ECOPERSIA

2014, 2 (2), 539-556

Storm-Wise Sediment Production of Gully Erosion in the West of Iran

Farhad Noormohammadi[1]*, Majid Soufi[2], Seyed Hamidreza Sadeghi[3], Shahram Mirrezaie[4], Vahid Kazemi[5], Hamidreza Karimzadeh[6], Mohammadreza Ekhtesasi[7], Mohsen Sheklabadi[8] and Hamidreza Azimzadeh[9]

[1] PhD Student in Watershed Management and Science, Faculty of Natural Resources, Lorestan University, Khorambad, Iran
[2] Assistant Professor, Fars Research Centre for Agriculture and Natural Resources, Fars, Iran
[3] Professor, Faculty of Natural Resources, Tarbiat Modares University, Noor, Iran
[4] MSc Student, Faculty of Natural Resources, Isfahan University of Technology, Esfahan, Iran
[5] MSc Student, Faculty of Natural Resources, Yazd University, Yazd, Iran
[6] Assistant Professor, Faculty of Natural Resources, Isfahan University of Technology, Isfahan, Iran
[7] Associate Professor, Faculty of Natural Resources, Yazd University, Yazd, Iran
[8] Assistant Professor, Faculty of Natural Resources, University of Boo Ali, Hamadan, Iran
[9] Assistant Professor, Faculty of Natural Resources, Yazd University, Yazd, Iran

Received: 19 September 2012 / Accepted: 23 September 2014 / Published Online: 26 January 2015

ABSTRACT Different types of soil erosion including gully erosion occur in many parts of Iran. The west of Iran is further threatened by gully erosion due to its specific physical and climatic conditions. However, few studies have been carried out to study the sediment production of gully erosion in Iran. This research was therefore conducted to measure storm-wise sediment production of gully erosion in the west of Iran. To achieve the study objectives, 48 gullies located in three small watersheds viz. Darreh-Shahr, Abbas-Abad and Hollowsh in Ilam and Lorestan Provinces were monitored. The volumes of gullies were measured before and after 5 rainstorms for Darreh-Shahr and Abbas Abad watersheds and 6 rainstorms for Hollowsh watershed from 2005 to 2007. Sediment production was calculated on storm basis for each gully. The results revealed that the minimum and maximum volumes of gully erosion were 0.002 and 1.010 m^3, respectively, for one millimeter of rainfall. The results indicated that soil moisture, percentage of silt and clay, amount and intensity of rainfall and drainage area were the most important factors on formation and sediment production of gully erosion.

Key words: *Gully erosion, Ilam, Lorestan, Rainfall event, Sediment production, West of Iran*

1 INTRODUCTION

Gully erosion is a process in which runoff accumulates in the channel and then causes soil detachment, transportation and consequently deepening of the channel (Poesen *et al.*, 2003). Gully is defined as an erosion channel with cross-sectional area of more than 1ft^2 (929cm^2) (Kompani-Zare *et al.*, 2011) that can be obliterated by conventional tillage (FAO, 1965). Several factors effect on gully formation. The rainfall threshold for gully initiation in Belgian cropland was estimated at 12 to 15 mm (Poesen *et al.*, 2006). The results of Seeger *et al.* (2007) in Spain showed that not

*Corresponding Author: PhD Student in Watershed Management and Science, Faculty of Natural Resources, Lorestan University, Khorambad, Iran, Tel: +98 918 842 8521, E-mail: fnoormohamadi@gmail.com,

only spatial and temporal (in six periods with 5 minutes rainfall at a time) rainfall pattern, influences on soil erosion, but also affects on runoff production such as infiltration capacity, soil moisture and aggregate stability. Using natural rainstorms for the measurements of soil erosion is reportedly the best method to determine erosion in an event scale (Gonzalez Hiadalgo *et al.,* 2007). These researchers collected daily soil erosion during three years in 17 regions of the Mediterranean area. The results indicated that the use of short term 24 hour periods causes inaccuracy in estimation of daily erosion. They recommended minimum periods of three days and more than 3 events per year for optimum results. Height and intensity of precipitation on an index of rates of rain erosion showed the role of rainfall in soil erosion (Capra *et al.,* 2009).

One of the most important characteristics of rainfall in soil erosion is rain erosivity (R) a factor that was introduced by Wishmeier and Smith (1978) (Capra *et al.,* 2009). Cumulative 24-hour precipitation, 3-day and 5-day precipitation were introduced as effective factors on soil erosion (Capra *et al.,* 2009). The results of Capra *et al.* (2009) in Italy indicated a close relationship between gully erosion and storm characteristics. They introduced a rainfall threshold equal to 51 mm for a three-day rainfall event for gully formation and development in the semi-arid regions of Italy. It was determined that the average sediment production by gullies was about 420 m^3 per year for an annual precipitation of 415 mm. Gully formation and development in the semi-arid regions often occurs in a single event due to high soil moisture and minimum vegetation cover (45%) at the time of precipitation (Capra *et al.,* 2009). The average amount of sediment produced from rain events was about 1.66 m^3 ha^{-1} on low slopes (less than 5%) and 5.603 m^3 ha^{-1} on steep slopes (above 15%) (Bouckmark *et al.,* 2009). The results also showed that rainfall of 40 mm day^{-1} was required as a threshold for gully formation and sediment production.

Hillslope processes in semiarid regions can be extremely vigorous during extreme rainfall events causing important soil erosion and flash floods in downstream area. This is an important hazard in dryland basins (Lopez-Bermudes *et al.*, 2002), although other hazards such as desiccation and degradation of soils by erosion and salinization are also important. Studies show that these risks will increase with climate change as rainfall in tensity will increase, storms will be more erratic and temperature will rise. The actual change in annual precipitation as a result of climate change is different for every region, but there seems a tendency for increasing drought in current semiarid environments (Solomon *et al.*, 2007).

More than 60% of Iran's land area is located in arid and semi arid regions, with about 100 million ha at high risk of desertification (Ahmadi, 2004). The distribution and variability of rainfall, the occurrence of prolonged drought periods over recent decades and the intensive utilization of agricultural land as well as overgrazing of the rangelands are all factors that contribute to the current trend of desertification in Iran, leading to increased soil erosion and the deterioration of ecosystems (Forest and Rangelands Organization, 2004). The vast land area of Iran (1.6 million km^2) combined with the presence of both wind and water are major contributing factors to the erosion process, while yet there is no documentation at a national level on particular and reliable soil erosion rates. However, based on an estimation of 137Cs measurement and suspended sediment gauging data for seven major dam watersheds of Iran, the water erosion rates in agricultural land varies from 7.6 to 32 ton $ha^{-1}Y^{-1}$ and 4.3-22 ton $ha^{-1}Y^{-1}$ in the rangelands (Nazari Samani *et al.,* 2009). These large variations have been attributed to the wide range of environmental characteristics that exist across Iran. Methods of modeling such as Pacific Southwest Interagency Committee (PSIAC) Erosion Potential Method (EPM) and Universal Soil Loss Equation (USLE) do take factors of uncertainty in to consideration. Much more research is therefore required to understand the role of gully erosion in Iran. A detailed survey of related studies indicated that in spite of many research on the recognition and assessment of identification of the influential factors on gully erosion, few studies have been done on sediment production by gully erosion that relate to a rainfall event scale.

The provinces of Ilam and Lorestan in southwest of Iran, experience gully erosion on rangeland and croplands. These regions are located near the Seymareh River and the sediment produced by gully erosion enters the storage facility of the Karkheh Dam. Therefore, this research on sediment yield of gully erosion and its relationship with watershed characteristics is a priority. The objective of this research is to determine the relationship between important rainfall characteristics and sediment production from gully erosion by determining factors for sediment production. The research aims to contribute to more effective land management (Jihad-e-Keshavarzi Organization of Ilam province, 2000 and Jihad-e-Keshavarzi Organization of Lorestan province, 2001).

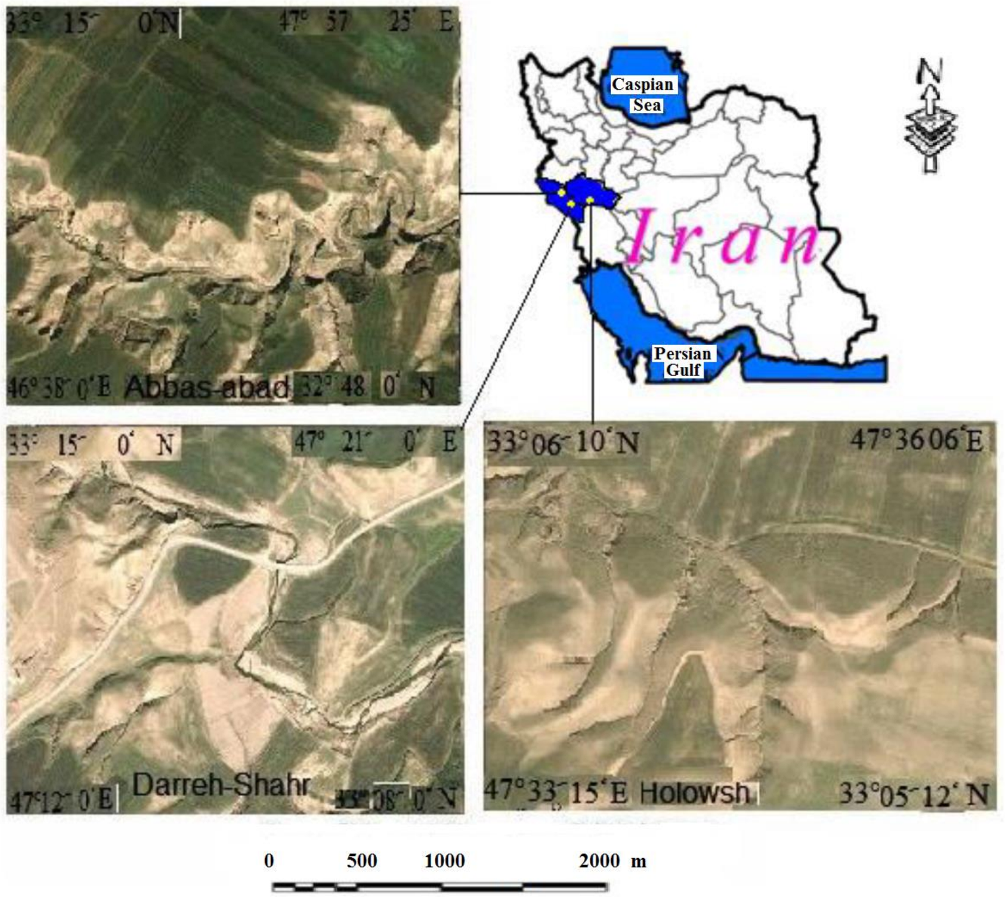

Figure 1 Location of gully regions in studied watersheds

2 MATERIAL AND METHODS

2.1 Study regions

2.1.1 Watersheds of Ilam province: Darreh-Shahr and Abbas-Abad

The watersheds of Darreh-Shahr and Abbas-Abad were selected in Ilam province (Figure 1). The city of Darreh-Shahr had the highest mean annual temperature in Ilam Province. The maximum mean of monthly precipitation in this city occurred in December with 69.8 mm and the minimum monthly precipitation occurred in August and September (Sadeghi *et al.,* 2008) (Table 1).

The most annual precipitation occurred in the months of December, January and February in Darreh-Shahr city. With respect to geology, this watershed is located in the folded Zagros zone. Lithologic and sedimentary units of this zone are affected by occurrences of geologic phenomena and processes and have distinguished characteristics in relation to other structural zones including Paleozoic, Mesozoic and era and Neogene and Quaternary periods from old to new, respectively (Sadeghi *et al.,* 2008).

The studied gullies were located in a semi-arid climate zone. 39% of the selected gullies were in rangeland and 61% in cropland. Most of the gullies were located on slopes lower than 10%. Management of the cropland was conventional, following proper principles for cultivation; and conventional animal husbandry was practiced in the rangeland with the number of animals larger than the range capacity notwithstanding. The mean annual precipitation was 428.7 mm in Abbas-Abad and Darreh-Shahr watersheds, with 101 mm for the maximum 24-hour precipitation, and mean rainfall intensity was equal to 0.995 mm hr^{-1} (Darreh-Shahr station, 30 years record). Forestation consisted of the following types; *Quercus, Quercus-Pistacia, Quercus-Pistacia-Crataegus, Quercus- Amigdalus Hassknechtii-Acer monspessulanum*. Range species included *Poaceae and more Pienomon acarna, Bromus danthonia, Bromus tectorum and Bromos sterilis* (Sadeghi *et al.,* 2008).

2.1.2 Watershed of Lorestan Province: Holowsh

The watershed of Holowsh is located in Poldoktar City, south of Lorestan province. The general characteristics of this watershed are given in Table 1. This city has the highest mean annual temperature in Lorestan province (Poldoktar climatological station, 20 year period). The maximum and minimum monthly precipitation occurred in the months of December, August and September, respectively. Most precipitation was in December, January and February as rainfall (Jihad-e-Keshavarzi Organization of Lorestan, 2001). The mean annual precipitation was 350 mm, the maximum 24-hour precipitation was 92.7 mm and the mean intensity of rainfall was 3.7 mm/hr. 53% of the gullies were located in the rangelands and 47% of them in croplands. Dendretic, bank and linear gullies were located in the slope classes of 0-5%, 5-10% and >10%, respectively. Land management in these regions was predominantly conventional agriculture with some disregard for the proper principles for cultivation in croplands and conventional animal husbandry with an animal number larger than the range capacity. Species growing on the rangelands included families of Compositae, Labiatse, Legominosae, Graminae, Polygonaceae. This watershed is located within the folded Zagros structure. Units of this watershed belong to Cenozoic era and the Tertiari and Quaterner periods. Figure 1 indicates regions of gully erosion in the three watersheds.

[DOR: 20.1001.1.23222700.2014.2.2.7.6]

Table 1 Characteristic of three study watersheds

Study Watersheds	Longitude	Latitude	Area (ha)	Annual average of temperature (˚C)	Annual average of precipitation (mm)	Climate	Major soil texture
Dareh-Shahr (Ilam)	46˚ 38 ' 00" to 47˚ 57' 25" E	32˚ 48' 00" to 33˚ 33 ' 25" N	10935	22.6	428.7	Semi arid	sandy loam, silt loam,
Abbas- abad (Ilam)	47˚ 12 ' 00" to 47˚ 21 ' 25" E	33˚ 08 ' 00" to 33˚ 15 ' 00" N	8375.3	22.6	428.7	Semi arid	loam, clay silt, clay
Holowsh (Lorestan)	47˚ 33 ' 15" to 47˚ 36 ' 06"E	33˚ 05 ' 12" to 33˚ 06 ' 10" N	743	24	350	Semi arid	loam, silt clay, silt loam

2.1.3 Research methodology

In this study spatial distribution of the gullies was determined by experienced experts from aerial photos on a scale of 1:40000. The selected gullies were used for fieldwork that involved their monitoring and measurement. These gullies had typical characteristics for climate, geological formation, vegetation and soil in each region. The selected gullies also had similar shape (Capra *et al.,* 2009). In total 18 gullies were selected in Darreh-Shahr, 15 in Abbas-Abad and 15 in Hollowshh watershed (Figure 4). For each gully, three sections from the upper, middle and lower parts of the channel at spaces of 1 to 2 meters in length were determined. The sections were marked with wooden pegs on both sides (Sadeghi *et al.,* 2008). Different morphological factors of the gullies were identified including upper and lower width, depth, distance between sections, head cut height, distance of head cut, gully length, and slope of banks were measured using a thread scaled with 25 cm intervals tied to wooden pegs (Figure 5).

The factors were measured for each gully before and after each rainstorm. Each cross section was depicted and calculated using AutoCAD version 14. The next stage, was a calculation of the difference of area, it was calculated in Excel version 2003 and multiplied to the length between the cross section to compute the volume of gully erosion in each rainstorm. Soil factors for each gully were determined from two samples, one of the surface horizon (0-50 cm) and the second of the sub-surface horizon (>50 cm) measurements were taken in the lab (Table 5). Soil texture was identified by a hydrometer, acidity of saturated soil by a PH meter model 744, and hydraulic conductivity was determined by an EC meter Jenway model of 3310. Moisture percentage of the saturated soil was determined by the weighted method, amounts of sodium and potassium in the saturated soil was evaluated by flame Photometry, and the amount of calcium was quantified by the titration method then ratios of sodium adsorption were calculated using a formula. Calcareous content was determined using elimination of calcareous by acid, the neutralization of the surplus acid by Soda.

Rainfall characteristics of the research sites were determined using recorded data from automatic rain gauges in the cities of Darreh-Shahr and Poldohktar.

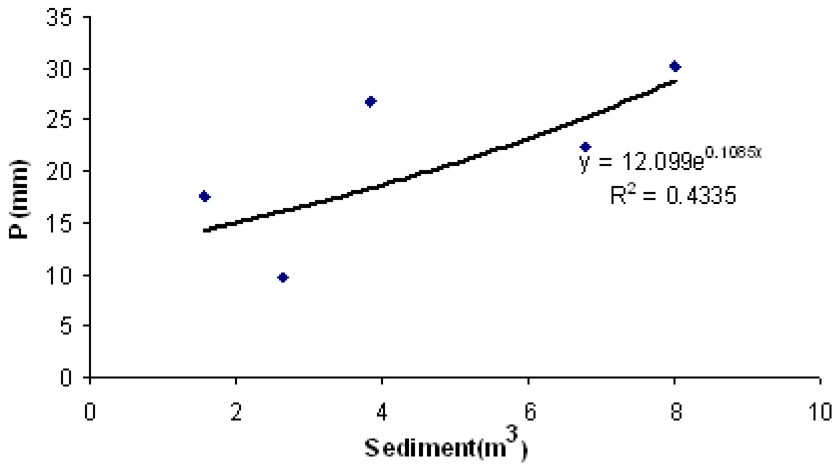

Figure 2 Relationship between sediment production of gullies and precipitation in Darreh-Shahr watershed

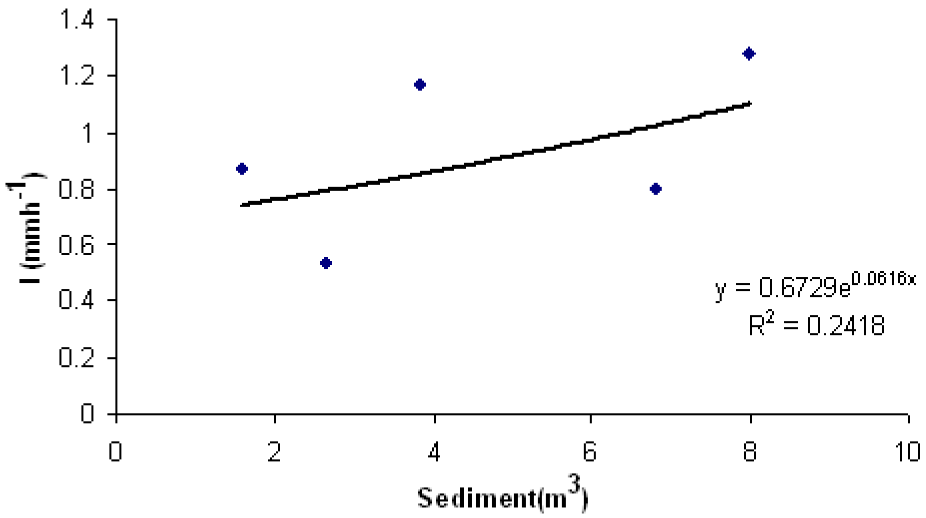

Figure 3 Relationship between sediment production of gullies and rainfall intensity in Darreh-Shahr watershed

3 Results and discussion

3.1 Sediment production in the gullies of the Darreh-Shahr watershed in Ilam province

Gullies of this watershed were formed in a semi-arid climate zone and land use included both cropland and rangeland. Gullies in the rangeland were mostly located in hilly areas with slopes higher than 10% while the gullies in croplands were located in alluvial plain with slopes between 2 and 5%. All the gullies were located on limestone and Quaternary formations and on Calcaric regosols (Table 2). The Sediment productions of gully erosion for linear, digitated and frontal gullies were 0.95, 2.8 and 1.47 m^3, respectively (Table 3).

Maximum gully development occurred in the second and first rainstorms respectively and the rate of development decreased in subsequent storms (Table 4).

Figure 4 Some views of study gullies in Darreh-Shahr (a), Abbas abad (b) and Holowsh watersheds (c)

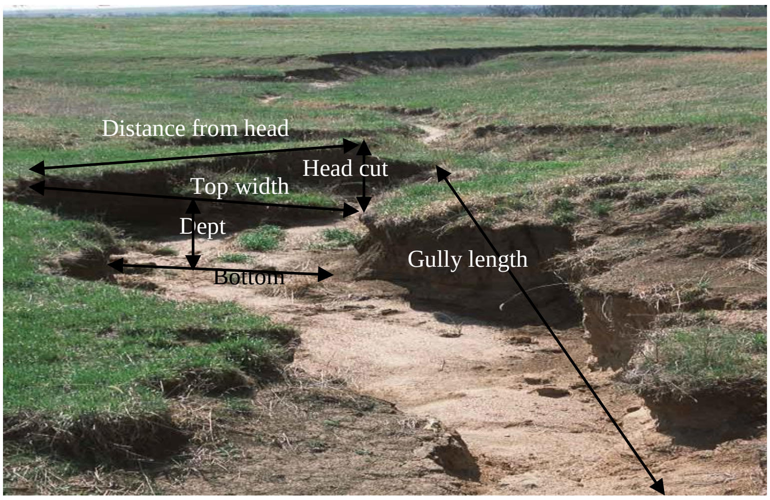

Figure 5 Measured characteristics of study gullies

[DOR: 20.1001.1.23222700.2014.2.2.7.6]

Table 2 Characteristics of gullies in three study watersheds, Iran

No.	Darreh-Shahr						Abbas Abad						Holowsh					
	Gully type	Soil type	formation	Land us	Geomorphologic unite	climate	Gully type	Soil type	formation	Land us	Geomorphologic unite	climate	Gully type	Soil type	formation	Land us	Geomorphologic unite	climate
1	Digitated	Calcaric Regosols	Lime stone-shiest	P. Rangeland*	Hill	Semi arid	Digitated	Calcaric Luvisols	Quaternary	T. Agriculture	Pediment	Semi arid	Linear	Lithosols	Pabdeh	P. Rangeland	Hill	Semi arid
2	Digitated	Calcaric Regosols	Lime stone-Shiest	P. Rangeland	Hill	Semi arid	Digitated	Calcaric Luvisols	Quaternary	T. Agriculture	Pediment	Semi arid	Linear	Calcaric regosols	Quaternary	T. Agriculture	Hill	Semi arid
3	Linear	Calcaric Regosols	Lime stone-Marl	P. Rangeland	Hill	Semi arid	Linear	Eutric Cambisols	Marl	P. Rangeland	Pediment	Semi arid	Linear	Lithosols	Pabdeh	P. Rangeland	Hill	Semi arid
4	Linear	Calcaric Regosols	Lime stone-Marl	P. Rangeland	Hill	Semi arid	Linear	Eutric Cambisols	Marl	P. Rangeland	Pediment	Semi arid	Linear	Calcaric regosols	Quaternary	T. Agriculture	Hill	Semi arid
5	Linear	Calcaric Regosols	Lime stone-Marl	P. Rangeland	Hill	Semi arid	Linear	Eutric Cambisols	Marl	P. Rangeland	Pediment	Semi arid	Linear	Calcaric regosols	Quaternary	T. Agriculture	Hill	Semi arid
6	Linear	Calcaric Regosols	Lime stone-Marl	P. Rangeland	Hill	Semi arid	Linear	Calcaric Luvisols	Quaternary	T. Agriculture	Pediment	Semi arid	Digitated	Lithosols	Quaternary	P. Rangeland	Hill	Semi arid
7	Digitated	Calcaric Cambisols	Lime stone-shiest	P. Rangeland	Pediment	Semi arid	Digitated	Calcaric Luvisols	Quaternary	T. Agriculture	Pediment	Semi arid	Digitated	Lithosols	Quaternary	P. Rangeland	Hill	Semi arid
8	Digitated	Calcaric Cambisols	Lime stone-shiest	T. Agriculture**	Pediment	Semi arid	Frontal	Calcaric Luvisols	Quaternary	T. Agriculture	Pediment	Semi arid	Digitated	Calcaric regosols	Quaternary	T. Agriculture	Hill	Semi arid
9	Digitated	Calcaric Cambisols	Lime stone-shiest	T. Agriculture	Pediment	Semi arid	Digitated	Calcaric Luvisols	Quaternary	T. Agriculture	Pediment	Semi arid	Frontal	Lithosols	Quaternary	P. Rangeland	Pediment	Semi arid

Table 2 (Continue)

10	Linear	Calcaric Cambisols	Lime stone-Marl Quaternary	T. Agriculture	Pediment	Semi arid	Linear	Calcaric Luvisols	Marl	T. Agriculture	Pediment	Semi arid	Frontal	Calcaric regosols	Quaternary	T. Agriculture	Pediment	Semi arid
11	Frontal	Calcaric Cambisols	Lime stone-Marl Quaternary	T. Agriculture	Pediment	Semi arid	frontal	Calcaric Luvisols	Quaternary	T. Agriculture	Pediment	Semi arid	Frontal	Lithosols	Quaternary	P. Rangeland	Pediment	Semi arid
12	Frontal	Calcaric Cambisols	Lime stone-Marl Quaternary	T. Agriculture	Pediment	Semi arid	Digitated	Calcaric Luvisols	Quaternary	T. Agriculture	Pediment	Semi arid	Frontal	Calcaric regosols	Quaternary	T. Agriculture	Pediment	Semi arid
13	Frontal	Calcaric Cambisols	Lime stone-Marl Quaternary	T. Agriculture	Pediment	Semi arid	Linear	Eutric Cambisols	Marl	P. Rangeland	Pediment	Semi arid	Linear	Lithosols	Pabdeh	P. Rangeland	Pediment	Semi arid
14	Frontal	Calcaric Cambisols	Lime stone-Marl Quaternary	T. Agriculture	Pediment	Semi arid	Digitated	Calcaric Luvisols	Quaternary	T. Agriculture	Pediment	Semi arid	Linear	Lithosols	Pabdeh	P. Rangeland	Pediment	Semi arid
15	frontal	Calcaric Cambisols	Lime stone-Marl Quaternary	T. Agriculture	Pediment	Semi arid	Linear	Eutric Cambisols	Marl	P. Rangeland	Pediment	Semi arid	Linear	Lithosols	Pabdeh	P. Rangeland	Pediment	Semi arid
16	Frontal	Calcaric Cambisols	Lime stone-Marl Quaternary	T. Agriculture	Hill	Semi arid												
17	Frontal	Calcaric Cambisols	Lime stone-Marl Quaternary	T. Agriculture	Hill	Semi arid												
18	Linear	Calcaric Regosols	Lime stone-Marl Quaternary	P. Rangeland	Hill	Semi arid												

Poor Rangeland*
Traditional Agriculture**

Table 3 Statistical factors for total sedimentyield from gully types in three watersheds

	Gully type	Min (m^3)	Max (m^3)	Mean (m^3)	SD	CV (%)
Darreh-Shahr watershed	Linear	0.38	1.83	0.95	0.87	0.07
	Digitated	0.79	8.5	2.8	3.2	0.04
	Frontal	0.69	2.4	1.47	0.56	0.91
Abbas Abad watershed	Linear	0.39	4.9	0.88	1.77	1.14
	Digitated	0.11	2.4	0.81	0.82	0.54
	Frontal	0.19	0.48	0.33	0.2	0.14
Holowsh watershed	Linear	0.77	14.2	5.1	5.45	4.3
	Digitated	3.51	17.58	12.27	7.64	5.84
	Frontal	4.05	7.52	5.33	1.52	1.09

Table 4 Amount of sedimentation from each gully (M^3) in three watersheds and per one millimeter from precipitation

	Gully	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Darreh-Shahr watershed	Storm1	0.054	0.005	0.017	0.005	0.006	0.002	0.004	0.008	0.039	0.014	0.026	0.011	0.22	0.007	0.013	0.008	0.013	0.003
	Storm2	0.110	0.016	0.021	0.004	0.003	0.005	0.005	0.007	0.018	0.007	0.021	0.019	0.017	0.006	0.020	0.006	0.006	0.004
	Storm3	0.019	0.003	0.009	0.006	0.009	0.002	0.004	0.007	0.014	0.006	0.011	0.008	0.005	0.005	0.016	0.004	0.002	0.002
	Storm4	0.014	0.013	0.013	0.018	0.004	0.005	0.042	0.006	0.028	0.016	0.017	0.007	0.023	0.013	0.028	0.005	0.006	0.004
	Storm5	0.008	0.001	0.003	0.000	0.001	0.002	0.024	0.011	0.010	0.002	0.001	0.004	0.003	0.002	0.000	0.000	0.008	0.001
Abbas Abad watershed	Storm1	0.160	0.049	0.002	0.001	0.168	0.025	0.206	0.421	0.582	0.366	0.066	0.061	0.078	0.007	0.016			
	Storm2	0.083	0.025	0.001	0.000	0.087	0.013	0.106	0.218	0.301	0.190	0.034	0.031	0.040	0.003	0.008			
	Storm3	0.053	0.016	0.000	0.000	0.056	0.008	0.069	0.141	0.195	0.123	0.022	0.020	0.026	0.002	0.005			
	Storm4	0.245	0.075	0.003	0.001	0.257	0.039	0.315	0.645	0.890	0.560	0.101	0.093	0.119	0.011	0.025			
	Storm5	0.109	0.033	0.001	0.000	0.115	0.017	0.141	0.288	0.398	0.250	0.045	0.041	0.053	0.005	0.011			
Holowsh watershed	Storm1	0.005	0.045	0.007	0.006	0.010	0.011	0.005	0.142	0.011	0.070	0.011	0.004	0.019	0.071	0.003			
	Storm2	0.001	0.036	0.002	0.006	0.003	0.007	0.004	0.007	0.037	0.007	0.001	0.002	0.003	0.034	0.004			
	Storm3	0.001	0.021	0.003	0.007	0.011	0.018	0.036	0.021	0.007	0.007	0.016	0.004	0.006	0.011	0.001			
	Storm4	0.001	0.001	0.001	0.000	0.004	0.000	0.000	0.002	0.014	0.007	0.000	0.001	0.009	0.012	0.002			
	Storm5	0.001	0.035	0.000	0.005	0.000	0.005	0.007	0.009	0.009	0.001	0.002	0.001	0.000	0.021	0.000			
	Storm6	0.001	0.166	0.008	0.000	0.010	.0000	0.020	0.006	0.008	0.020	0.001	0.000	0.006	0.005	0.002			

[DOR: 20.1001.1.23222700.2014.2.2.7.6]

Table 5 Statistics of parameters in three watersheds

	Darreh-Shahr watershed				Abbas Abad watershed				Holowsh watershed			
	Min.	**Max.**	**Mean**	**SD**	**Min.**	**Max.**	**Mean**	**SD**	**Min.**	**Max.**	**Mean**	**SD**
Gravel (%)	0.31	4	2.1	2.6	0.2	3.2	1.1	1.01	5	35	18.5	12.5
Moisture (%)	26.6	63.1	44.8	25.8	25	55.1	40.05	21.3	25.6	50.3	35.6	7.6
Mg (me/l)	14	1.4	40.2	26.5	3	19	6.8	4.5	0.2	0.9	5.2	2.1
Ca (me/l)	105	2650	59.1	621.4	9.03	46	23.7	9.03	11	40	22.8	10.9
Na (me/l)	54	268	148.1	6.69	46.6	24	155.3	46.6	0.87	44.7	10.2	16.4
K (me/l)	55.2	1065	32.9	31.5	50	916	331.2	15.2	0.21	1.3	0.48	0.4
SAR	2.5	26	11.5	6.1	2.4	12	5.1	2.4	0.26	10.2	2.4	3.7
$CaCO_3$ (%)	2.8	44.3	23.5	29.3	3.03	42	37.3	3.05	37.5	42.5	39.6	2.12
OM (%)	0.10	2.2	0.94	0.68	3.2	16.3	11.7	3.2	0.03	2.14	0.89	0.75
Silt (%)	13	54	38.8	11.2	23	55	34	8.5	33.5	47	41.3	4.2
Sand (%)	32	86	48.8	13.6	16	46	34.8	7.4	3.3	49.6	28.1	14.5
Clay (%)	1	22	13.3	6.6	28	60	41.8	7.4	16.7	55.9	30.5	13.9
P (mm)	9.7	30.2	21.3	8.07	10.2	46.4	25.02	14.10	17	57	37.1	15.6
I (mm/h)	0.54	1.28	0.93	0.29	0.18	2.4	1.06	0.82	2.8	4.2	3.7	0.56
Slop (%)	2.5	45	12.5	13.3	1.6	24	11.7	6.3	2	22	13	7.4
Drainage Area (%)	0.1	1.2	0.32	0.28	0.2	1.2	0.74	0.3	0.05	0.5	0.2	0.11

Table 6 Correlation coefficients between sediment production of gullies and independent variables in three studied watersheds

Area	Gravel	Moisture	Mg	Ca	Na	K	SAR	$Caco_3$	OM	Silt	Sand	Clay	P	I	Slop	Drainage Area
Darreh-Shahr	0.305	0.611*	0.391	0.181	0.141	0.566*	-0.327	0.311	-0.163	-0.565*	0.397	-0.090	0.590*	0.760*	0.589*	0.522
Abbas Abad	0.255	0.581*	0.590	0.307	0.331	0.381	0.721*	0.240	0.750	0.717*	0.455	0.617*	0.964*	0.560*	0.147	0.516*
Holowsh	-0.540*	0.529*	0.501	0.511	-0.622	0.900	0.700*	-0.120	0.210	-0.900*	0.000	0.300	0.940**	-0.430	-0.410	0.520*

** Significant at the 0.01 level
* Significant at the 0.05 level

[DOR: 20.1001.1.23222700.2014.2.2.7.6]

Linear gullies in Darreh-Shahr city produced the minimum sediment production for each millimeter of precipitation of 0.0005 m^3; and the maximum was 0.021 m^3. The digitated gullies produced the minimum sediment of 0.001 m^3 and the maximum of 0.110 m^3. The frontal gullies produced the minimum sediment of 0.0005 m^3 and the maximum of 0.098 m^3 (Table 3). The relationship between sediment production and rainfall is shown in Figure 2. The relationship is significant (p=0.003) and indicates the effect of rainfall on sediment production. This relationship shows that the required rainfall for producing sediment is 10 mm.

The relationship between changes in the volume of gully erosion and rainfall intensity in Darehshahr was significant (p=0.007), showing that the least rain intensity for sediment production was 0.6 mm hr^{-1} (Figure 3).

The results from Darehshahr demonstrated the effect of the amount of rainfall and its intensity on gully development. The correlation coefficient (Table 6) indicates that the slope above the head cuts, amount and intensity of rainfall and soil moisture are the most important factors on gully development in this region. In the Darreh-Shahr watershed, gullies in the rangelands are mostly linear and some of them are digitated. The maximum sediment was produced in digitated gullies. Poor range condition, lack of vegetation cover (Capra *et al.*, 2009), animal trampling, and slope higher than 10% reduced soil infiltration and increased gully erosion (Aazami *et al.*, 2004).

Consideration of the effect of rainfall on gully erosion in the Darreh-Shahr watershed, indicated that gully development was less in spite of having the highest amount of precipitation in the first rain storm. It seems that the first rain storm increased soil moisture. The formation of gullies was higher in the second storm with less rainfall. In the third storm, similar to the second, more rain was converted into surface runoff, and gully volume also increased. Gully development decreased in the fourth and fifth storms. The amount of gully development in the fifth rain storm was less compared with the preceeding storms (Table 4).

3.2 Sediment production by gullies in the Abbasabad watershed

The gullies are located in a semi-arid climate zone and the area supports two land uses, rangelands and croplands. Gullies in the rangelands are located in alluvial plain and slopes higher than 10% are croplands and slopes between 2 and 10% are flood plain. Gullies are formed on Marl and Quaternary formations and Calcaric Luvisols (Table 2). The rate of gully development for linear, digitated and frontal gullies was 0.88, 0.81 and 0.33 m^3, respectively (Table 3). The maximum rate of gully development occurred from the fourth and fifth rain storms (Table 4).

Soil moisture, exchangeable sodium, silt and clay, amount and intensity of rainfall and area of watershed were the most important factors for gully development and sediment production in the Abbas-Abad watershed (Table 6). For linear gullies, the minimum sediment production was 0.0003 m^3 and the maximum rate was 0.560 m^3. For the digitated gullies, the minimum rate was 0.002 m^3 and the maximum rate was 0.890 m^3. For the frontal gullies, the minimum rate was 0.005 m^3 and the maximum rate was 0.647 m^3 (Table3). The relationship between volume of gully erosion and rainfall amount in the Abas-Abad watershed (Figure 6) was not significant (p=0.108). The minimum amount of rainfall for gully development was 10 mm (Figure 6).

The relationship between gully volume and rain intensity was not significant (p=0.20) in Abas-Abad watershed and the minimum rain intensity for gully development was 0.75 mm hr^{-1} (Figure 7).

The results indicated that there was no significant relationship between gully development and rainfall cahracteristics in the Abbas-abad watershed (Figures 6 and 7).

[DOR: 20.1001.1.23222700.2014.2.2.7.6]

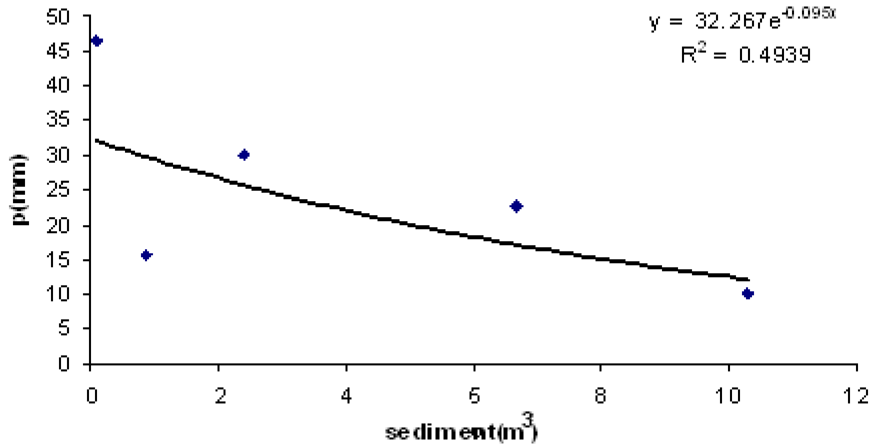

Figure 6 Relationship between gullies volume and storm precipitation in Abbas Abad watershed

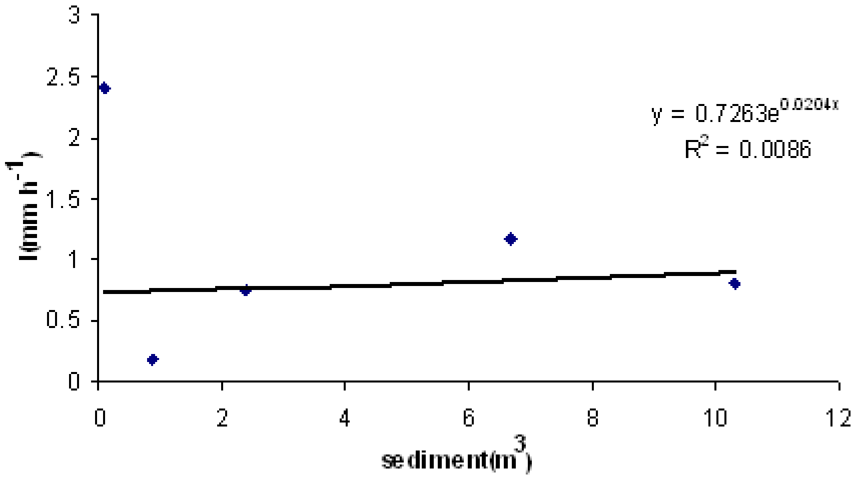

Figure 7 Relationship between gullies volume and storm rainfall intensity in Abbas Abad watershed

The maximum sediment formed in the digitated gullies in the Abbas-Abad watershed. These gullies were located on croplands of Quaternary formation on a slope less than 10%. Based on the results of Sadeghi *et al*. (2008), for gully formation from rills on croplands with low intensity rain in Spain, it was reported that improper cultivation, suceptible geologic formation with high silt content caused gully erosion in this type of watershed. With respect to gullies in this watershed (Figure 6), gully banks were dissected by surface runoff and the condition for block failure was prepared facilitating increased sediment production (Boucknak *et al.*, 2009). The mean annual rainfall was 428 mm, the soil was silty clay and therefore vegetation was poor. These conditions led to the formation of gullies.

3.3 Sediment production by gullies in the Holowsh watershed in the south of Lorestan province

The gullies were located in a semi-arid climate zone with two land uses, rangelands and croplands. Gullies in the rangelands were on alluvial plain with slopes higher than 10% and gullies in croplands were on flood plain with slopes of between 2 and 5%. Gullies were formed on the Pabdeh and Quaternary formations and Calcaric regosols and Lithosols (Table 2). The averages of gully development for linear, digitated and frontal gullies were 5.1, 12.27 and 5.33 $m^{3,}$ respectively (Table 3). The maximum gully development occurred in the sixth and second rainstorms (Table 4).

Soil moisture, rainfall amount, silt, exchangeable sodium and watershed area were the most important factors on gully development and volume in the Holowsh watershed (Table 6).

For linear gullies, the minimum gully development was 0.77 m^3 and the maximum was 14.2 m^3. For the digitated gullies, the minimum gully development was 3.51 m^3 and the maximum was 17.58. Finally, for the frontal gullies, the minimum development was 4.05 m^3 and the maximum was 7.52 m^3 (Table 3). The relationship between the volume of gully development and amount of rain was not significant (p= 0.29) in the Holowsh watershed (Figure 8). The minimum rainfall for gully formation was estimated at about 20 mm.

The relationship between rain intensity and gully erosion was not significant (p= 0.86) in the Holowsh watershed. The minimum intensity for gully development was about 3.5 mm h^{-1}. This implies that rainfall characteristics did not affect gully development.

The maximum gully development was evident in linear and frontal gullies in the Holowsh watershed. Linear gullies were formed mostly on the areas Pabdeh geologic formation with slopes higher than 10% and frontal gullies were located on Quaternary formation with slopes less than 10%. Gullies on the Quaternary formation produced more sediment due to higher watershed area and more hydraulic gradient around the Seymareh River. The formation of linear gullies was mostly in the rangelands.

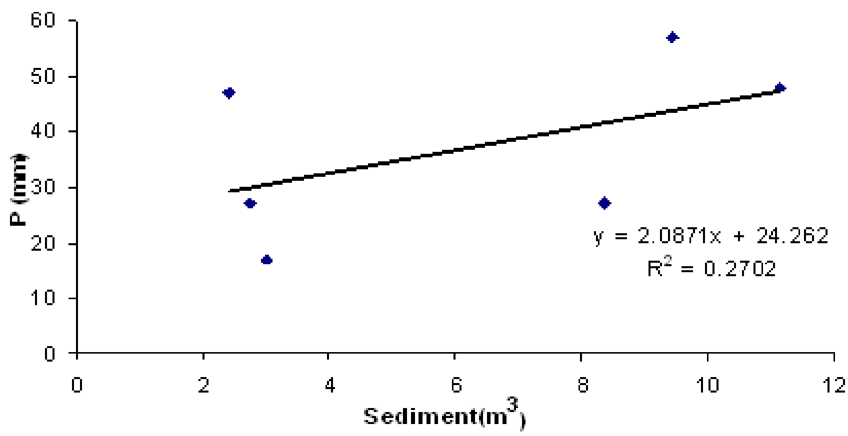

Figure 8 Relationship between the gullies volume and precipitation in Holowsh watershed

4 CONCLUSION

The results revealed that sediment production from gullies was higher in the Holowsh watershed than in the other watersheds for all gully formations; linear, digitated and frontal. The main cause can be attributed to higher silt and clay content, higher slopes and higher rainfall intensity of the Holowsh watershed. In the Darreh-Shahr watershed, the maximum sediment was produced in the digitated gullies. These gullies were located in rangelands on a geological formation of limestone and shist with slopes higher than 10%. Poor rangelands condition, animal trampling and higher slopes (>10%) increased gully formation.

Factors such as amount and intensity of rainfall, slope above head cuts, silt and sand content, soil moisture and calcium in the soil provided conditions for surface runoff in the Darreh-Shahr watershed. The maximum gully development occurred in the first and second rain storms (Table 4). This result supports the research of Capra *et al.,* (2009), which demonstrated that the maximum sediment occurred from the first rainstorms in semi-arid regions. The rain intensity recorded in Darreh-Shahr (0.6 mm hr^{-1}) was similar to the result obtained by Capra *et al.,* (2009) research in Italy with an intensity of 0.7 mm hr^{-1}.

In the Abbas-Abad watershed, the maximum sediment production was in the digitated gullies. These gullies were located on croplands and on a Quaternary geologic formation with slopes higher than 10%. Improper traditional cultivation, suceptible geologic formation and silt and clay content contribute to an increased potential to produce surface runoff.

Factors such as soil moisture, rainfall amount, silt, exchangeable sodium and watershed area above the head-cuts were the most important factors influencing gully development in the Holowsh watershed. The maximum gully development occurred in the linear and digitated gullies. Linear gullies were formed on a Pabdeh geologic formation with slopes higher than 10%. Other gullies were formed on a Quaternary formation with slopes below 10%. More sediment was produced on the Quaternary formation. Linear gullies in the rangeland with higher slopes produced more sediment due to block failure. This result supports the research of Bouchnak *et al.,* (2009) stating that there was a 77.8% contribution to increased gully formation from block failure on the higher slopes. In the frontal gullies on Quaternary formation around the Seymareh River, a larger drainage area and higher hydraulic gradient caused more sediment production.

Amounts of silt, clay and sand in the Darreh-Shahr watershed were 38.8, 13.3 and 48.8 %, respectively; in the Abbas-Abad watershed, they were 34, 41.8 and 34.8%, and in the Holowsh watershed they were 41.3, 30.5 and 28.1%, respectively. These Figures show higher sand content in Darreh-Shahr, higher clay content in Abas-Abad, and higher silt content in Holowsh; indicating suitable conditions for producing surface runoff. The results indicated that among the three watersheds, the minimum and maximum gully development per mm rainfall occurred as 0.001 and 0.89 m^3 in the Darreh-Shahr and the Abbas-Abad watersheds. The minimum sediment produced in Darreh-Shahr watershed was due to higher sand content (48.8%) and the maximum sediment in Abas-Abad watershed was due to higher clay content (41.8%). The most sediment was produced by the digitated gullies (2.8 m^3) and frontal gullies (1.47 m^3) with attention to their geologic formation and land uses. It can be implied that geologic formation and land use has an important role in gully development, as rainfall intensity was not particularly high in these regions.

In the Holowsh watershed, the actual watershed area was less but the average slope was higher than the other watersheds. Although

[DOR: 20.1001.1.23222700.2014.2.2.7.6]

the mean volume of gully erosion in relation to rainstorms was higher in the Holowsh watershed, the required minimum rain intensity was higher (3.5 mm hr^{-1}), indicating higher resistance of the specific geologic formation and more suitable range conditions in this watershed in comparison with the others. Pabdeh formation is composed of shale and clayey calcareous substances. Shale has a resistance coefficient of between 4 and 6 in terms of resistance to erosion. The resistance coefficient of quaternary sediment varies from 0.7 to 2, depending on slope gradient and vegetation cover. These coefficients are in the range of 17 for quartzite and 0.7 for alluvials. In addition, the gullies that were linear in the Holowsh watershed and that had less head-cut produced more sediment in relation to the other watersheds.

5 REFERENCES

Aazami, A., Hossien Zadeh, H. and Pirani, A. Assessment of plant covers role on run off and sediment, Research center institute of Ilam Province, 2004; 36 P. (In Persian).

Ahmadi, H. Introduction to Iranian model of desertification assessment (IMDPA), Unpublished technical report for presenting in Committee of Science and Technology, United Nation Convention to combat desertification, the 7th Session of Conference of Parties (COP7), Nairobi, Kenya, 2004; 56 P.

Arenaez, J., Larrea, V. and Ortigosa, L. Surface runoff and soil erosion on unpaved forest roads using rainfall simulation tests in northeastern Spain, Catena, 2004; 57: 1-14.

Bouchnak, H., Mamennoubi, S.F., Mohamed, R.B. and Mohamed, H.S. Slope and rainfall effects on the volume of sediment yield by gully erosion in the Seur lithology formation (Tunisia), Catena, 2009; 78: 170-177.

Capra, A., Porto, P. and Scicolone, B. Relationships between rainfall characteristics and ephemeral gully erosion in a cultivated catchments in Sicily (Italy), Soil Till. Res. 2009; 105: 77-87.

Chaplot, V., Caadou Le Brozec, E., Silvera, N. and Valentin, C. Spatial and temporal assessment of linear erosion in catchments under sloping lands of northern Laos, Catena 2005; 63: 164-184.

Descroix, L., Gonzalez Barrios, J.L., Vramontes, D., Poulernard, J., Anaya, E., Esteves, M. and Estrada, J. Gully and sheet erosion on subtropical mountain slopes: Their respective roles and the scale effect, Catena, 2008; 72: 325-339.

Food and Agricultural Organization-FAO, Soil Erosion by Water, Some Measures for its Control on Cultivated Land. FAO, Rome, 1965. 81 P.

Gonzalez-Hiadalgo, J.C., Pena-aaamonne, J.L. and de Luis, M. A review of daily soil erosion in Western Mediterranean Area, Catena, 2007; 71: 193-199.

Jihad-e-Keshavarzi Organization of Ilam Province, Physiographical report on Darreh-Shahr Watershed, 2000; 150 P. (In Persian).

Jihad-e-Keshavarzi Organization of Lorestan Province, Physiographical report on Gol Gol Watershed, 2001; 132 P. (In Persian).

Mazda Kompani-Zare, M., Soufi, m., Hamzehzarghani, H. and Dehghani, M. 2100. The effect of some watershed, soil characteristics and morphometric factors

[DOR: 20.1001.1.23222700.2014.2.2.7.6]

on the relationship between the gully volume and length in Fars Province, Iran, doi:10.1016/j.catena. 2011.03.008.

Lopez-Bermudez, F., Conesia-Garcia, C. And Alonso, F. Floods: Magnitude and frequency in ephemeral streams in the Spanish Mediterranean region. In: Bull, L.J., Kirkby, M.J. (Eds.), Dryland Rivers: Hydrology and Geomorphology of Semi-Arid Channels. Wiley, Chichester, 2002; 329-350.

Nazari Samani, A., Ahmadi, H., Jafari, M., Boggs, G., Gh, J. and Malekian, A. Geomorphic threshold condition for gully erosion in southwestern Iran (boushehr-Smal watershed). J. Asian Earth Sci., 2009; 35: 180-190.

Poesen, J., Nachtergaele, G. and Valentin, C. Gully erosion and environmental change: importance and research needs, Catena, 2003; 50: 91-103.

Poesen. J., Vanwalleghem. T., Vente. J., Knapen. A., Verstraeten. G. and Martinez-Casasnovas. J. A. Gully Erosion in Europe, John Wiley and Sons, Section 2006; 2(5): 515 P.

Sadeghi, S.H.R., Nourmohammadi, F., Soufi, M. and Yasrebi, B. Estimating of storm-wise sediment yield from gully erosion using important rainfall components, J. Agri. Sci. Natur. Resour., 2008; 15(1): 172-180. (In Persian).

Seeger, M. Uncertainty of factors determining runoff and erosion processes as quantified by Rainfall simulation, Catena, 2007; 71: 56-67.

Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., Tignor, M. And Miller, H.L. (Eds.), 2007. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge and New York, NY, 2007; 996 P.

Wilson, G.V., Cullum, R.F. and Romkens, M.J.M. Ephemeral gully erosion by preferential flow through a discontinuous soil-pipe, Catena: 2008; 73: 98-106.

رسوب زایی ناشی از فرسایش آبکندی به ازای رگبارها در غرب ایران

فرهاد نورمحمدی[۱*]، مجید صوفی[۲]، سیدحمیدرضا صادقی[۳]، شهرام میررضایی[۴]، وحید کاظمی[۵]، حمیدرضا کریم زاده[۶]،
محمدرضا اختصاصی[۷]، محسن شکل آبادی[۸] و حمیدرضا عظیم زاده[۹]

۱- دانشجوی دکتری علوم و مهندسی آبخیزداری، دانشگاه لرستان، خرم آباد، ایران
۲- استادیار، مرکز تحقیقات کشاورزی و منابع طبیعی استان فارس، شیراز، ایران
۳- استاد، دانشکده منابع طبیعی، دانشگاه تربیت مدرس، نور، ایران
۴- دانشجوی کارشناسی ارشد، دانشکده منابع طبیعی، دانشگاه صنعتی اصفهان، اصفهان، ایران
۵- دانشجوی کارشناسی ارشد، دانشکده منابع طبیعی، دانشگاه یزد، یزد، ایران
۶- استادیار، دانشکده منابع طبیعی، دانشگاه صنعتی اصفهان، اصفهان، ایران
۷- دانشیار، دانشکده منابع طبیعی، دانشگاه یزد، یزد، ایران
۸- استادیار، دانشکده منابع طبیعی، دانشگاه بوعلی همدان، همدان، ایران
۹- استادیار، دانشکده منابع طبیعی، دانشگاه یزد، یزد، ایران

تاریخ دریافت: ۲۸ شهریور ۱۳۹۱ / تاریخ پذیرش: ۱ مهر ۱۳۹۳ / تاریخ چاپ: ۶ بهمن ۱۳۹۳

چکیده بخش عمده ای از ایران تحت پوشش انواع مختلف فرسایش و خصوصاً فرسایش آبکندی قرار دارد. وسعت زیادی از نواحی غربی ایران نیز به دلیل شرایط سخت حاکم بر آن توسط فرسایش آبکندی تهدید می شود. با این وجود تحقیق گسترده ای در ارتباط با میزان فرسایش آبکندی در مناطق مذکور صورت نگرفته است. به همین دلیل تحقیق حاضر با هدف اندازه گیری میزان تولید رسوب آبکندهای این منطقه در مقیاس رگبار انجام پذیرفته است. برای این منظور ۴۸ آبکند در سه حوزه آبخیز کوچک در استان های ایلام و لرستان (درّه شهر و عباس آباد در استان ایلام و هلوش در استان لرستان) و وضعیت فرسایش آبکندی در آن ها مورد پایش قرار گرفت. مقدار حجم فرسایش آبکندی از آن ها قبل و بعد از ۵ رگبار در حوزه های دره شهر و عباس آباد و ۶ رگبار در حوزه هلوش در سال‌های ۱۳۸۴ تا ۱۳۸۶ برآورد گردید. میزان تولید رسوب هر آبکند به ازای رگبارها محاسبه گردید. نتایج بدست آمده از تحقیق نشان داد که حداقل و حداکثر حجم فرسایش آبکندی از آبکندهای مطالعاتی به ازای هر میلی متر بارش ۰/۰۰۲ و ۱/۰۱۰ متر مکعب بوده است. هم چنین نتایج تحقیق نشان داد که در مناطق غربی ایران خصوصیاتی مثل مقدار رطوبت موجود در خاک، درصد سیلت و رس، مقدار و شدت بارش و مساحت حوزه زهکشی آبکندها بر گسترش و تولید رسوب آبکندها تاثیر دارند.

کلمات کلیدی: ایلام، تولید رسوب، غرب ایران، فرسایش آبکندی، فرسایش ناشی از رگبار، لرستان