (1)}$$

Where, r_o is radius of plug flow (cm), L is pore length (cm) and ΔP is the difference in pressure (Pa).

The soil water retention curve was determined in the laboratory and was used to measure non-gravitational pore size distribution, while gravitational pores were observed using morphological method. Soil sample was prepared from local soil in a cylinder with 10 cm depth and 10 cm diameter, soil sample was adjusted at 5 cm depth and 10 cm of diameter and was compacted same as field condition. The matric potential was determined using Em50 data logger and weight changes were recorded using weight scale. Pore size distribution was calculated using Equation below:

$$r = 0.15 / h \qquad \text{Eq. (2)}$$

Where, r is the pore radius (cm) and h is the matric potential (cmH_2O).

Surface Runoff Experiment

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. Surface runoff experiments were also conducted in the field (Fig. 2).

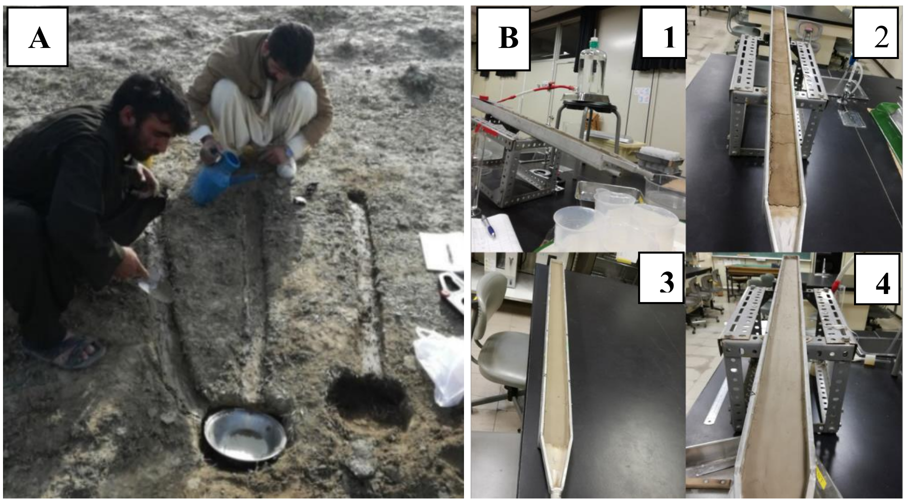

Fig. 2 Field (A) and laboratory (B) runoff experimental plots (1), cracks in the soil (2) and soil surface after clay dressing (3, 4)

RESULTS AND DISCUSSION

Two types of clayey dressing 1st silty clay loam and 2nd clay loam were extracted with 38 µm and 75 µm sieves, respectively in the laboratory and in the field using a cloth and were applied on the soil surface. Soil properties of the two extracted clay dressing is shown in Table 1. Most water harvesting techniques are quite expensive and usually interfere with the natural environment and deprive the land for other possible uses. While, the use of less permeable soils as a top layer dressing to reduce infiltration and enhance runoff presents an interesting and viable option that could give appreciable results (Amu-Mensah et al., 2013).

Table 1 Particle size distribution of clayey dressing

Soil type	Sieve (μm)	Sand (%)	Silt%	Clay%	Total%	Sieved soil texture
Loam	38	14.3	51.8	33.9	100	Silty clay loam
Sandy loam	75	27.2	41. 7	31.1	100	Clay loam
Field	Cloth	19.6	52.7	27.7	100	Silty clay loam

Surface Runoff

The amounts of surface runoff generated under different treatments compared to control are shown in Table 2. Silty clay loam dressing with 57%, 53% and 47% concentration increased runoff by 30.07%, 28.29%, and 15.81%, respectively. While, clay loam dressing with 65%, 60% and 53% concentration increased runoff by 42.57%, 40.59%, and 27.13%, 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. Sherazi 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 to use equipment. Availability and generation of extra rainfall runoff water can help to revive agriculture in the study area and cultivate large dry uncultivated lands.

Table 2 Surface runoff water under different treatments

Soil Texture	Dry density g cm^{-3}	Treatment	Disc. (dm^3 m^{-2})	W. used	Infil. (dm^3 m^{-2})	Coef.	Percentage increase from control
Loam	1.3	Control	9.70 a**	12.96	3.20	0.75	
		SiCLD 57%	12.62 b**	12.96	0.00	0.97	30.07
		SiCLD 53%	12.45 b**	12.96	0.99	0.96	28.29
		SiCLD 47%	11.24 b**	12.96	1.68	0.87	15.81
Loam	1.5	Control	8.68 a**	12.96	3.82	0.67	
		CLD 65%	12.38 b**	12.96	0.00	0.95	42.57
		CLD 60%	12.20 b**	12.96	0.00	0.94	40.59
		CLD 45%	11.04 c**	12.96	1.55	0.85	27.23

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

The amounts of surface runoff generated under different treatments in the field compared to control are shown in Table 3. Silty clay loam dressing onto Deh Ponba soil with 65% and 58% concentration increased runoff by 42.55% and 41.47%, respectively. While, clay loam dressing onto Doda Mast soil with 65%, 60% and 53% concentration increased runoff by 58.58% and 55.28%, respectively. Parvizi and Sepaskhah (2016) examined the effect of gravel removal, rill construction across to slope and applying of baking soda on surface runoff, rainfall infiltration. The most effective in the runoff enhancement were gravel removal, rill construction across to slope and baking soda 31.20, 29.30 and 22.00%. Application of less permeable soil onto soil surface to create possibility for harvesting and storing rainwater (Amu-Mensah et al., 2013). Statistical analysis showed that there was significant difference in surface runoff between control and clayey dressing treated soils both in laboratory and in the field. Sandy soils have a relatively low water-holding capacity but a high intake rate. Instead, a clay or loam soil on the other hand, hold more water than a sandy soil but will not absorb water as quickly. Hence, soils with 20% or more clay content were found to be the most sensitive to crust formation and have the lowest infiltration rate. It was concluded that the increase in surface runoff using clayey dressing was due to its low permeability.

Table 3 Surface runoff experiment in the field

Site	Treatment	Discharge (dm^3 m^{-2})	W. applied	Coef.	Percentage increase from control
Deh Ponba	Control	27.73 ^{a**}	45.00	0.62	
	SiCLD 65%	39.53 ^{b**}	45.00	0.88	42.55
	SiCLD 58%	39.23 ^{b**}	45.00	0.87	41.47
Doda Mast	Control	25.27 ^{a**}	45.00	0.56	
	SiCLD 65%	40.07 ^{b**}	45.00	0.89	58.58
	SiCLD 58%	39.23 ^{b**}	45.00	0.87	55.28

*SiCLD = Silty Clay Loam Dressing, **denotes significance difference level at P<0.01*

With an increasing percentage of clay, the soil structure become more stable (Ben-Hur et al., 1985). The result showed remarkable improvements in runoff generation and the percolation reduction over the layered (dressed) soil surface as opposed to the control runoff experiments. Amu-Mensah et al., (2013), reported that, application of a clay soil layer (dressing) on the soil surface remarkably improving runoff generation. Clay is applied at the bottom of ponds alone onto porous soils or mixed with a porous soil form an impermeable layer (Keese, 2006).

Rheological Properties of Clayey Suspension

The results of rheometer tests showed that suspension Bingham yield and plastic viscosity values increased with increase in the mass concentration of clayey, and with decrease in mass concentration, Bingham yield and plastic viscosity values decreased. The results of rheometer tests as shown in Fig. 3 had a direct impact on the plug flow radius of the clayey suspension.

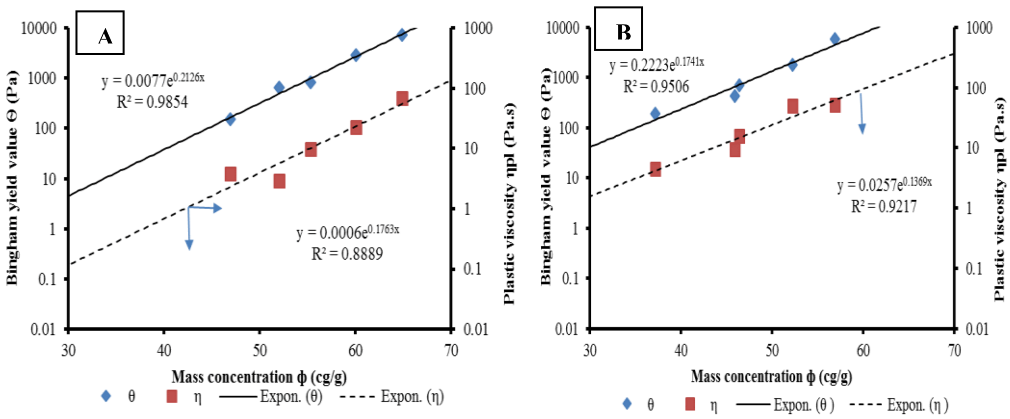

Fig. 3 Changes in Bingham yield value and plastic viscosity with mass concentration of silty clay loam (B) and clay loam (A) suspension

Relationship between Pore Size Distribution and Plug flow

The result of plug flow radius calculation showed that the radius of plug flow minimizes with a decrease in concentration of clayey suspension as shown in Table 4. Clayey suspension of silty clay loam at 56.95%, 52.28%, 46.41%, 45.88% and 37.16% concentration produce plug flow radius with 0.61 m, 0.195 m, 0.079 m, 0.048 m and 0.023 m, respectively, and clayey suspension of clay loam at 64.86%, 60.05%, 55.35%, 52.06% and 46.96% concentration produce plug flow radius with 0.725 m, 0.292 m, 0.086 m, 0.071 m and 0.017 m, respectively. Clay soils are insensitive cohesive soils that have a water content higher than the liquid limit. The behavior of clay soils and sandy soils or even clay-silt soils differ from each other and even become more complex with water content. The transformation of soil from a plastic state to a viscous liquid state is primarily caused by a change in the water content of the soil mass. As the water content increases, the soil mass gradually starts to behave like a viscous liquid (Fakher et al., 1999).

Table 4 Plug radius of clayey dressing suspension

(Conc.) cg g^{-1}	(θ) Pa	(ρ) kg m^{-3}	(h) m	(m sec^{-2}) G	(ΔP) Pa	(r_o =2Lθ/ΔP) (m)
56.90	5888.0	1939	0.005	9.81	95.1	0.610
52.28	1815.0	1863	0.005	9.81	91.36	0.195
46.41	694.4	1766	0.005	9.81	86.61	0.079
45.88	426.5	1757	0.005	9.81	86.18	0.048
37.16	189.9	1613	0.005	9.81	79.13	0.023
(Conc.) cg g^{-1}	(θ) Pa	(ρ) kg m^{-3}	(h) m	(m sec^{-2}) G	(ΔP) Pa	(r_o =2Lθ/ΔP) (m)
64.86	7370.0	2070	0.005	9.81	101.5	0.725
60.05	2851.0	1991	0.005	9.81	97.65	0.291
55.35	814.1	1913	0.005	9.81	93.85	0.086
52.06	650.2	1859	0.005	9.81	91.18	0.071
46.96	150.9	1775	0.005	9.81	87.05	0.017

Θ=Bingham yield, h= clayey dressing depth, ρ=Bulk density

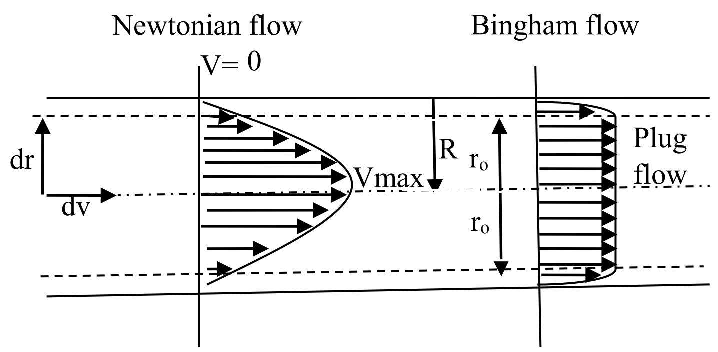

Fig. 4 Newtonian and Bingham flow

Plug flow radius of the clayey suspension also increased with an increase in Bingham yield values as it is shown in Table 4. Two type of structural clogging take place 1st immediate clogging course particles fixed in the pores and 2nd gradual clogging by adhesion and sedimentation of fine particles to the inner wall. Bingham fluids such as clayey suspension produces plug flow. Clayey suspension causes both immediate and gradual clogging (Mihara and Ysutomi, 1992).

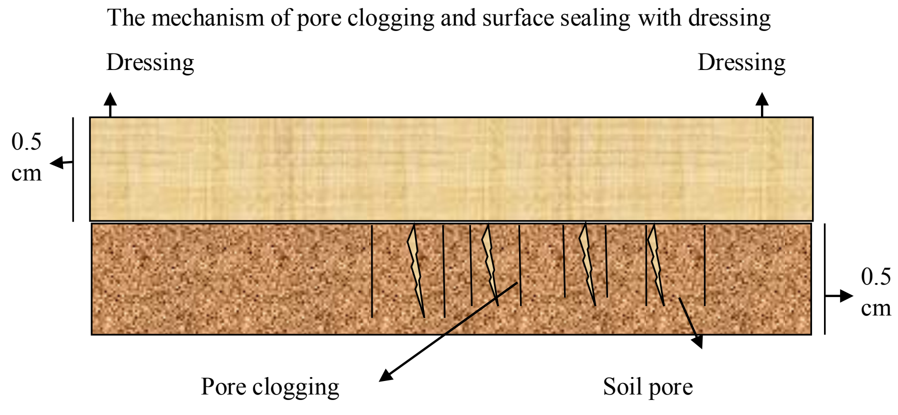

Fig. 5 Mechanism of pore clogging and surface sealing

The pore volume for each pore class was calculated from the pore size distribution curve. The pore diameter was classified into 5 categories as shown in Table 5. Pore classes of macropores, mesopores, micropores, ultramicropores and cryptopores constitute at 26.47%, 30.88%, 19.85%, 6.62% and 16.18% of the total pore volume, respectively. A pore is not simply a void in the solid structure of soil. However, various pore size categories have different characteristics and contribute different attributes to soils depending on the number and frequency of each type. A widely used classification of pore size is that of (Brewer, 1964).

Table 5 Pore size distribution of Qargha Reservoir Watershed soils

Class*	Subclass	Pore size (mm)	Volume (cm^3)	Volume (%)
Cryptopores		0.1>	47.16	26.47
Ultrmicropores		0.1 to 5	55.02	30.88
Micropores		5 to 30	35.37	19.85
Mesopores		30 to 100	11.79	6.62
Macropores	Coarse	100 to 1000	0.10	0.22
	Medium	1000 to 2000	0.91	2.00
	Fine	2000 to 5000	1.99	4.39
	Very fine	5000>	4.34	9.57

**Source: Brewer (1964)*

Changes in the pore size distribution evidently modify soil water retention. The direct relation between pore size distribution and the soil water content can be defined as macropores and mesopores control the water content at soil saturation, micropores and ultramicropores control water content at field capacity and cryptopores are very tinny pores filed by water for long time and very little amount of water of these pores are available of plant consumption. 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 happens when the plug flow radius of suspension is bigger than the radius of soil pores. Mihara et al. (1993) also confirm that pore radius smaller than radius of plug flow causes structural clogging.

CONCLUSION

As a semi arid country, crops in Afghanistan need regular irrigation due to low and unequally divided annual rainfall throughout the growing season. During the growing season hardly any rainfall event takes place in the study area. Therefore, this study aimed to develop water harvesting technique with clayey dressing for runoff inducement in order to reduce water shortage problems in the study area. The results from both laboratory and in the field experiments indicated that clayey dressing application onto soil surface considerably increase surface runoff. Two types of clayey dressing 1st silty clay loam and 2nd clay loam were extracted with 38 µm and 75 µm sieves, respectively in the laboratory and in the field using a cloth and were applied on the soil surface. Silty clay loam dressing at 57%, 53% and 47% concentration increased runoff by 30.07%, 28.29% and 15.81%, respectively compared to control. While, clay loam dressing at 65%, 60% and 53% concentration increased runoff by 42.57%, 40.59%, and 27.13%, respectively. The results of field expeiments showed that, clayey dressing applied onto Deh Ponba soil at 65% and 58% concentration increased runoff by 42.55% and 41.47%, respectively. While, clayey dressing onto Doda Mast soil with 65% and 60% concentration increased runoff by 58.58% and 55.28%, respectively compared to control. Clayey suspension of silty clay loam at 56.95, 52.28%, 46.41%, 45.88% and 37.16% concentration produced plug flow radius at 0.61 m, 0.195 m, 0.079 m, 0.048 m and 0.023 m, respectively, and clayey suspension of clay loam at 64.86%, 60.05%, 55.35%, 52.06% and 46.96% concentration produce plug flow radius with 0.725 m, 0.292 m, 0.086 m, 0.071 m and 0.017 m, respectively. It is concluded that, silty clay loam dressing at 37.16% or lower concentration and clay loam dressing with 46.96% or lower concentration can effectively clog pores and seal soil surface. Therefore, development of proper strategies on water resource development/management is needed to achieve sustainable agriculture.

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