DOI:10.18869/modares.Ecopersia.4.2.1395 **2016, 4 (2): 1395-1409**

Soil Erosion under Simulated Rainfall in Loess Lands with Emphasis on Land-Use, Slope and Aspect

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Received: 12 April 2016 / Accepted: 22 June 2016 / Published Online: 1 July 2016

ABSTRACT The runoff generation and soil erosion in the Kechik Watershed, Golestan Province, was assessed, using a designed and constructed portable rainfall simulator. Treatments were applied on different land-uses, slopes and aspects as the most influential factors. Results showed that land-use significantly affected runoff generation (13.35 l, 6.9 l, and 4.12 l, respectively for agriculture, forest and rangeland uses), however slope (7.7 l for Class I; 9.23 l for Class II) and aspect (8.52 l for the northern aspects; 8.32 l for the southern aspects) did not have significant influence. All factors, significantly altered sediment concentration (Agriculture 9.6 g l^{-1}, forest 8.24 g l^{-1}, and rangeland 5.26 g l^{-1}; slope class I 6.6 g l^{-1} and slope class II 8.7 g l^{-1}; northern aspect 8.7 g l^{-1}, and southern aspect 6.9 g l^{-1}). Agricultural fields generated the highest runoff and sediment under simulated rainfalls. Rangeland and forest did not have significant runoff generation and sediment concentration. Results showed that land-use management, especially in terms of agriculture, could not only hamper current erosion, but reduced further advancement of this encroaching phenomenon.

Key words: *Golestan Province, Land conversion, Rainfall simulator, Runoff generation, Soil loss*

1 INTRODUCTION

Soil is fundamental for many ecosystem functions that directly affects human food production and hence survival. Therefore, the preservation or improvement of this resource should be considered in its utmost level (Zachar, 2011; Adugna *et al*., 2015). Despite its importance, poor management and indiscriminate intentional or unintentional utilizations, constantly challenge the ability of soil to provide its critical functions. Human living affects soil and its consequences embrace the way human being lives (Smith *et al*., 2015).

The human impact on the soil can be caused by the type of its application for different purposes, which is generally known as the land-use, which is defined as "the planning to the allocation of activities to land areas to benefit human" (LUP, 1975). Failure to comply intended land-use with the underlying soil or

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intense pressure fromland-uses on soil and its components, lead to severe soil degradation in the form of pollution (industrial pollution, salinization of land, sealing) and erosion (by water and wind). This incompatibility also facilitates the conversion of rainfall into runoff which simply manifests itself in terms of soil erosion and nutrient loss (Kosmas *et al*., 1997; Fu *et al*., 2002; Schmidt, 2013).

Soil conservation and planning, as defined by Morgan (2009), requires understanding the processes and the extent of erosion (Hashim *et al*., 1995), which involve a combination of various agents affecting this phenomenon. This makes understanding the nature and causes of soil erosion under natural condition difficult. Therefore, simplification of the experimental conditions becomes an essential part of this understanding (Vahabi and Nikkami, 2008).

Rain simulators involving interactions of rainwater with soils have become common tool for studying hydrologic processes that also involve soil erosion, overland flow generation, and infiltration (Lora *et al*., 2016), and various researchers have attempted to build and test a variety of rain simulator devices (e.g., Arabkhedri *et al*., 2008). Although rainfall simulation in the soil erosion assessment has a fairly short history, several articles have been published in this area. For instance, soil infiltration rate under various conditions (Cerdà, 1997a; Cerdà, 1998b),the effect of land-use and precipitation on runoff and sediment yield (Kosmas *et al*., 1997; Sadeghi *et al*., 2006, 2011; Soleimankhani *et al*., 2014), the impact of various factors on soil erosion (Cerdà, 1998a; Bakhshi Tiregani *et al*., 2011; Cerdà and Jurgensen, 2011; Moreno-Ramón *et al*., 2014; Khaledi Darvishan *et al*., 2015; Rodrigo Comino *et al*., 2016), andeffects of various factors on soil nutrient loss (Aghabeigi Amin *et al*., (2014).

Loess soil, covering almost all the study area, is believed to be among the most fertile soils (Vitharana *et al*., 2008), but improper land-uses and ground cover conversions in recent decades have resulted in severe soil degradation and erosion in the area (Niknahad Gharmakher and Maramaei, 2011). Harnessing erosion, devising mitigating measures and proper management of the natural resources demand accurate measurement of erosion rate and runoff production. The latter parameters are under the influence of a multitude of factors, among which land-use, slope gradient and aspect are the most significant. Thus, the primary objective of this study was the assessment of the effect of different land-uses, slope classes and directions on runoff generation and sediment concentration by means of the BSTF1 rain simulator device designed by the authors, at the Gorgan University of Agricultural Sciences and Natural Resources.

2 MATERIALS AND METHODS

2.1 Study area

Enclosing an area of about 3600 ha, the Kechik watershed (55º 52´ 10″ to 55º 57´ 10″E and 37º42´ 15″ to 37º 46´ 15″N) is one of the sub-units of Qarnaveh basin of the Maraveh Tappeh district, Kalaleh County, in the farthest end of the Golestan Province (Figure 1). The annual precipitation in the area ranges from 300 to 700 mm, mainly in the winter. Based on the records of the adjacent rain gauge stations (Maraveh Tappeh and Golidagh, respectively at the distances of 7 and 9 km from the center of the study area), the average rainfall intensity during the study period (summer) reached 80 $mm.h^{-1}$ on 30 min durations. Slope of the area varies between 10 to 90%, however mainly distributed in the 0-15% and 15-30% classes.

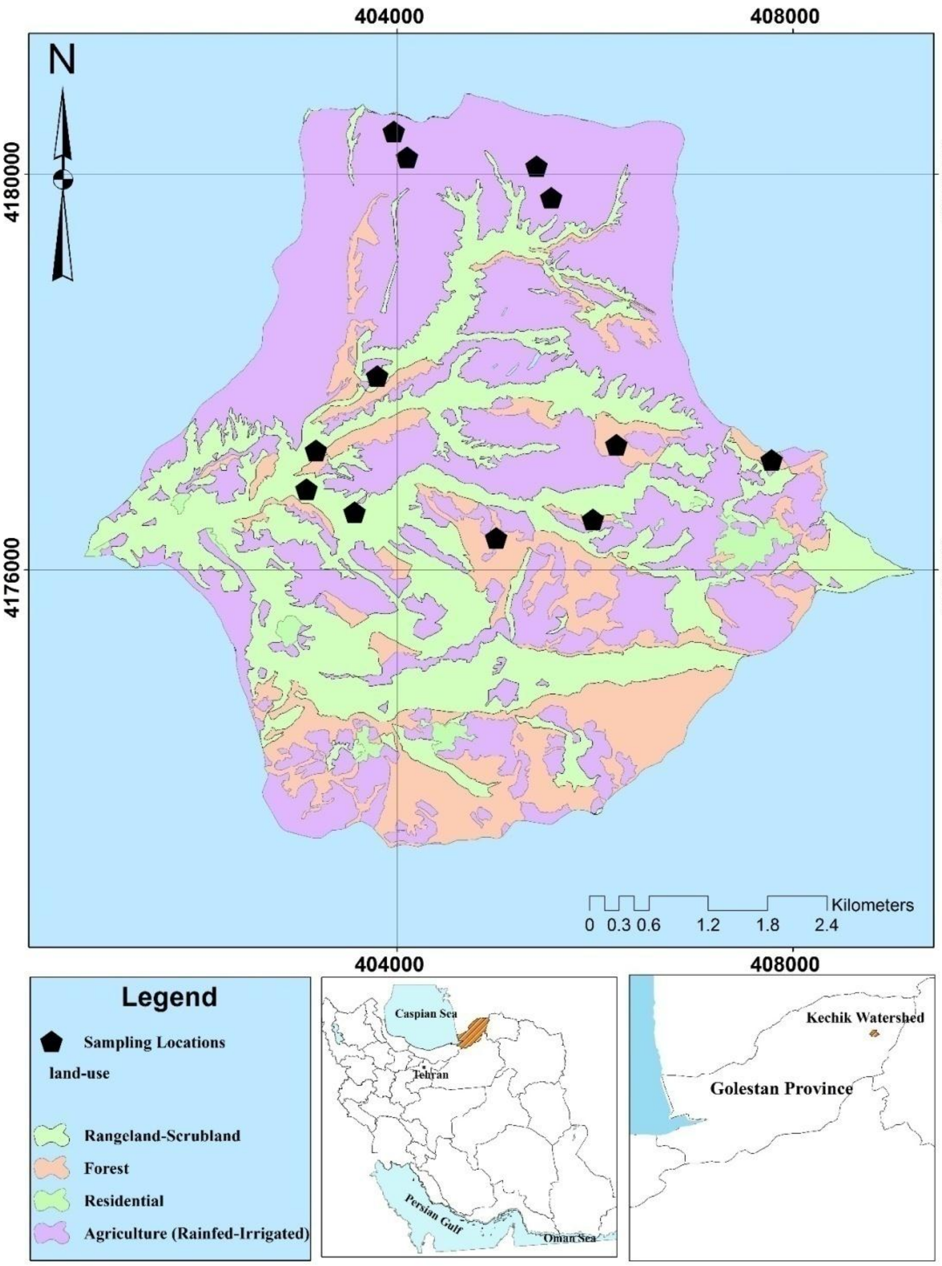

Figure 1 Sampling locations along with different land-uses (above& lower left), location the study area (Kechik watershed) within Golestan Province (lower right) and within Iran (lower-middle)

The Kechik watershed is characterized by various land-uses (Figure 1) and a very fertile soil that has undergone heavy agricultural activities in recent decades (Niknahad Gharmakher and Maramaei, 2011). Major crops are wheat and canola during autumn to spring, while melons and watermelons are sown during summer. Almost all fertile lands are plowed for cropping, which has shrunk forests only to small patches in higher slopes where it is not

[DOR: 20.1001.1.23222700.2016.4.2.5.8]

possible for agricultural machineries to reach. Other patches of forest are found in the locally protected areas. Pinewoodlands are found in some areas which are the remnant of the past afforestation projects. Rangelands are mostly found on steep and impassable slopes overlooking the valleys**.**

2.2 Land-use map

Landsat images were used to extract land-use map of the area. This study applied supervised classification-maximum likelihood algorithm in ENVI to detect land-use, using multispectral satellite data from Landsat 7 for 2011. In order to randomly distribute rain simulations on the study area, Kechik watershed was classified into four major land cover/use classes, viz., agriculture, rangeland, settlements, and forest lands. Resultant land cover/land-use was produced in ArcGIS 10. Digital elevation map, with the resolution of 30 m, was also acquired from the ASTER GDEM NASA website to extract slope the maps of gradient and aspect for the area.

2.3 Sampling location

Sampling was conducted randomly in three land-uses, viz., agriculture, forest and rangeland. Two slope classes of 0-15% and 15-30% gradients were considered to evaluate the effect of slope on runoff generation and sediment loss. However, as no forest areas existed below 20% slope gradient, the classification for this case was adjusted to 0-20% and 20-40% to include forest patches. Two slope directions were evaluated, viz., the southern slope directions (either eastern or northern aspects), and the northern slope directions (either southern or western aspects). An overview of the slope and aspect map could be found in Figure 2.

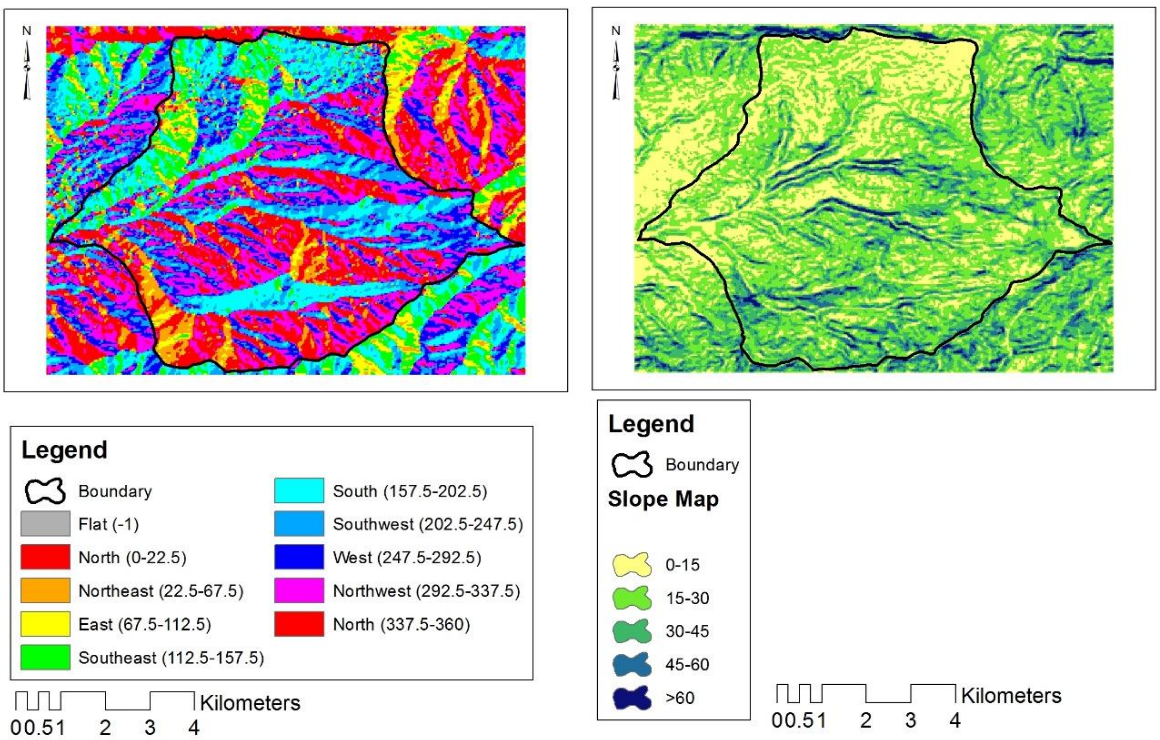

Figure 2 Slope direction map of the area (left), and slope gradient map (in percentage) (right)

2.4 Rain simulation

The device designed for this study, named BSTF1 (Figure 3), has the capability of simulating rainfall over a plot of 2m×1m and equipped with the spraying nozzle Vjet80100 that is widely used in rainfall simulators. In order to reach a suitable raindrop diameter, a height of fall of about 2.2 m was considered to reach terminal velocity similar to natural condition. Raindrops are produced through the reciprocation of the two nozzles via two special rotors. Rainfall evenness was tested in the laboratory environment via small cups distributed along the virtual plot and there was no overlapping in the range of the two nozzles.

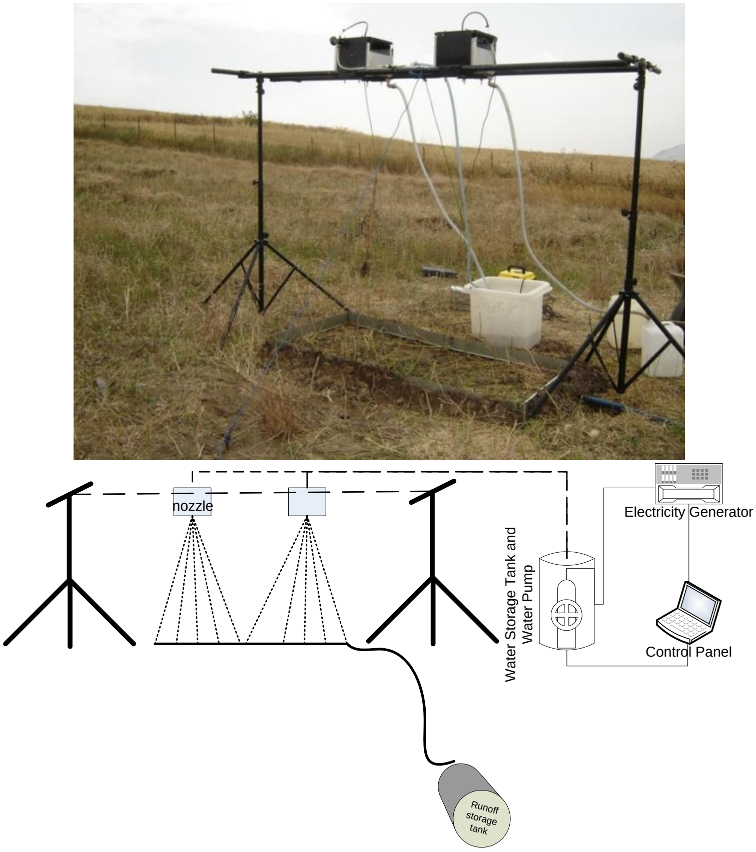

Figure 3 View of the BSTF1: the actual device (above), and the general structure (below)

2.5 Experimental set-up

Based on the rainfall distribution records in the region (Maraveh Tappeh and Golidagh stations), a high-frequency simulated rainfall with an intensity of 80 mm $h^{-1}$for a 30-min duration was selected. The observed data series were generated by applying a fully randomized design with two repetitions per land-use, slope gradient and direction. Thus, a total of 24 rainfall simulations were carried out during a two weeks period (from June to September, 2015) on rectangular experimental plots (2m×1m). Test plots were aligned parallel to the slope with the longest aspect running down. Other co-variables such as near-saturated infiltration, vegetation density, initial moisture, soil texture, surface gravel percentage, etc., were also recorded for each plot. The total runoff volume and runoff initiation time were recorded by means of a graded cylinder and a stopwatch. Collected runoff was then thoroughly mixed, poured into two 1.5 L bottles, then transferred to the lab and left to settle for 48 hours, then filtered with the Whatman 40 filter papers. The filtrates were dried up in the oven for 24 hours and weighed. Data analysis was carried out in the form of factorial ANOVA using R software. This test requires the satisfaction of two primary conditions, viz., normal distribution of parameters, and homogeneity of variance. The first criterion was tested by the Shapiro-Wilk test, and the homogeneity was confirmed according to the Levene's test.

3 RESULTS

Table 1 shows the average values of the main physical properties of the soil for each of the three land-uses. Out of 24 experimental plots, three simulations did not produce runoff. The agricultural land-use produced higher volumes of runoff and greater sediment. Rainfall simulations, in case of the forest land-use, were carried out in the understory covers in open-canopy forest. Runoff generation in the forest was higher than that of the rangeland, but no significant difference was observed for the sediment concentration. Moisture content, measured in the top-five centimeter of the soil profile, was significantly low, which was due to harsh, dry and hot conditions of the area during the sampling period. Vegetation cover in the forest and rangeland areas was greater than that of the agriculture, but no significant changes occurred in the surface litter cover. Since, subsequent to the harvest period and prior to the next sowing time (early season canola is followed by growing cucurbits), remarkable volumes of crop residues remained on the surface, no remarkable differences existed in this term between the land-uses. A longer runoff initiation time was observed in the rangeland, followed by the forest. On the other hand, infiltration rate, measured through the application of the double-ring method, was significantly lower in the agricultural areas than the other two land-uses.

Table 1 Physical parameters in three land-uses of agriculture, forest and rangeland

Land-Use	Vegetation cover (%)	Litter (%)	Infiltration (mmh^{-1})	Initial moisture (%)	Time to runoff (min)	Runoff Volume (l)	Sediment concentration ($gr\ l^{-1}$)
Agriculture	6.9	20.0	4.4	4.7	11.1	13.4	9.7
Forest	66.7	18.3	6.15	4.1	13.3	7.0	5.9
Rangeland	37.9	29.3	7.58	3.9	18.3	4.1	5.3

The results of one-way ANOVA for the effects of land-use, slope and aspect on the total runoff generation and sediment concentration revealed only the land-use had significant influence on the runoff generation (Table 2), but all the three factors had significant effects on the sediment concentration, and the higher values of runoff generation did not necessarily result in higher sediment concentration.

[DOR: 20.1001.1.23222700.2016.4.2.5.8]

Table 2 One-Way ANOVA for the effects of land-use, slope and aspect on the runoff and sediment concentration under simulated rainfall

	df	SS	MS	F-value	p-value	Sig.
Runoff generation						
Land-Use	2	305.80	152.94	11.8	0.005	**
Slope	1	4.57	4.57	0.35	0.57	ns
Aspect	1	9.33	9.33	0.72	0.42	ns
Sediment concentration						
Land-Use	2	69.69	34.84	8.21	0.014	*
Slope	1	29.10	29.10	6.86	0.034	*
Aspect	1	37.81	37.81	8.91	0.020	*

The greatest runoff and sediment concentration occurred in the agricultural land-use, followed by forest and rangeland (Figure 4). Slope classes were classified into two categories of 0-15% and 15-30% gradients, with the exception of forest land-use which was only observed in higher slope levels. Although the runoff volume was larger in 20-40 and 15-30% slopes, the changes were not significant (Figure 5). Yet, higher slope gradients experienced significantly higher sediment concentration (measured in terms of averaged grams per liter per rainfall event). As for the two aspects (Figure 6), no significant changes in the total runoff and sediment concentration were detected in the northern and southern aspects (northern aspect covered north-western to north-eastern slope directions, while southern aspect included south-western to south eastern aspects).

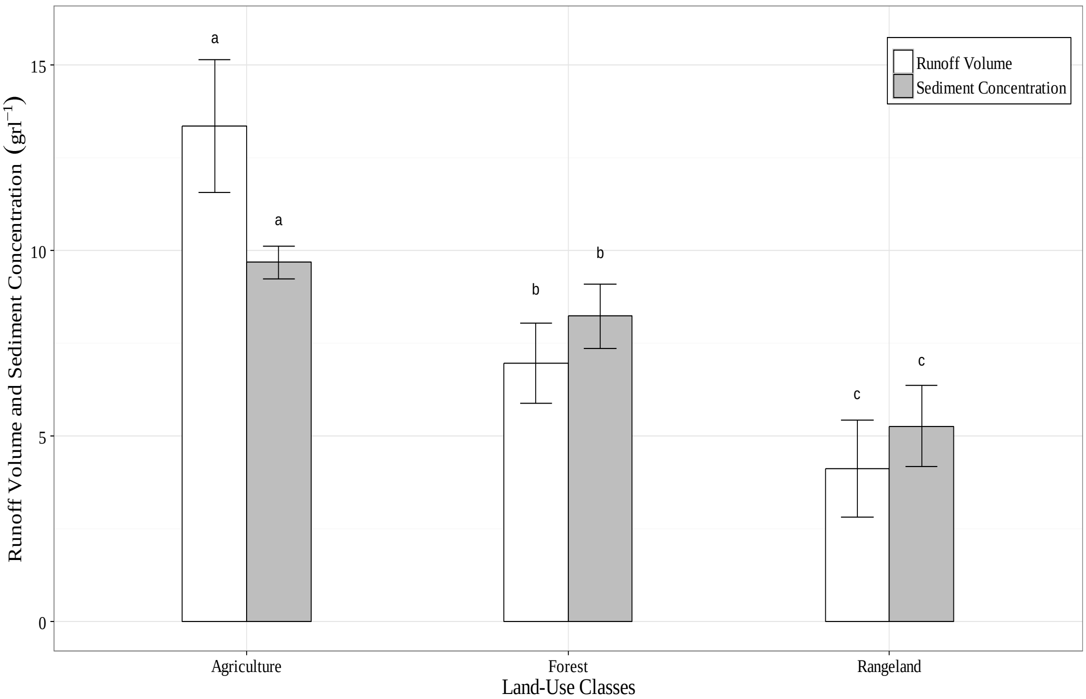

Figure 4 Effect of land-use on total runoff volume (l) and seiment concentration (gr l^{-1})

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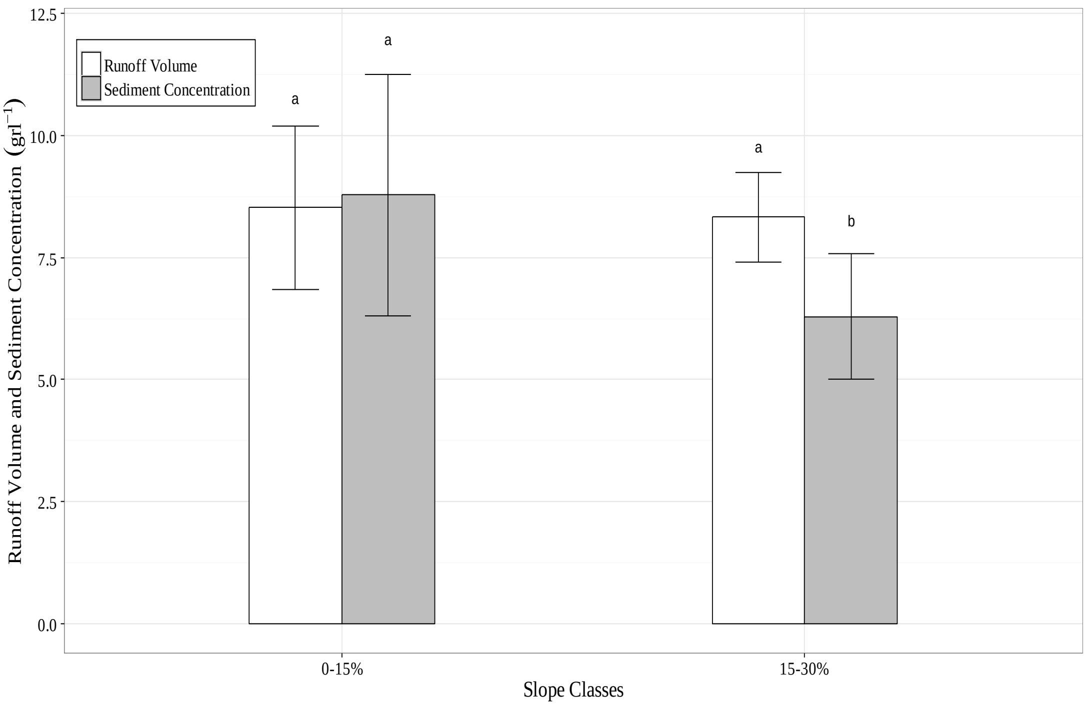

Figure 5 Effect of slope on total runoff volume (l) and sediment concentration (gr l^{-1})

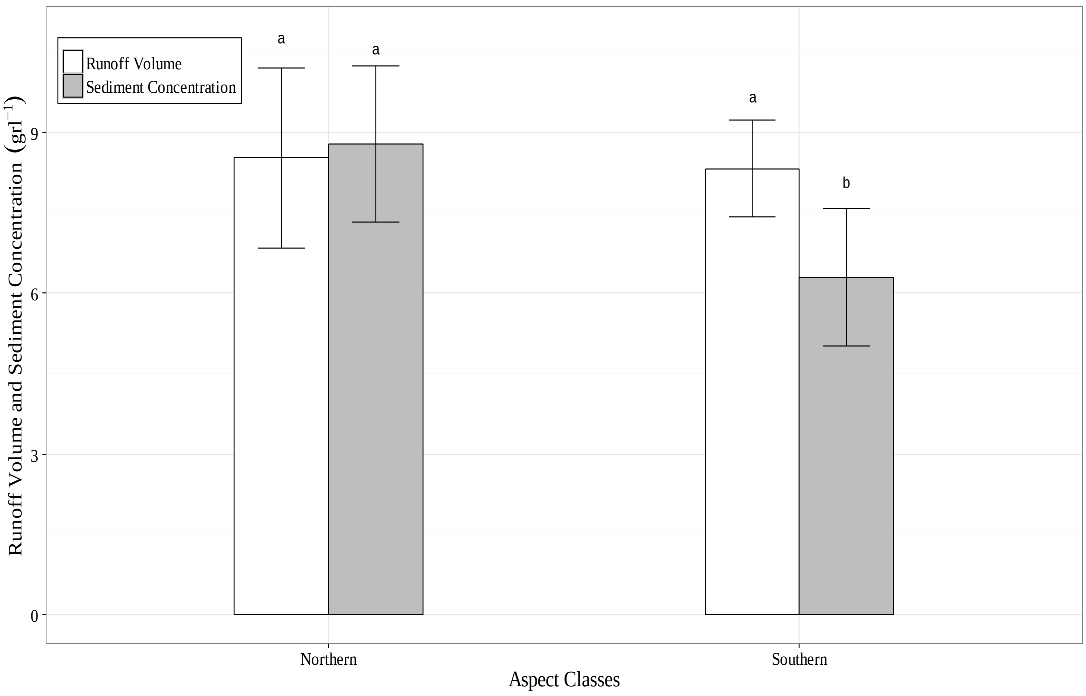

Figure 6 Effect of aspect on total runoff volume (l) and sediment concentration (gr l^{-1})

Runoff volume, measured every 5 min during experiments, in different land-uses, slopes, and aspects slightly increased until soil saturation or sealing of the upper soil profile occurred (Figure 7), at which point the runoff generation sharply increased (Figure 7A). Higher slope gradient encouraged more runoff. Although it seems a lag time of 10 minutes holds for the initiation of runoff surge, the sharp increase in the accumulative runoff in the higher slope gradient outruns that of the lower gradient (Figure 7B). Slope direction also resulted in different runoff generation regime, although neither slope nor aspect significantly affected the total runoff volume. Nevertheless, a noticeable shift in runoff generation was observed for the southern aspect somewhere around the lag time of 15 minutes (Figure 7C).The recent lag time was also observed for the other cases of slope and land-use classes.

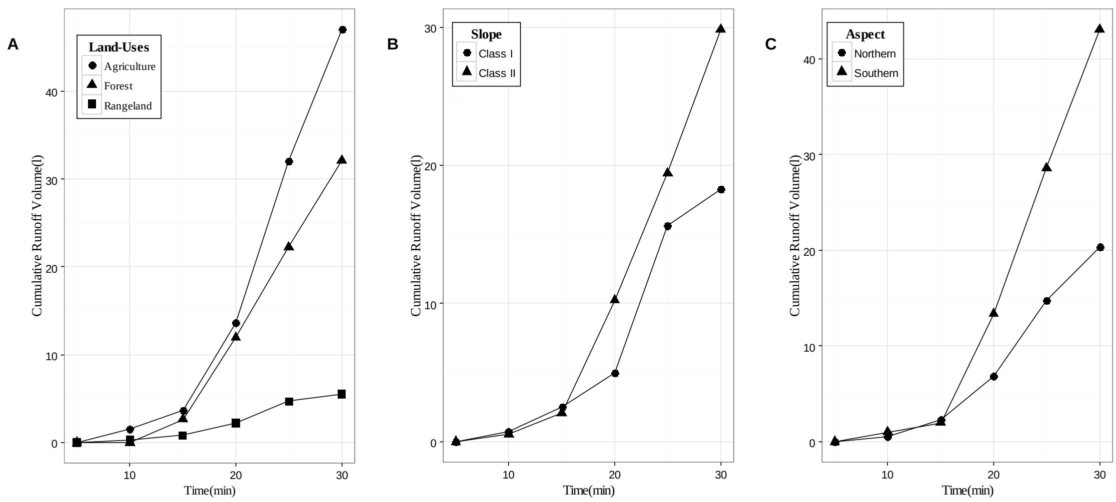

Figure7 Runoff generation in different land-uses, slope classes and aspects

4 DISCUSSION

This study was performed to evaluate the role of various types of land-uses, slope gradients and aspects in runoff generation and sediment concentration.

4.1 Effect of land-use on runoff and sediment yield

Runoff generation and sediment loss were higher for agricultural land-use compared to rangeland and forest, which is in correspondence with the findings of Wei *et al*. (2007) who found runoff coefficient and erosion among the five land-uses as: cropland > pastureland > woodland > grassland >shrubland. García-Ruiz (2010) also argued that land cover conversion into orchards or other crops could result in a higher runoff and sediment loss. Ziadat and Taimeh (2013) have shown significant influence of cultivating the land on soil erosion. Next to agricultural land-use, the highest runoff and sediment loss occurred in forest plots. Unlike rangeland, under-canopy in forest areas was covered by broad-leave plants which resulted in more runoff generation and quicker surge in runoff compared with rangeland plots. In contrast, Li *et al*. (2014) stated that under canopy vegetation patches could significantly reduce runoff and sediment production under heavy rainshowers.

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The effect of land-use in different forms on runoff generation and sediment loss has been well documented (Cerdà, 1997b;Bakhshi Tiregani *et al*., 2011; Soleimankhani *et al*., 2014). The higher runoff generation and sediment concentration in agricultural fields are mainly due to the type of land management and soil cover. In this scheme, post-harvest activities and land preparation for summer sowings could expose the soil to erosive summer rain showers. Although in most cases an amount of crop residues still remains on the ground between the two phases, soil disturbance by plowing buries the residues underground which further renders soil surface vulnerable. Along with land management, Laflen and Colvin (1981) believe that slope and soil characteristics along with crop residues are responsible for the recorded soil erosion and runoff volume.

As with the rangeland, dense-dried-grass cover with intense root networks caused more water penetration, which also resulted in comparatively less sediment concentration. Cerdà (1998a) and Reid *et al*. (1999) have also reported the role of vegetation cover in reducing runoff and sediment. As shown in this study, the processes of runoff and soil loss are complicated and uncertain with the interaction of rainfall and land-use. This is mainly due to the different stages of vegetation succession and soil surface characteristics. For instance, Giménez-Morera *et al*. (2010) argued that the nature of the soil protective layer (in this case cotton geo-textile) could affect runoff and sediment production in different manners. In their study, it was observed that dry cotton layer acted differently from the wet, and hence, result in more runoff generation and less sediment. Cerdà (1997a) and Cerdà and Doerr (2007) also evaluated the effect of soil surface dryness during the summer period and found that land-uses with bare soil surface had higher water repellency which resulted in higher runoff generation and soil erosion.

4.2Effect of slope gradient on runoff generation and soil loss

On steep slopes no external force is needed to set loosened detritus in motion (Zachar 2011). Although runoff from higher slope gradient seemed larger than that of the lower gradient, this study found no significant changes in the total runoff. Contrary to the finding of this study, Cerdà (1998a), Bakhshi Tiregani *et al*. (2011), Sajjadi and Mahmoodabadi (2015), and Khaledi Darvishan *et al*. (2015) believe slope gradient to be significantly effective in enhancing runoff generation and sediment loss. On the other hand, slope with higher gradient showed a quick surge in runoff generation in the time lag of 15 minutes forward, compared with the lower gradient slope. Soil particle loss through sediments in high gradient slope was significantly larger. The total runoff volume did not alter significantly between the two slope classes, which was largely due to the effect of runoff kinetic energy in the higher slope gradients. Bakhshi Tiregani *et al*. (2011) found no meaningful effect of slope gradient on runoff volume, but Ziadat and Taimeh (2013) believed that soil erosion on uncultivated land was mostly affected by slope steepness, while on cultivated land, it was primarily affected by moisture content. On the other hand, Assouline and Ben-Hur (2006) stated that soil erosion during rainfall was strongly affected by runoff and slope steepness. Runoff generation was drastically increased when a seal was formed at the soil surface during rainfall. Sajjadi and Mahmoodabadi (2015) revealed the importance of rain intensity, slope steepness and soil aggregate size on aggregate breakdown and seal formation, which could control infiltration rate and the consequent runoff and erosion rates. Meaningful effect of slope on runoff and sediment was also reported by Aghabeigi Amin *et al*. (2014).

4.3 Effect of aspect on runoff generation and soil loss

Slope direction did not significantly alter the total runoff volume and sediment, which was in contrast to the findings of Cerdà (1997b), Cerdà (1998a), and Khaledi Darvishan *et al*. (2015), but consistent with Bakhshi Tiregani *et al*. (2011) and Aghabeigi Amin *et al*. (2014).

Runoff in the northern aspect from the lag time of 15 minutes surged sharply compared to the southern aspect. Slope gradient and vegetation cover didn't significantly differ between the slope directions. Average slope gradient was 27% in the northern aspects and23% in the southern aspects. Vegetation cover in the northern aspect reached 37% compared to 22% in the southern aspects. No significant soil moisture changes were also observed between the two slope directions. Vaezi *et al*. (2016) believe that soil texture and moisture conditions are the most significant determiners of soil erodability in semi-arid areas which is not compatible with the result of this study. However, Cerdà (1998b) supports our finding given that soil initial moisture is not the only determiner of runoff generation and sedimentation as he observed less runoff in wet soils with high infiltration rate. On the contrary, Khaledi Darvishan *et al*. (2015) found significant relationship between runoff initiation and threshold and soil precedent moisture content. Agassi *et al*. (1990) concluded that slope steepness and facing affect runoff generation and soil loss.

Near saturated infiltration rate in the northern aspect averaged about 5.91 mm hr^{-1}, which didn't show significant shift from 6.11 mm hr^{-1} in the southern aspect. Given that the total runoff generation didn't differ between the two, the higher sediment loss from the northern aspect might pertain to the higher slope gradient. In this regard, Cerdà (1999) found greater steady state infiltration rates and faster runoff in slopes than in pediments. Eshghizadeh *et al*. (2016) argue that no significant difference existed between different slope, aspect and soil textures in terms of runoff and soil loss, but they found a significant difference for runoff generation and sediment yield between various land covers. Yet, Seutloali and Beckedahl (2015) in their work found that widths and depths of the rill erosion increased with the increase in slope gradient and decreased with an increase in percentage of vegetation cover, which was in agreement with the findings of this study.

5 CONCLUSION

The volumes of runoff and soil loss in different land-uses were statistically different, with the highest runoff in agricultural fields and the lowest in rangelands. This also holds for sediment concentration for agricultural plots compared to the other land management schemes. In general, it can be stated that in the study area, management of the agricultural fields has a tremendous capability in reducing soil loss and erosion (given improper cultivation principles and utilization of unsuitable slopes for this purpose). This study shows that management of land-uses, especially in higher slope gradients can decrease erosion meaningfully. It is highly recommended to evaluate the impact of other factors on soil erosion using the reliable rainfall simulation technique, given its great applicability and flexibility in erosion assessment studies.

5 ACKNOWLEDGEMENT

This study has been part of research project, funded by the Gorgan University of Agricultural Sciences and Natural Resources, NO 91-306-59. We thank our colleagues from the Department of Watershed Management who provided insight and expertise that greatly assisted this research.

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[DOR: 20.1001.1.23222700.2016.4.2.5.8]

فرسایش خاک تحت بارش شبیه‌سازی شده با تأکید بر کاربری اراضی، شیب و جهت

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تاریخ دریافت: ۲۴ فروردین ۱۳۹۵ / تاریخ پذیرش: ۲ تیر ۱۳۹۵ / تاریخ چاپ:۱۱ تیر ۱۳۹۵

چکیدهتولید رواناب و فرسایش خاک در در کاربری‌های مختلف اراضی، شیب و جهت جغرافیایی (سه عامل اصلی در فرسایش)، با استفاده از دستگاه باران‌ساز طراحی شده و قابل حمل انجام شد. نتایج بیانگر تأثیر معنی‌دار کاربری اراضی بر تولید رواناب بود (۱۳/۳۵ لیتر، ۶/۹ لیتر، و ۴/۱۲ لیتر در کاربری های کشاورزی، جنگل و مرتع)، در حالی‌که شیب (به میزان ۷/۷ لیتر در کلاس ۱ و ۹/۲۳ لیتر در کلاس ۲) و جهت (به میزان ۸/۵۲ لیتر در شیب شمالی و ۸/۳۲ در شیب جنوبی) اثر معنی‌داری نداشتند. از طرف دیگر، تمام عوامل بر بار رسوب تأثیر معنی‌داری داشتند (کشاورزی ۹/۶، جنگل ۸/۲۴ و مرتع ۵/۲۶ گرم بر لیتر؛ شیب ۱ و ۲ به ترتیب ۶/۶ و ۸/۷ گرم بر لیتر؛ جهت شمالی و جنوبی ۸/۷ و ۶/۹ گرم بر لیتر). اراضی کشاورزی بیش‌ترین تولید رواناب و رسوب را تحت بارش شبیه‌سازی شده به خود اختصاص دادند. کاربری جنگل و مرتع نیز در مقایسه با کشاورزی، تأثیر معنی‌داری بر رسوب و رواناب تولیدی نداشتند. نتیجه اصلی این تحقیق آن است که با افزایش تمرکز بر اراضی کشاورزی و ممانعت از تغییر کاربری می‌توان فرسایش را در برهه فعلی مهار کرد و از پیشرفت آن جلوگیری نمود.

کلمات کلیدی:تبدیل اراضی، شبیه ساز باران، تولید رواناب، هدررفت خاک، گلستان