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Hydrological responses of soil to Rain Water Harvesting (RWH) in Semi-Arid regions of central Iran

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Abstract

Rain Water Harvesting (RWH) techniques are among the approaches that are used to meet the increasing need for water in the watersheds. Some of these techniques do not have much effect on the living and non-living elements of the ecosystem; however, some of them can affect the physical and biological properties of ecosystem. Hydrological characteristics of the soil are among the most important causes of hydrological events, such as floods and landslides movements. In the present study different RWH treatments were carried out in various watersheds in semi-arid and sub-humid regions of central Iran and factors such as bulk density of the soil, moisture content of the saturated soil, percentage of stone and gravel, texture, structure, and permeability were measured and the results are analyzed statistically. There were quite significant and meaningful differences in the permeability, bulk density of the soil, liquid limit, and plastic limit of the soil in various RWH treatments. RWH treatment has changed the physical and hydrological properties of soil and has altered the potential of the soil and vegetation in protecting the soil and preventing excessive sediment production and consequently, it has affected other features of the ecosystem.

Keywords : Rain Water Harvesting, floods, landslides, semi-arid, sub-humid regions, permeability, bulk density and hydrological properties.

Introduction

In the new millennium, despite many technological advances, increased demand for drinking water and agriculture has increased the use of water resources. Historically, water from rainwater harvesting methods was used for drinking, farming, and greenery (Waterfall, 2006). Due to the effectiveness of rainwater harvesting systems for several utilizations such as water extraction, increasing the moisture content of soil and required water for plants, erosion and flood control, and water supply, the system can be implemented as a tool for sustainable development of watersheds in rural and urban areas (Gammoh, 2011).

In terms of factors affecting RWH systems, two major groups of biophysical factors and socioeconomic factors have been classified in recent years (Adham *et al.,* 2016).

Recommendation for a development paradigm, indicated that rainwater management in natural areas should consider biological, economic and physical characteristics of the region. Management model should be an innovative and comprehensive enough to consider all effective components of the system (Barron and Okwach, 2005).

In order to use water harvesting in GIS environment for farming systems in West Asia and North Africa, Oweis and Hachum (2006) used information layers such as soil depth, soil texture, rainfall and vegetation. Andersson *et al.* (2009) in their case study in Africa indicated the hydrologic effects of RWH and stated that if the components of sustainable development in the use and implementation of RWH systems is taken into account, these systems can have a positive effect on the hydrological properties of soil. Welderufael *et al.* (2013) studied the effect of RWH on water resources of South Africa and concluded that implementation of RWH method can dramatically affect the efficacy and the amount of the annual water supply, and that the use of water in this method in irrigated agriculture does not affect the downstream regime.

Norfolk *et al.* (2012) used a type of RWH technique as an agro forestry system to increase its capacity for natural green environment development of the Sinai Desert in Egypt. This method involved the use of a kind of pitting for the increase of soil moisture. The result of their study of watershed ecosystems on which these treatments were administered showed that the implication of this method and change the soil surface and land cover and do not have noticeable effects on the diversity of species of the area, and emphasized that these methods do not have a harmful effect on the biodiversity of this region.

Al-Shamiri and Ziadat (2012) in a case study of RWH in arid areas of soil-landscape modelling and land suitability evaluation investigated soil depth, soil texture, rock and pebble covering, land cover type, and slope in order to determine the suitability of these criteria for the implementation of RWH methods.

In the present work an attempt was made to study the geological responses of soil to rain water harvesting (RWH) in the Sami-arid regions of Central Iran.

Materials and Methods

According to the United Nations experts, harvesting water is the systematic collection and storing of rainfall from the watersheds and this method is different from collecting water from natural runoffs and rivers using dams. Accordingly, rainwater harvesting is divided into two methods: *in-situ* rain water harvesting and *ex-situ* rain water harvesting. All rainwater harvesting systems have three components: catchment area, delivery system, and storage area. In *in-situ* RWH, catchment and storage areas are situated in natural areas. Examples of this method include terraces, furrows, pitting, and grooves. In *ex-situ* RWH, catch- ment area is in natural, artificial, or a residential area and a delivery system carries the collected water to other areas in order to be used and stored. The best known methods include the use of levee, bandsar, domestic storage, roofs, urban insulation surfaces, traditional rainwater harvesting systems (water storage reservoirs, natural insulation surfaces, etc.).

In this study samples of hydrological properties of soil were taken from the RWH implemented watersheds in the central regions of Iran.

For soil sampling, depths of 0 to 5, 5 to 10, and 10 to 30 cm were selected. Samples were taken from four RWH treatments, including furrowing, terraced lands, irrigated lands, and rain-fed cultivation. A total of 36 samples were taken from the depths of 0 to 5, 5 to 10, and 10 to 30 cm and from every horizon one indicator profile was chosen. In order to achieve homogeneity, all watersheds were chosen from the semi-arid climate of central Iran. At each site, RWH implementation was conducted on three drilled and sampled profiles at the depths of 0 to 5, 5 to 10, and 10 to 30 cm. In addition, in each site a sample was also taken from a reference profile. In the main profiles, the surface horizon of soil (A) and other genetic layers were sampled until reaching the parent rock or limiting layers. Physical tests include measurement of bulk density, moisture content of saturated soil, plastic limit, and liquid limit. As indicated before, all treatment were chosen from homogenous units, and four treatments

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including terracing, furrowing, pitting, and *ex-situ* operation were sampled and tested, at three depths of 0 to 5, 5 to 10 , and 10 to 30 cm, and the results were analyzed using a SAS software.

Results and Discussion

Results of laboratory tests on hydro-physical properties of the sample are shown in the Table 1 and 2. After conducting double-ring infiltration test and determining linear equation and permeability equations for each conduct one infiltration equation was specified.

The following are the equations obtained for each of the various RWH treatments of furrowing, terracing, *ex-situ*, and pitting:

Infiltration equation in furrowing treatment

$V = 34.136* (t^{-0.596})$

Infilteration equation in terracing treatment

$V = 31.17* (t^{-0.702})$

Infilteration equation in *ex-situ*

$V = 20.09* (t^{-0.860})$

Infilteration equation in pi

$V = 30.15* (t^{-0.698})$ a

In these equations V and i te infiltration velocity in centimeter per h me in hours, respectively. With reference to the obtained equations, infiltration curves are shown in Figure 1. Infiltration rate in furrowing sites are more than terracing sites, and the rate in these two sites are more than ex-situ and pitting sites. Vertical change of water infiltration into the soil is :

ex-situ sites <pitting sites <terracing sites< furrowing sites

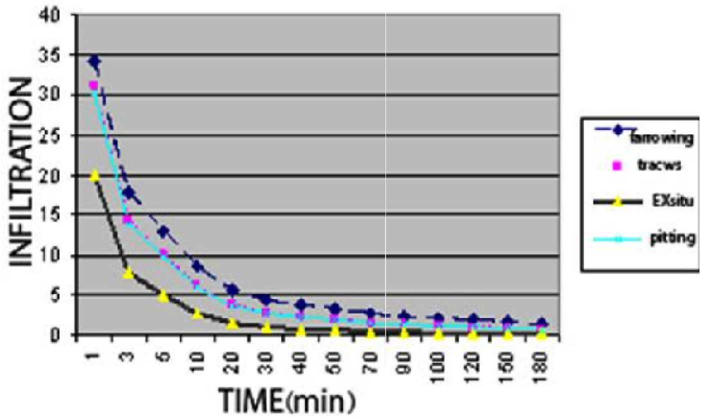

Fig.-1. Infilt each RWH treatment

rate in furro ore than other sites and in *ex-situ* sit on is less than other sites. It seems that the decrease in the velocity of infiltration of water in *ex-situ* sites is due to preparation activities, movement of vehicles, the increase in soil density, and interference in soil structure. The comparison of infiltration in each RWH treatment with bulk density in each application indicated that the smallest amount of bulk density, being 1/35 per cubic centimeter of soil, and the greatest amount of water infiltration in the soil occurs in furrowing sites. Also *ex-situ* sites with the maximum amount of bulk density, being 1/57, have the lowest amount of water infiltration.

Hydro-physical properties were also measured and statistically analyzed.

From the variance table, it is obvious that the

The result of analysis of variance shows that infiltration in the three-hour duration for each RWH effect of various applications on the change of bulk density at the five percent level, and also the effect of depth at one percent level show significant differences. Statistical indicators concerning liquid

treatment is significantly different. The comparison of means using Duncan's method shows that infiltration

limit and plastic limit show that these indicators in various sampling of the RWH treatments are significantly different. The results of variance table display no significant

difference between the liquid and plastic limits in various depths. The results of the comparison of means are given in Table 2.

Table - 1. Analysis of variance for physical and hydrologic properties of soil.

Mean squares						Variation source
LL	PL	gr/cm^3 bulk density	SP	PH saturated soil	Degree of freedom	
**297.01	21.66**	0.052**	216.87**	0.084	33	RWH treatments
24.48	1.780	**0.264	61.51	0.737 **	22	Depth
2.53	0.185	0/00	5.05	0.038	22	Repetition

*** and ** indicate significance at level 5 and 1, respectively.**

With respect to Duncan's table for comparison of means the amount of bulk density of each RWH sample fall into two statistical groups: the smallest amount is realized in furrowing, being 1/35, and the highest amount in seen in pitting, being 1/51. The reason for the increase of bulk density in these lands is soil compaction due to RWH. In addition, bulk density of each of these samples statistically falls into three groups

: the highest amount is 1/57 at the depth of 0 to 5 cm, and the least amount is 1/29 at the depth of 10 to 30 cm. Soil compaction as the result of various actions, crust formation on the soil surface, aggregate breakdown, and compaction of the surface layer of soil are the main reasons for the increase of bulk density. According to Duncan's table for the comparison of means, liquid limit of each of these samples in various RWH treatments fall into three statistical groups: the smallest amount in terracing is 23/40 and the highest amount in pitting is 26/93. Moreover, the average value of this factor in different sampling depths falls into one statistical group. According to Duncan's table for the comparison of means, plastic limit of each of the samples in different RWH treatments can be divided into three groups: the least amount in terracing is 32/60, and the highest amount in pitting is 45/66. In addition, the average value of this factor in different sampling depths falls into a statistical group. Liquid and plastic limit in the implementation of terracing are signifi- cantly less than furrowing and it can be concluded that

Table - 2. Duncan's table for comparison of means for physical and chemical properties of soil

Means			Variation sources
LL	PL	Bulk density gr/cm^3	Treatment RWH
39.59a	25.29b	1.35b	furrowing
32.60c	23.40c	1.38b	Land
43.54a	26.35a	1.51a	Ex-situ
45.66a	26.93a	1.336b	pitting
Means			(cm) Deepth
38.70a	25.05a	1.57a	0-5
41.19a	25.72a	1.35b	5-10
41.16a	25.71a	1.29c	10-30

*** The numbers with similar letters have no meaningful difference at 5 percent level**

continuous and successive activities can profoundly alter the structure and physical properties of soil and this, in turn, heavily alters the liquid and the plastic limit index. Changes in the plastic and liquid limits index and the fact that soil rapidly reaches the threshold of liquid and plastic limits cause mass movements in these lands.

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