

The role of rainwater harvesting on providing vegetation water requirement in arid and semi-arid regions

M.T. Dastorani^{*}, B. Kouhzad¹, A. Sepehr¹ and A. Talebi²

¹ Faculty of Natural Resources and Environment, Ferdowsi University of Mashhad, Iran

² Faculty of Natural Resources, Yazd University, Yazd, Iran

* e-mail: dastorani@um.ac.ir

Abstract: Water harvesting Knowledge has an ancient history. From old times, people, specially, occupants of arid lands whose access to water was limited, invent different ways to collect and conserve water. Today, many of these methods are reclaimed and introduced as Indigenous Knowledge. There are many case studies in different branches of water harvesting and new methods based on Indigenous Knowledge have been presented. These studies especially in our country, which is situated in the desert belt, are of importance. Present study was carried out in a watershed near Mashhad in Iran. Given that Mashhad city is situated in a semi-arid zone in Khorasan Razavi, therefore, is in a good situation for this study. Selected area located in Dehbar district, south of Mashhad contains different parts with various slopes. Basic meteorology data were collected and essential soil properties were measured in soil lab. Based on references, experiences and the local characteristics, it was tried to choose the best structures for the area. Negarim microcatchment and absorbing Banquet was chosen for both of slopes. During nine months, after each precipitation, soil sampling was done with six time repeating process. Soil moisture was calculated after each time. Using basic data and soil information, Changing Procedure of soil moisture was studied. Graph analysis showed that in total, both structures performances were 20% better than the control plots. At the end of precipitation period, losing moisture in control plots is about two times more than the structures, an average of 30%. The acquired results confirm the success of tested structures on utilization of soil moisture.

Key words: Harvesting, Arid lands, Negarim Microcatchment, Absorbing Banquet, soil moisture

1. INTRODUCTION

In arid and semi-arid areas, rainfall is low and unpredictable with unsuitable timing. Majority of rainfall is transformed into runoff due to several factors including lack of vegetation and high intensity. Furthermore, in these areas evaporation is very high which would make the low level of rainfall unavailable. That's why various systems for collecting and utilization of water has been frequently used since old times (Laura, 2004). Available records in rainwater harvesting field shows that after widespread drought in Africa that caused serious damage to the crops, in 1970's and 1980's general attention focused on water harvesting which led Evanari et al. (1971), to use these methods for the first time in Palestine desert (with the average precipitation of 90 mm per year) that resulted in increased food production. Boers and Ben Asher (1982), executed water harvesting systems including farming contours, surface runoff storage in underground reservoirs, construction of regional microcatchments to improve soil moisture and water storage in small turkey nest farms in the Negev Desert. Hatibu and Mahoo (1999), did a comprehensive study on the usage of water harvesting systems for the recovery of soil moisture within a field in Tanzania. Martinez et al. (2016), studied indigenous knowledge of structures such as microcatchments, contour bunds, Bankettes and rock bunds. The purpose was to evaluate the effect of a modified model for these water harvesting structures on the hydrological regime of soil and vegetation without damaging interference in the region's ecosystem. The result of these findings ultimately led to presentation of Modipe software model. The application of this model is to estimate the most efficient structure for the land according to local conditions. In a study, Razzaghi (2011), investigated the positive impact of Meskat reclamation systems and Zey pitting holes on increasing moisture retention in the region,

improving the efficiency of agricultural production and restoring the pastures in Libya. Hosseini et al. (2005), assessed and monitored soil moisture retention in the Bankettes using statistical tests, to compare them with the natural conditions in a 5 month study in Taleghan, Iran. Results showed the positive effect of Bankette structure in increasing soil moisture. Tabatabaei Yazdi et al. (2010), attempted to estimate rainwater harvesting potential for using in rainfed supplemental irrigation in Khorasan Province of Iran with arid and semi-arid climatic conditions, and stated about 70% increase in production outputs. Gebretsadic (2009), managed to grow native plant species with no irrigation and only using water stored in Negarim Microcatchments constructed at the project site, in a three-year time period in a case study in dry cold heights of Austria. Studies on the effects of diamond and crescent microcatchment systems on soil moisture and seedlings survival in Azadshahr region of Golestan province in Iran showed that in a 5 year period, soil moisture increased, and seedlings grown under rainfed conditions, while seedlings in observation areas did not survive, so the systems are suitable locations to store moisture and seedlings grown under rain fed conditions while seedlings in observation plot did not survive (Shahini and Roughani, 2012). Studies on diamond microcatchments on the east of Golestan province of Iran in Maravetape area showed that in semi-arid conditions in this area, rainfed Olive gardens can be created. Establishing an insolation nylon system in the collecting area of these systems, increased the runoff volume in the planting areas of olive seedlings three times more than the annual rainfall of the area (Shahini and Roughani, 2013).

Present study tried to assess the effects of few rainwater harvesting systems on soil moisture increase and also moisture remaining time period to supply vegetation water requirement in arid and semiarid areas near Mashhad in north east of Iran.

2. MATERIALS AND METHODS

2.1 Location of the study

Since the study was to evaluate the effect of water harvesting systems in arid and semi-arid, the area under study selected in Khorasan Razavi province of Iran, about 10 km distance from the Mashhad city, and in south of Torghabeh county, Dehbar watershed, with $59^{\circ}, 22'$ and $27''$ E longitude, and $36^{\circ}, 13'$ and $31''$ N latitude. This area is a part of Binalud highlands in terms of topography. Figure (1) shows a view of related study area inside Dehbar watershed.

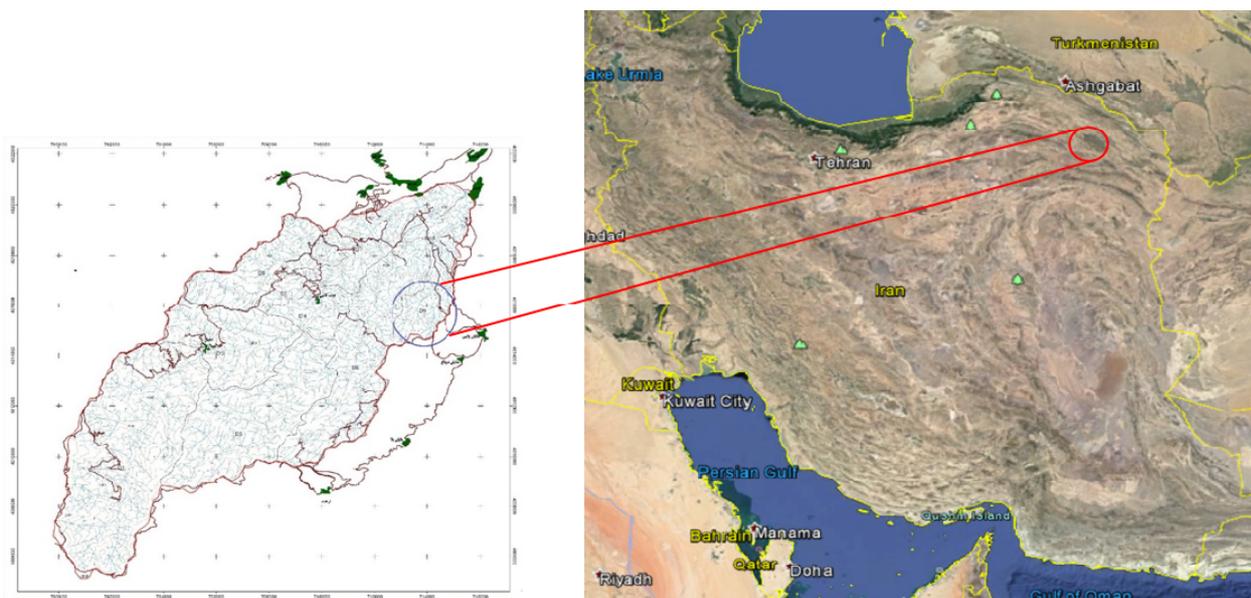


Figure 1. Study area location

2.2 Research data and methodology

On the selected hillside of the case study, the slope of the area was measured and two places were selected for construction of the systems one in upstream part with 2.4% land slope and the other one in downstream part with 22% land slope. From geological point of view, the study area is situated in Mashhad geological sheet which is a part of Binalud structural zone, containing gray to black Teriassic aged Mashhad slits and Filits in rotation with Shale, sandstone and Jurassic Conglomerate. Important characteristics of soil including texture, pH, EC, Lime percent, Porosity, Organic materials, Bulk density and True density were measured in lab for both catchment areas and infiltration pits of the structures in two depths of 0-15 and 15-30 cm. The results of these assessment showed that based on pH, regional soils are in the category of low alkaline soils. Also the salinity is in low level, and texture is loam and clay loam in all collected soil samples. Soil Lime percentage and organic materials are low as well. In terms of porosity, bulk density and true density, the soils are classified in agricultural average condition.

To collect precipitation data, Rain gauge graphs of Mashhad synoptic meteorological station were used. By extracting information from these graphs and unit conversion, the amount, Intensity and duration of precipitation events were calculated for the nine-months study duration.

According to initial investigation for constructing the structures, it was decided that each structure had to be built in both slopes with an observation (control) area for each one. Selected sides for each microcatchment was 3.33 meters preparing about 10 m² runoff collecting area. The area of infiltration pits was selected 1 m² so the rate of catchment area to cultivated area is about 10. Infiltration pits were situated in the lowest part of each microcatchment to ease the runoff flow from all parts of the catchment. Figure 2 shows the constructed microcatchments in this research. Each microcatchment contains two parts: catchments area where provides the runoff, and the cultivated area where receives the runoff collected in catchment area.



Figure 2. A view of the constructed Negarim Microcatchment (a) and Bankette (b) structures

To study the soil moisture process, after each precipitation, from all the runoff collecting areas and also infiltration pits in both slopes (2.4% and 22%) and in two depth (0-15 and 15-30 cm) soil samples were collected and the moisture content was measured. For each precipitation event, sampling had 5 repeats (with three days time intervals). Therefore, in every sampling round, 20 samples were collected and transferred to the lab. To review and assess the soil's hydrological condition and completing the needed data for evaluation, Curve Number (CN) had to be calculated. Due to the results of soil texture, soil hydrological group was estimated as group C. In field visits, pasturelands hydrological condition was estimated as poor with less than 50% vegetation cover. Also, precedencesoil moisture status was calculated using the results of precipitation monitoring. Using these information, curve numbers were calculated as are shown in Table (1).

Table 1. Rainfall events and Curve Number calculation

Sampling date	Cumulative precipitation of last 5 days	Total precipitation	Precedence moisture condition	Curve Number
2014.10.14	1.6+5.0+0+0+1.3	7.9	1	72
2014.11.6	3.1+7.7+7.1+1.0+8.7	6.18	2	86
2014.11.26	0+0+0+2.6+9.2	1.9	2	86
2014.12.24	1.1+0+9.3+2.40	2.9	2	86
2015.1.11	2.2+2.8+9.20+0	14	2	86
2015.2.16	5.0+5.15+0+2.1+6.2	8.19	2	86
2015.2.19	9.4+9.0+0+5.0+5.15	8.21	3	94
2015.2.22	3.1+10+3+9.4+9.0	1.20	3	94
2015.3.7	1.0+3.10+5.1+0+1.1	13	3	94
2015.3.10	3.10+1.0+7+0+0	4.17	3	94
2015.3.27	6.6+7+0+0+4.0	7.7	3	94
2015.3.31	6.6+7+0+0+0	6.13	3	94
2015.4.5	0+0+0+3.2+2.3	5.5	3	94
2015.5.8	0+0+3.4+1.1+9.12	3.18	2	86

3. RESULTS AND DISCUSSION

3.1 Calculation of runoff and infiltration

For each structure in each rainfall, the amount of runoff and infiltration was calculated. According to Table (2), result of these assessment showed that in the first months of sampling, about half of the occurred precipitation forms the total runoff and infiltration and the other half has been lost from the area in different shapes of waste especially evapotranspiration. Due to low precipitation amount and intensity and high potential of evapotranspiration, soil moisture in the first three months of sampling was very low. Increase in the rainfall events in winter months and it's continuity affects the infiltration and runoff percentage positively. The aim of monitoring the rates of runoff and infiltration is to analyze soil moisturechanging procedure during the sampling time period.

Table 2. The calculation of runoff and infiltration in structures

Sampling dates	Negarim Upstream catchment		Bankette Upstream catchment		Negarim Downstream catchment		Bankette Downstream catchment		Total Q+W
	Q(mm)	W(mm)	Q(mm)	W(mm)	Q(mm)	W(mm)	Q(mm)	W(mm)	
2014.10.14	1.2	0.56	0.95	0.6	1.05	0.58	1.1	0.57	6.61
2014.11.6	0.7	0.66	1.5	0.63	1.2	0.64	1.2	0.64	7.17
2014.11.26	0.8	0.92	0.8	0.92	0.7	0.93	0.7	0.93	6.7
2014.12.24	1.2	0.44	1.2	0.44	2.4	0.4	2.4	0.4	8.88
2015.1.11	2.5	0.76	2.6	0.76	2.7	0.75	2.7	0.75	13.52
2015.2.16	2.9	0.68	3	0.62	3.1	0.62	3	0.62	14.54
2015.2.19	0.28	0.79	3	0.67	3.2	0.68	2.8	0.7	12.12
2015.2.22	3.1	0.51	3	0.52	3.2	0.51	3.1	0.51	14.45
2015.3.7	2.7	0.54	2.7	0.54	2.8	0.53	2.8	0.53	13.14
2015.3.10	2.9	0.53	3	0.53	3.2	0.52	3.2	0.52	14.4
2015.3.27	2.7	0.41	2.7	0.41	0.27	0.62	0.27	0.62	8
2015.3.31	2.9	0.89	3.2	0.86	0.36	1.1	3.3	0.86	13.47
2015.4.5	0.27	0.47	0.27	0.47	1.1	0.4	1.1	0.4	4.48
2015.5.8	2.5	1.32	2.6	1.31	2.8	1.3	2.8	1.3	15.93

3.2 The effect of the proposed structures on the soil moisture process

To investigate the usefulness of implemented techniques in the soil moisture, sampling occurred regularly after each rainfall event with five repeats every three days to calculate bulk and volumetric moisture. Using these data provided the possibility to evaluate and compare of changes

in soil moisture volume during a crop year in study and the related observation areas. According to Figures (3) and (4), this study showed that there is an average of 25% difference in moisture retention, between Negarim Microcatchment infiltration pits and the related observation area for the of 2.4% slope site. This difference reaches 30% in the 22% slope site. There wasn't a meaningful difference between the moisture content of (0-15) and (15-30) depths. Also, the difference in moisture content between Absorbing bankette infiltration pit and the related observation area in 2.4% and 22% slopesites were respectively 27% and 31%. There wasn't a meaningful difference between depths here either. Study shows that in the beginning of sampling in Autumn, where amount, intensity and duration of the rainfall events were relatively low and the soil was dry (due to hot summer with no rainfall), moisture change processis mild. The increase in rainfall intensity, duration and occurrences in Febraury and March made a stable moisture period in infiltration pits which followed by 30% increase in soil moisture of both structures while moisture increase in observation areas were only about 15% in average. These results show an agreement with those reported by the case studies of Martinez et al. (2004), Martinez (2008), Hosseini et al. (2005), Gebretsadic (2009), Razaghi (2011), Shahini and Roghani (2012, 2013), Sadeghzadeh et al. (2013), Rehman et al. (2014). Also in all of these studies the common method for determining soil moisture were TDR or bulk moisturemeasurement like this study.

To verify the effect of structures on runoff harvesting, two statistical hypothesis tests (0 and 1 tests) were used. In the first Test, zero hypothesis (H0), absence of significant difference in moisture between infiltration pits and observation area and in one hypothesis (H1), Existence of significant difference in moisture between infiltration pits and observation area was considered.

According to the results,there is no difference between moisture average of catchments areas and the related observation areas in significant level of 1% and 5% in both structures with same slope and depth. So it can be safely said that there is a harmony between catchments and the related observation areas. Test results between infiltration pits of both structures and the related observation areas show significant difference in moisture average in significant level of 1% and 5% in both depths and slopes, means differences in moisture retention between infiltration pits and the observation areas are impressive and the structures functions are successful. Studies of Hosseini et al. (2005), Razzaghi et al. (2011), Shahini and Roghani (2012, 2013), Sadeghzade et al. (2013) and Rehman et al. (2014) who used hypothesis tests to prove the significance of their results, also found the same results.

4. CONCLUSIONS

In overall, the performance of both structures used in this research is much better than the observation areas. In 2.4% slope area, absorbing Bankette was better than the Negarim microcatchment by the average of 2%. This difference in 22% slope area is only 1%. Sampling depth did not have a significant effect on the results. Also, the average performance of both structures in comparison to the observation areas is by about 10% higher. This difference reaches 30% in winter rainfall events. In the last few rainfalls, moisture decrease process in structures is about 10% in average, while the observation areas lost about 30% of soil moisture during the same time period. By examining the performance of the structures, it can be said that using water harvesting methods, is a non-aggressive approach in the recovery of soil moisture in local scale, which has an impressive effect on soil moisture storage especially in short time periods with relatively low expenses. Using these methods on longer periods of time (more than two years) can also help the vegetation recovery and soil fertility. Also this study proves the success of both of the structures provided and tested. Using similar methods and promoting them as native case studies would help the development of scientific resources and information in water harvesting and management. Using this case study especially for longer periods of time can also improve soil fertility and green coverage in addition to soil moisture increase as well as aquifer recharge, which would present a chance to improve the water and agricultural condition on arid and semi arid regions.



Figure 3. Moisture content comparison between catchment and infiltration areas of both structure

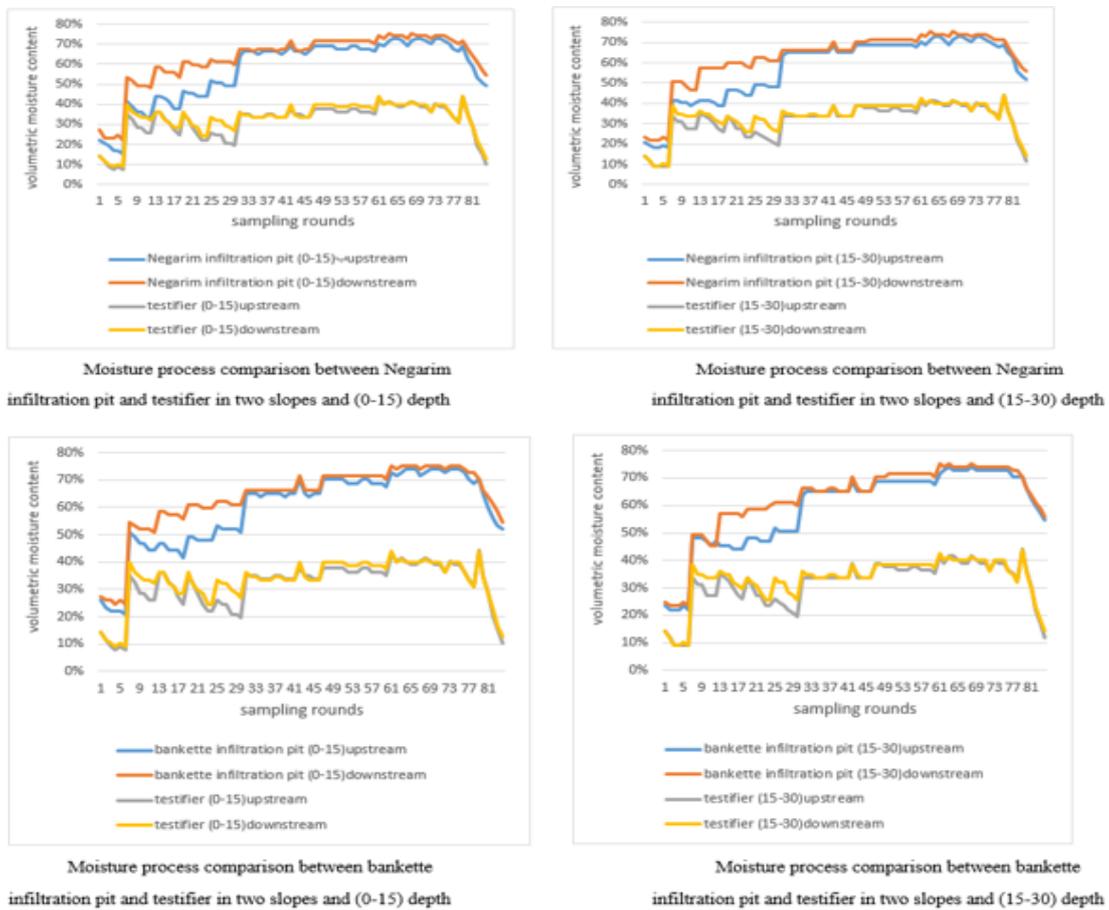


Figure 4. Moisture content comparison of infiltration pits of both structures with the related observation plot in both slopes

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