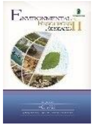

Environmental Resources Research
Vol. 7, No. 1, 2019

GUASNR

Soil loss and runoff generation in rangeland, rain-fed and abandoned rain-fed agriculture under simulated rainfall

M.A. Goodarzi[1], A.A. Jamali[2], A. Jafarpoor[3], A. Gholami[4], M. Jafari Shalamzari[5]*
[1]MSc graduate, attended the Faculty of Watershed Management, Islamic Azad University, Meybod, Iran,
[2]Assistant Professor, Faculty of Watershed Management, Islamic Azad University, Meybod, Iran
[3]MSc graduate, attended the Faculty of Watershed Management, Hormozgan University, Iran
[4]PhD student, Aerospace Information Research Institute, University of Chinese Academy of Sciences, Beijing, China
[5]PhD student, Institute of Atmospheric Physics, University of Chinese Academy of Sciences, Beijing, China

Received: March 2018 ; Accepted: December 2018

Abstract

Soil erosion is a global challenge, seriously threatening soil and water resources and environmental qualities. One of the important factors to consider in the process of runoff generation and soil erosion is the physical and chemical properties of soils under different land-uses. The aim of this study is to estimate soil erosion and runoff in rangeland, rain-fed and abandoned rain-fed agriculture in Karafs Watershed (Sarduyeh) in Jiroft County using rainfall simulation. The experiment was conducted in 2012 and three land-uses with uniform soil and lithology were considered. Simulated rainfalls were 46 and 88 mm.hr^{-1} of intensity with 3 iterations, which totaled 36 samples. Soil samples were taken close to the locations of rainfall simulation from the top 0-20 cm and transferred to the laboratory for further analysis. The results showed a significant effect of land-use on runoff and erosion in different rainfall intensities, so that the highest runoff was generated in the abandoned rain-fed agriculture at the intensity of 88 mm.hr^{-1}, with the least being generated in the rain-fed agriculture at the intensity of 46 mm.hr^{-1}. Likewise, we found that land-use changes had a large impact on soil erosion, with the highest levels at the abandoned rain-fed agriculture which resulted in the increased runoff generation. This factor could be explained by the increased clay, silt, and lime content at the expense of the removal of sand from these areas. Increasing rainfall intensity to 88 mm.hr^{-1} led to respectively 14% and 47% higher runoff volumes and sediment loads compared to the initial intensity.

***Keywords*: Erosion, Runoff, Rainfall simulator, Land-use**

*Corresponding author; msdjafari@radi.ac.cn

Introduction

Soil is one of the most important natural resources and the basis of plant production. Soil erosion is regarded as a major environmental challenge, and when occurred, it can deteriorate natural resources and increase the likelihood of flood occurrence (Martz, 1992). A number of factors bear upon soil erosion and runoff generation, and based on the general characteristics of a given area, some factors are comparatively more dominant. The role of land-use change is of especial interest for its impacts on vegetation and soil properties as well as the amount of runoff and soil erosion (Pei, 2007). In this regard, soil properties play a major role in the occurrence of runoff and soil erosion. Since the inappropriate land-use changes, particularly natural ecosystems, exert significant influences on physical, chemical and biological soil properties and hence affect runoff and soil erosion, it is worth investigating the relationship between these factors in a more accurate manner. Nowadays, population growth and increasing demand for agricultural products have led to the degradation of natural ground cover, particularly in the form of converting forests and rangelands into agricultural land with an alarming speed (Izquierdo, 2009).

Various methods exist for calculating the amount of runoff and soil erosion, with artificial rain simulators as a common technique. In theory, the application of rain simulators not only saves time and money, but provides the capacity for the evaluation of runoff and erosion processes in a quantitative manner with numerous iterations (Sheridan *et al.,* 2008). However it should be noted that the use of rain simulators is not exempt from limitations. These devices function in deviation in some ways from natural condition (Jordan *et al.*, 2008) and face limitations when simulating rain showers at smaller plots (Sheridan *et al.*, 2008).

Several studies have been carried out to investigate the role of land-use in erosion processes. Foltz *et al.* (2009) used a rain simulator to determine runoff, infiltration, and erosion on two forest roads with low and high traffic in North America. Their results showed that the amount of runoff and sediment on forest roads with high traffic is due to the loss of vegetation and changes in soil physical properties. Celik (2005) in the study of the impacts of three land-uses of forest, rangeland and agriculture on organic matter content and soil physical properties in the Mediterranean highlands in the south of Turkey, found that erosion in the agricultural areas were as high as twice the rangeland condition. Sing & Khera (2008) found that barren lands, agriculture, rangeland and forest had the highest erosion rate in their study location in the order of priority. Mellese & Defersha (2012) in an in-vitro research project in Ethiopia evaluated the effect of rainfall intensity, slope, soil types and moisture on sediment concentration. Their tests included rainfall intensities of 120, 70 and 55 mm.hr-1.

Three slope gradients of 9, 25, and 45 % over three soil types, ranging in texture from clay to sandy loam and in moisture from wet to dry, were selected in the Alamaya basin in Ethiopia. Results showed that the amount of sediment production is significantly associated with previous moisture content. Soil moisture reduced sediment production in soil samples A, B and C by 23, 45.7 and 1.3% respectively. The initial moisture content, slope and rainfall intensity influenced erosion, with moisture content attenuating sediment production. Nourmohamadi *et al.*. (2013) evaluated sediment production from gully erosion using rainfall simulation in Zagros forests. Their results showed that maximum and average rainfall intensity play the most important role in the soil erosion. Sheikh *et al.* (2016) evaluated the effect of the land-use, slope gradient and aspect on soil loss using the BSTF rainfall simulator. Based on their findings, agricultural fields generated the highest runoff and sediment under simulated rainfalls. Rangeland and forest did not have significant difference in terms of runoff generation and sediment concentration. Mohamadi, (2016) examined the relationship between the environmental factors with runoff and infiltration using a rainfall simulator in the rangelands of North

West Iran. The results showed that 77% of the runoff coefficient could be explained by factors such as soil moisture, canopy cover, soil organic carbon levels, clay content, and nitrogen. Factors such as clay content, soil organic carbon and soil gypsum produced 82% of variance in runoff generation while altitude, slope, soil organic carbon and silt explained 60% variations in infiltration depths. Elsewhere, Sheikh *et al.* (2017) evaluated the effect of land-use, slope gradient and aspect on soil's major nutrient loss in Kechick area, Golestan Province using a rainfall simulator. Their results showed significant effects of land-use and slope on the loss of the major soil nutrients. This study is an attempt to evaluate erosion and runoff generation in three land-uses of rangeland, rain-fed and abandoned rain-fed agriculture in the Karafs Watershed (Sarduyeh), Jiroft County, Iran, along with the quantitative demonstration of the role of different soils in shaping these processes.

Materials and Methods

Study Area

The Karafs Watershed lies between $57^0 9'46''$ to $57^0 11'10''$ E, and $29^0 11'28''$ to $29^0 18'52''$ N with a total area of 3634.6 ha. The study area is 12 Km away from Sarduyeh which is located in Jiroft County. The elevation reaches 3270 m at the rim, down to 2990 m at the outlet. Major settlements of the area are Karafs, Khardan, Qanat Bid, and Nahr Kamal. The sketch of the study area is provided in Figure 1, relative to Iran and Kerman boundaries.

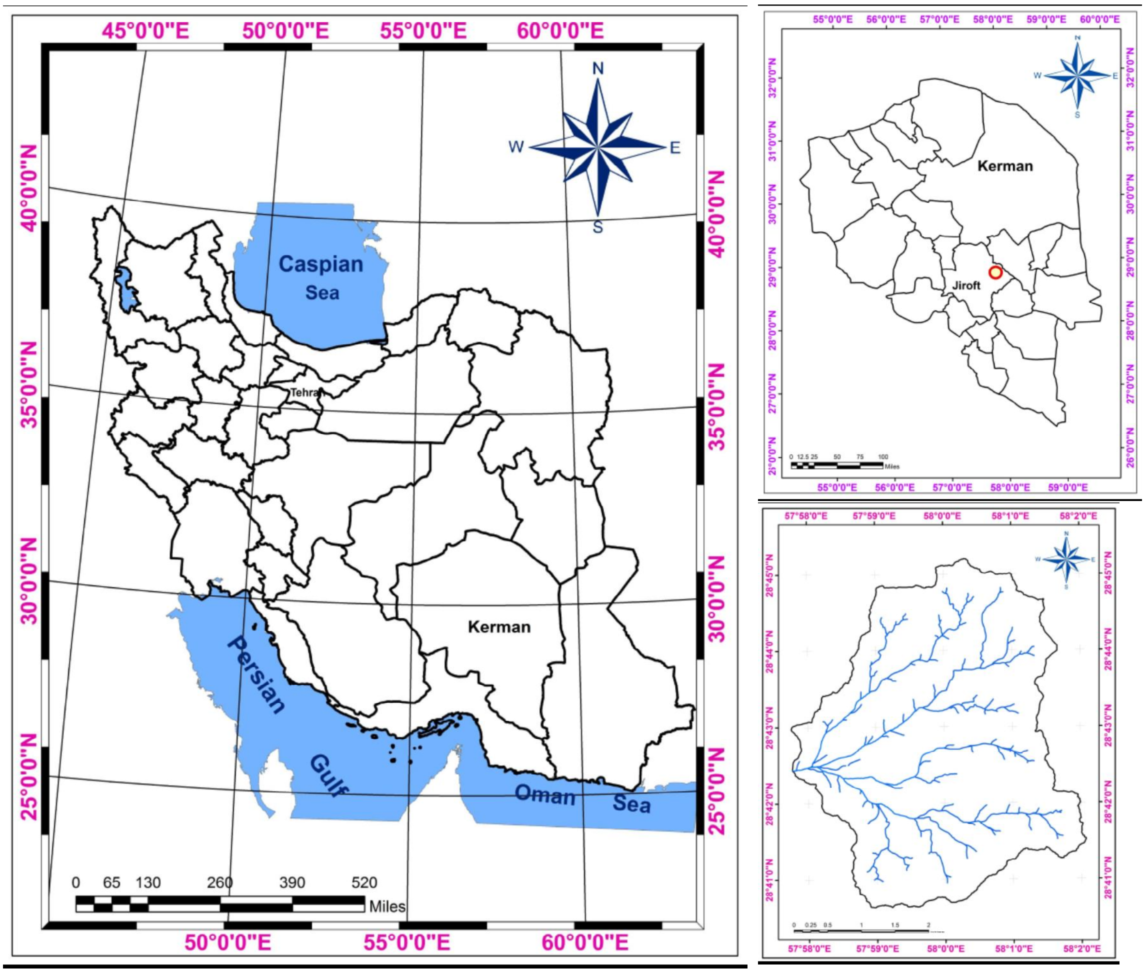

Figure 1. Location of the study area

Rain Simulator Specifications

A rainfall simulator with the total plot area of 0.09 m^2 (30 × 30 m) was used. This device includes a graded cylinder and a rectangular cube which are manually filled prior to the tests. The rain simulator has four height-adjustable bases to modify the height of water drop release. Rainfall intensity is measured by the submerged aeration tube and its cap. The produced mixture of runoff and sediment is diverted via a metallic frame to the containers. The rainfall simulator is adaptable for the standard characterization of soil erosion and water infiltration and it has the capacity to be used in soil conservation research to determine the erosion of surface sediments in desert conditions.

Sampling Technique and Laboratory Analysis

Rainfall intensities of 46 and 88 $mm.hr^{-1}$ were considered. According to the research objectives, the role of land-uses on erosion and runoff production must be exclusively examined by maintaining other variables unchanged. Thus, we attempted to keep the condition of sampling locations in rangeland, rain-fed and abandoned rain-fed agriculture as close as possible to each other (Figure 2).

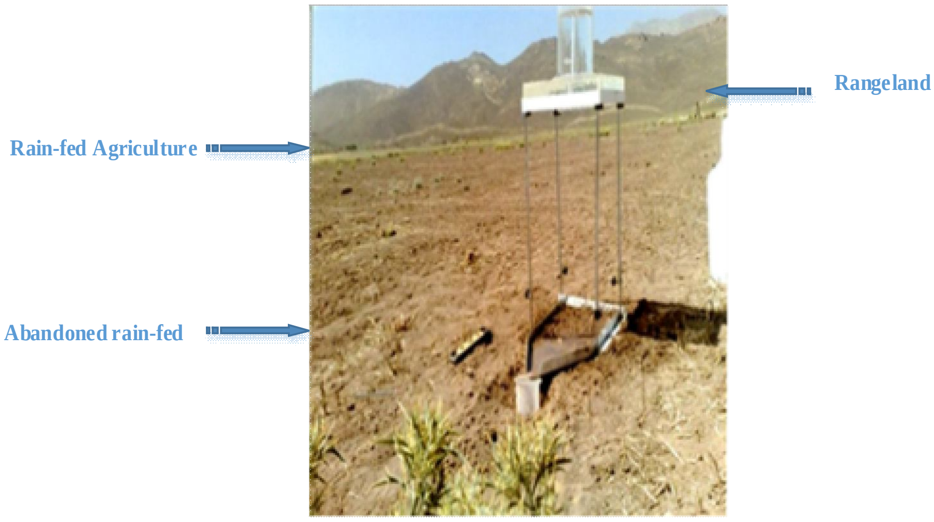

Figure 2. Different land-uses in the study area with identical climatic and lithological characteristics

After the proper installation of the device in the desired locations according to the slope gradient, and the adjustment of the device's bases, rain simulation tests were performed. The samples were then transferred to the lab and passed through the Whatman Filter Papers No 40, three times to separate the sediment from the runoff. The collected sediments were dried in the oven for 24 h at 105℃, and then weighed. Sediment weights and runoff volumes were averaged for different land-uses and rainfall intensities. As mentioned earlier, to examine the effect of land-uses on soil properties, soil samples were taken from the top 0-20 cm, adjacent to sampling locations, and then analyzed in the lab. Data normality was primarily tested in SPSS 17 according to the Shapiro Kolmogorov-Anderson and Kramer tests, and group mean comparison was performed in SAS using the Duncan's test at the 5% level of confidence. Figure 3 shows the proper installation of the rain simulator in three land-uses of rangeland, rain-fed and abandoned rain-fed agriculture.

Figure 3. Proper installation of the rain simulator in rangeland, rain-fed and abandoned rain-fed land-uses

Results

The results of the analysis of the soil properties including sediment weight, clay, silt, sand content, organic matter, calcium carbonate, erosivity, EC, pH, SAR, ESP and K as well as the runoff volume are provided in Tables 1 to 4 and Figures 4 and 5. Level of significance was determined based on the results of the analysis of variance.

Table 1. The results of group mean comparisons in different land-uses

Land-uses	Runoff (l)	Sediment (gr.l)	Clay	Silt	Sand	EC (ds/m)	pH	ESP	AR	$CaCO_3$	OM	Erosivity (gr)
Rain-fed	682.50c	1.18c	3.91c	28.83c	70.25a	1.8a	7.2c	1.0a	1.5a	17.46a	0.23b	0.14c
Abandoned rain-fed	1255.83a	4.69a	9.00a	52.91a	38.08c	0.8b	7.5b	1.43b	1.1b	16.81a	0.077c	0.47a
Rangeland	932.08b	2.38b	6.25b	42.33b	51.41b	0.8c	7.5a	0.52c	1.0c	2.73b	0.52a	0.27b

Table 2. Correlation matrix of runoff volume in different land-uses and rain intensities

		Land-use			*Rain intensity*	
	Variable	Rain-fed	Abandoned rain-fed	Rangeland	46 mm.hr	88 mm.hr
Runoff	Clay content	-0.25	-0.11	0.29	0.87*	090*
	Silt content	0.34	-0.14	0.003	0.97**	0.86*
	Sand content	-0.31	0.14	-0.07	-0.98**	-0.87*
	EC(ds/m)	-0.63	0.60	0.78	-0.78	0.60
	pH	0.004	0.07	0.71	0.71	0.53
	ESP	0.62	0.18	0.55	-026	0.06
	SAR	0.82	0.45	0.13	-0.29	0.07
	Calcium Carbonate	-0.91	0.26	-0.55	-0.17	0.16
	Organic Matter	-0.61	0.07	0.18	-0.46	-0.38
	Erosivity	0.88	0.88	0.96*	0.96**	0.99**

Table 3. Correlation matrix of sediment production in different land-uses and rain intensities

	variable	***Land-use***			***Rain intensity***	
		Rain-fed	Abandoned rain-fed	Rangeland	46 mm.hr	88 mm.hr
Sediment	Clay content	-0.014	-0.58	0.52	0.93**	0.89*
	Silt content	-0.07	-0.29	-0.39	0.95**	0.89*
	Sand content	0.07	0.33	0.34	-0.97**	-0.89*
	EC(ds/m)	-0.50	0.57	0.46	-0.78	-0.55
	pH	-0.22	-0.39	0.57	0.67	0.45
	ESP	0.37	0.46	0.39	-0.21	0.17
	SAR	0.56	0.79	-0.27	-0.29	0.20
	Calcium Carbonate	-0.65	0.67	-0.74	-0.13	0.28
	Organic Matter	-0.44	-0.39	0.34	0.52	-0.51
	Erosivity	0.99**	0.57	0.97*	0.93**	0.94**

*significant at 5%, ** significant at 1%

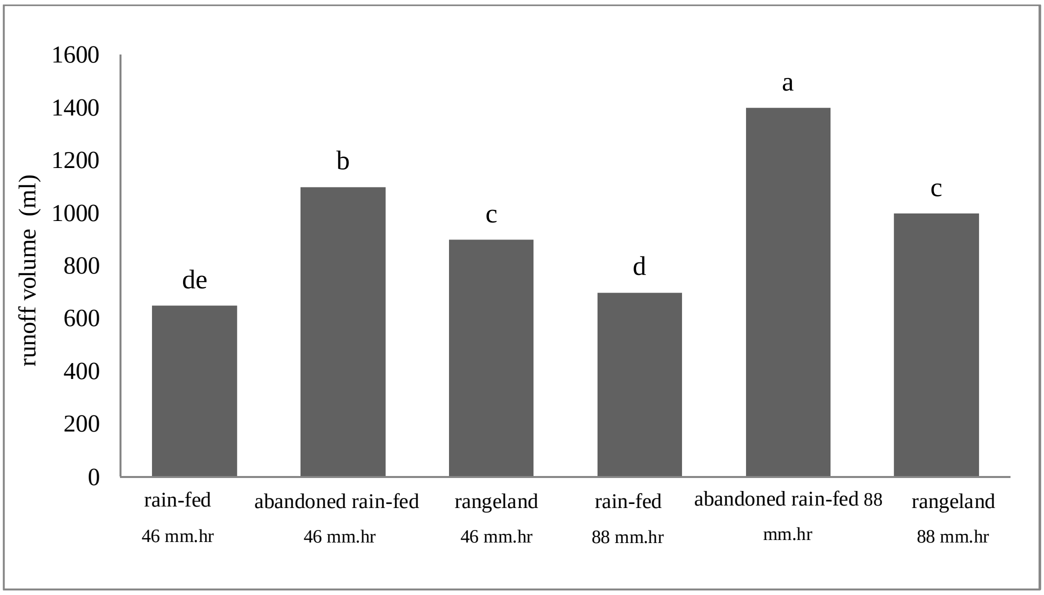

Figure 4. The mutual effect of rain intensity and runoff production in different land-uses at 1% level

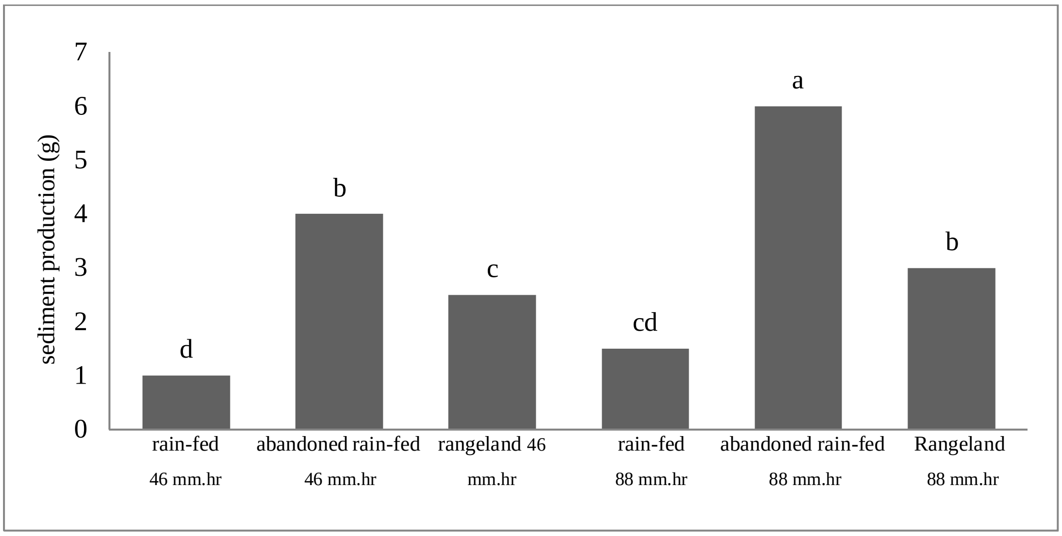

Figure 5. The mutual effect of rain intensity and sediment production in different land-uses at 1% level

Table 4. Correlation of different variables with slope gradient, land-use and rain intensity

	Runoff volume (l)	Sediment (gr.l)	Clay content	Silt content	Sand content	EC	pH	ESP	SAR	Calcium carbonate	Organic matter	Erosivity (gr)
Runoff volume (l)	1											
Sediment (gr.l)	0.95**	1										
Clay content	0.85**	0.81**	1									
Silt content	0.82**	0.76**	0.89**	1								
Sand content	-0.84**	-0.78**	-0.92**	-0.99**	1							
EC	-0.63*	-0.45	-0.71**	-0.81**	0.81**	1						
pH	0.52	0.14	0.62*	0.74**	-0.73**	-0.95**	1					
ESP	-0.04	0.60	-0.01	-0.62	0.42	0.71**	-0.76**	1				
SAR	-0.05	0.70	-0.31	-0.52	0.23	0.96*	-0.75**	0.98**	1			
Calcium carbonate	0.03	0.31	0.01	-0.61	0.31	0.64*	-0.70*	0.98**	0.97**	1		
Organic matter	-0.4	-0.74	-0.53	-0.72	0.92	-0.72	0.4	-0.83**	-0.81**	-0.87**	1	
Erosivity (gr)	0.97**	0.90**	0.89**	0.83**	-0.85**	0.60*	0.05	-0.02	-0.03	0.70	-0.43	1

Discussion

Runoff Production

Runoff and sediment production potential of three land-uses including rangeland, rain-fed and abandoned rain-fed agriculture were compared at two intensities of 46 and 88 mm.hr^{-1}. Given the results in Table 1, the abandoned rain-fed agriculture had comparatively higher runoff volume, soil erosivity and silt, clay and calcium carbonate content. Rangelands had higher soil organic matter and pH and hence less runoff volume, which is in agreement with the findings of Dongsheng *et al.* (2006) stating the positive correlation between pH and soil erosivity. In another study by Angers *et al.* (1993), soil structure degradation, following the collision of rain drops which clogs soil pores and thus reduces infiltration rates, was introduced as the major cause of runoff augmentation. Traditional agricultural methods produces fine grain soil structure by breaking the soil aggregates into smaller particles which are susceptible to water erosion. In this study, the abandoned rain-feds had the highest runoff volume among the three land-uses. Given that the rain-fed agriculture had the highest sand content, ESP, SAR, EC and calcium carbonate, a significant reduction in runoff volume was observed. It was also seen that rain intensity has significant effect on runoff volume (Table 2). Likewise, according to Figure 4 and the mutual relationship between rainfall intensity and land-use changes, the largest runoff volume was observed for the 88 mm.hr^{-1} intensity in the abandoned rain-fed agriculture. This is attributable to the high calcium carbonate, clay and silt content along with high soil erosivity (Table 1). A rationally less runoff volume is expected in the rain-fed agriculture (Molina *et al.*, 2007), since higher sand content results in augmented infiltration rate and less runoff production (Zhang *et al.*, 2010). One reason for higher runoff volume in the abandoned rain-fed agriculture is lower soil organic matter. Organic matter improves soil moisture holding capacity, porosity and infiltration (Jordan *et al.*, 2008). Recall from Table 6 that runoff volume has a positive significant relationship with soil clay and silt content and a negative correlation with soil sand content at the significance level of 1%. The correlation matrix (Table 3) also indicated that, contrary to the soil's sand content, silt and clay content has a positive correlation with runoff volume (Thanapakpawin *et al.*, 2007; Emadi *et al.*, 2009). Soil erosivity also correlates positively with runoff volume, where higher soil erosivity results in higher runoff volume (Alan *et al.*, 2007).

Erosion and Sedimentation

Based on our results (Table 1), land-use has a major influence on soil clay and silt content, sand, EC, pH, ESP and SAR, carbonate calcium, organic matter and erosivity, and hence on soil erosion (Mohamadi, 2016). As previously stated, significantly higher sediment production levels were measured at the abandoned rain-fed agriculture. This could be initially explained by the increased soil silt and clay content compared to the other land-uses (Celik, 2005). Back to Table 5, the highest correlation was detected between soil erosivity and sediment production in rain-fed and rangeland settings. Sediment production had also negative correlation with the soil's sand content (Izquirdo & Ricardo, 2009; Adekalu *et al.*, 2006). Despite the role of clay particles in improving soil's resistance against erosion, a contradictory result was obtained. In this case, animal trampling in the abandoned rain-fed agriculture could severely degrade soil structure and break soil aggregates into fine particles which per se intensifies erosion. Less soil organic matter also bears severe consequences for this land-use (Kwanchai & Koontanakulvong, 2009).

The lowest erosion rates were recorded at the rangeland and rain-fed agriculture respectively. This might pertain to the higher sand and lower silt content (Table 1). Based on the results of the group mean comparisons provided in Table 2, rain intensity of 88 mm. hr^{-1} produced higher erosion as a result of rain drop's kinetic energy (Hager, 1987) as well as rainfall and runoff volume which give more capacity to rain drops to collapse soil aggregates and for runoff water to carry soil particles (Bronstert *et al.*, 2002). In terms of the mutual relationship between rainfall intensity and sediment production, the abandoned rain-fed agriculture and the rainfall intensity of 88 mm.hr^{-1} produced the highest levels of soil loss. Therefore, the importance of higher rainfall intensities and land-use changes on erosion could be deduced (Izquierdo *et al.*, 2009). Based on the results, the lowest erosion occurred in rain-fed agriculture and at the 46 mm.hr^{-1} intensity. In Table 5, soil's silt and clay content has a positive significant relationship with sediment production under different intensities at 1% level of significance (Defersha & Mellese, 2012) with a negative relationship occurring between sand and sediment production (Santos *et al.* , 2003). Soil erosivity has also a positive significant relationship with erosion (Gebremicael *et al.*, 2012). Table 4 shows the relationships along with their significance levels.

Conclusion

In light of the results obtained in this study, erosion and sediment production depends upon a multitude of factors including soil physiochemical properties, rainfall intensity, and land-use changes, among others. In this study, the highest erosion and runoff production were observed in the abandoned rain-fed agricultural areas. Given the importance of lands in Saduyeh for local farmers, more attention must be directed towards the issues such as soil erosivity, land capability, and land-use planning. Thus it is recommended that managerial plans be prepared based on soil type and ecological capacity of the area, in order to produce the maximum benefit for the people and future generations, while minimizing soil erosion and runoff production.

References

Adekalu, K.O., Okunade, D.A., and Osunbitan, J.A. 2006. Compaction and mulching effects on soil loss and runoff from two southwestern Nigeria agricultural. Geoderma, 137: 226-230.

Angers, D.A., Samson, N., and Legere, A., 1993. Early changes in water-stable aggregation induced by rotation and tillage in a soil under barley production. Canadian journal of soil science, 73(1):51-59.

Bronstert, A., Niehoff, D., and Burger, G. 2002. Effects of climate and land- use change on storm runoff qeneration: present knowledqe and modeling capabilities. Hydrological processes, 16: 509-529.

Celik, I. 2005. Land-use Effects on Organic Matter and Physical Properties of soil in a Southern Mediterranean Highland of Turkey. Soil & Tillage Research, 83: 270-277.

Defersha, M.B., and Mellese, A.M. 2012. Effect of rainfall intensity, slope and antecedent moisture content in the runoff response of semi-arid catchments: a simulation approach. Journal of Hydrology, 284: 114-130.

Dongsheng, Y., Xuezheng, S., and Weindorf, D.C. 2006. Relationships between permeability and erodibility of cultivated acrisola and cambisols in Subtropical China. Soil science society of China, 16: 304-311.

Emadi, M., Baghernejad, M., and Memarian, H.M. 2009. Effect of land-use change on soil fertility characteristics within water-stable aggregates of two cultivated soils in northern Iran. Land Use Policy, 26: 452-457.

Foltz, R.B., Copeland, N.S., and Elliot, W.J. 2009. Reopening abandoned forest roads in northern Idaho, USA: Quantification of runoff, sediment concentration, infiltration and inter-rill erosion parameters. Journal of Environmental Management, 56: 1-9.

Hager, W.H. 1987. Lateral outflow over side weirs. Journal of Hydraulic Engineering, 113(4): 491–504.

Izquierdo, A.E., and Ricardo Grau, H. 2009. Agriculture adjustment, Land-use transition and protected areas in Northwestern Argentina. Journal of Environmental Management, 90: 858-865.

Jordan, A., Martinez-zavala, L., and Bellinfante, N. 2008. Heterogeneity in soil hydrological response from different land cover types in southern Spain. Catena, 74: 137-143.

Kwanchai, P., and Koontanakulvong, M. 2009. The effect of land use change on runoff in the nan basin. Catena, 69: 31-35.

Martz, L.W. 1992. The Variation of Soil Erodibility with Slope Position in a Cultivated Canadian Prairie Landscape. Earth Surface Processes and Landform, 17:543-556.

Mohamadi, S. 2016. Studying the Relationship between Environmental Factors, Runoff Characteristics and Infiltration Depth Using Rainfall Simulator in Northwestern Rangelands of Iran. Journal of Rangeland Science, 6(3): 205-220.

Molina, A., Govers, G., Vanacker, V., Poesen, J., Zeelmaekers, E., and Cisneros, F. 2007. Runoff generation in a degraded Andean ecosystem: Interaction of vegetation cover and land use. Catena, 71: 357-370.

Nourmohamadi, F., Fatollahi, T., Mirzaei, J., Soleimani, K., Habibnejhad Roshan, M., and Kavian, A. 2013. Estimation of storm wise sediment yield of gully erosion using important rainfall components in different land use of Zagros forest, Iran. Journal of Rangeland Science, 3(4): 302-311.

Pei, J., shi, J., Ai, W., and Jing, Z. 2007. The effect of land use/cover change on surface runoff in Shenzhen region, china. Catena, 69: 31-35.

Santos, F.L., Reis, J.L., Martins, O.C., Castanheria, N.L., and Serralherio, R.P. 2003. Comparative assessment of infiltration, runoff and ersion of sprinkler irrigation soil. Biosystems Engineering, 86(3): 355-364.

Sheikh, V. B., Jafari Shalamzari, M., Farajollahi, A., and Fazli, P. 2016. Soil Erosion under Simulated Rainfall in Loess Lands with Emphasis on Land-Use, Slope and Aspect. ECOPERSIA, 4 (2): 1395-1409.

Sheikh, V. B., Jafari Shalamzari, M., Farajollahi, A., and Fazli, P. 2017. Sediment-bound soil nutrient loss under simulated rainfall. Journal of the Faculty of Forestry Istanbul University, 67(1): 37-48

Singh, M.J., and Khera, K.L. 2008. Soil Erodibility Indices under Different land uses in Lower Shiwaliks. Tropical Ecology, 49(2): 113-119.

Sheridan, G., Noske, P., lean, P., and Sherwin, C. 2008. Using rainfall simulation and site measurements to predict annual inter rill erodibility and phosphorus generation rates from unsealed forest roads: Validation against in-site erosion measurement. Catena, 73: 49-62.

Tao, P., and Shi-jie, W. 2012. Effects of land use, land cover and rainfall regimes on the surface runoff and soil loss on karst slopes in southwest China. Catena, 9: 53-62.

Gebremicael, T.G., Mohamed, Y.A., Betrie, G.D., van der Zaag, P., and Teferi, E. 2013. Trend Analysis of Runoff and Sediment Fluxes in the upper Blue Nile Basin: A Combined Analysis of Statistical Tests, Physically-based Models and Land use Maps. Journal of Hydrology, 482: 57-68.

Thanapakpawin, P., Richey, B., Thomas, D., Rodda, S., Campbell, B., and Logsdon, D. 2007. Effects of landuse change on the hydrologic regime of the Mae Chaem river basin, NW Thailand. Journal of Hydrology, 334(1-2): 215-230.

Zhang, Z., Cao,W., Guo,Q., and Wi, S. 2010. Effects of land use change on surface runoff and sediment yield at different watershed scales on the Loess Plateau. International Journal of Sediment Research, 25(3): 283-293.