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ORIGINAL RESEARCH PAPER

# Effect of natural land covers on runoff and soil loss at the hill-slope scale

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**ABSTRACT:** Erosion plots were selected for characterizing the effects of main natural factors on runoff and soil loss in a semi-arid region. These erosion plots with an area of 40 $m^2$ are located in the Kakhk experimental watershed in Gonabad County of Khorasan-e Razave Province in the north-eastern Iran. Data acquired from 2008 to 2015 include slope, aspect, soil texture and land covers (canopy and litter) factors that were selected as main natural factors and it was tried to determine the effects of these factors on runoff and soil loss amount. In the next stage, it was focused on evaluation of the effects of land covers on runoff generation and soil loss in more details. For this purpose, in each class of the mentioned factors, the relationship between land covers and runoff and soil loss was analysed. The maximum of runoff and soil loss were occurred at E site with the amount of 15.6 mm and 140 g/$m^2$ respectively. Results showed that soil loss and runoff have decreased where the amounts of land covers have increased, and the line gradient is steeper for soil loss reduction than runoff generation. The result especially characterized the role of land covers on soil loss. Based on these results land covers have a significant effect on soil loss but this effect is mostly highlighted in the highest and lowest conditions of erosion potential, rather than the medium erosion potential condition. Furthermore, in each plot and event, a dominant factor determines the quantity of the effect of land cover on runoff and soil loss.

**KEYWORDS:** *Canopy; Erosion; Litter; Plot; Runoff; Vegetation*

## INTRODUCTION

The runoff generation and soil loss processes in semi-arid regions are complex (Parsons, *et al*., 1997; Bracken and Kirkby, 2005). Researchers have tried to describe the global pattern of soil loss in terms of climatic factors (Cerdà, 1998), effect of relief and elevation of catchment (Milliman and Syvitski, 1992; Summerfield and Hulton, 1994; Cerdà 1998), and vegetation controlled by climate and land use (Verstraeten and Poesen, 2001; Cerdà and Doerr, 2007). In general, the plot studies area part of wide research projects that aim at an enhanced understanding of reciprocal relations between the processes including hydrological, climatic and biological factors (Wainwright *et al*., 2000). The plot-scale studies can provide information regarding the runoff, soil loss and land cover changes processes (Abrahams *et al*., 1998; Parsons *et al*., 1998).

The hydrological processes of a hill-slope are usually determined by vegetation, topography and soil characteristics (Breedlow *et al*., 1998; Pellant *et al*., 2005). These processes are also dependent on slope and aspect of the hilly terrain. Fox *et al*., (1997) found that infiltration had been lower with increasing slope gradients as a result of more rapid runoff velocities. The runoff generation and soil loss in semi-arid regions

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are affected by non-linear and complex interdependency among rainfall properties, soil moisture content and vegetation characteristics (Beven, 2002). The vegetation, topography and soil properties are closely associated with infiltration, runoff and soil loss (Wilcox, *et al*., 1988; Truman, *et al*., 2001; Wilcox, *et al*., 2006). Increasing the vegetation has been widely encouraged for its multiple benefits, such as soil loss control, runoff and sediment reduction, as well as hydrological regime regulation (Yu *et al*., 2013). The litter, roots and canopy of vegetation are believed to affect the soil loss process. They impede crust formation, leading to an increase in the amount of interception, a decrease in raindrop impact, and an increase in the soil's ability to absorb rain (Dunin, 1976). The role of vegetation can be summarized into reducing water runoff and increasing soil inûltration (Naylor *et al*., 2002; Wainwright and Parsons, 2002; Rey, 2003; Puigdefabregas 2005; Durán *et al*., 2006; Durán, *et al*., 2008). Vegetation cover decreases runoff generation by increasing the surface roughness and soil pore spaces (Li, *et al*., 1992). Also plants stabilize the soil with their roots (Gyssels, *et al*., 2005; De Baets *et al*., 2007a, b) and decrease the energy of raindrops with their canopy (Bochet *et al*., 1998; Durán *et al*., 2008). Moreover vegetation creates a physical barrier that it can hold sediment on the soil (Van Dijk, *et al*., 1996; Lee, *et al*., 2000; Martínez, *et al*., 2006). Increasing the amount of vegetation can be lead to runoff generation and erosion control (Zhou and Shangguan, 2007; Durán and Rodríguez, 2008; Michaelides *et al*., 2009; Cantón, *et al*., 2011). Holiûeld Collins *et al., (*2015) showed that the runoff and sediment yield were correlated with canopy. Kateb *et al.,* (2013) demonstrated that the amount of erosion is considerably influenced by changes in vegetation cover. Zhao *et al.,* (2013) showed that runoff and sediment yields were meaningfully influenced by vegetation cover.

This paper is based on the fieldwork and statistical tests on data that provided by continuous monitoring and recording of rainfall-runoff-sediment production field monitoring data at plot-scale. The objectives of this research is characterising the effects of main natural factors on runoff and soil loss by considering main natural factors such as slope, aspect, soil texture and land covers (canopy and litter). Moreover, the existence of the threshold for the amount of land cover was investigated as it can strongly reduce the amount of erosion and runoff. For this purpose the present study was focused on the effect of land covers (canopy and litter) on runoff generation and soil loss in more details. This study has been performed in Gonabad County of the Khorasan-e Razave Province, northeast of Iran during 2008 to 2015.

## MATERIALS AND METHODS

### *Study area*

The study area was located in Gonabad County of the Khorasan-e Razave Province, northeast of Iran (Lat 34°4'34" N, Long 58°35'37" E). The studied area is known as Kakhk experimental watershed. Kakhk experimental watershed is a national project of the Forests, Ranges and Watershed Management Organization of ministry of Jihade agriculture. In this project is evaluating the main factors affecting runoff, erosion and sedimentation are evaluated. These factors are erosion, sedimentation, hydrology, vegetation, infiltration and meteorological parameters. Installing the equipment and measuring started in 1998 and completed in October 2000. But regular collection of meteorological digital data are available since 2006, and other data such as hydrometry, erosion and sedimentation data have been recorded since 2008 (Forests, Range and Watershed Management Organization, 2012).

Kakhk experimental watershed includeds two sub-catchments. These sub-catchments are almost similar in all aspects and differed only based on watershed management practices implemented since 1998. One of the sub-catchments is called sample sub-catchment in which watershed management practices (mechanical, biomechanical, biological, and management) have been implemented on this one. The other sub-catchment called control sub-catchment in which no watershed management operations have been performed on it. Location of the studied area is shown in Fig. 1. Table 1 demonstrates physical characteristics of the sub-catchments (Eshghizadeh *et al.,* 2015).

### *Field installation*

The field studies were carried out using a 40 $m^2$ plots inthe Kakhk experimental watershed. In each sub-catchment, nine experimental erosion plots were established on three sites. The plots that were studied under natural rainfall events were 22.1 × 1.8 m. They

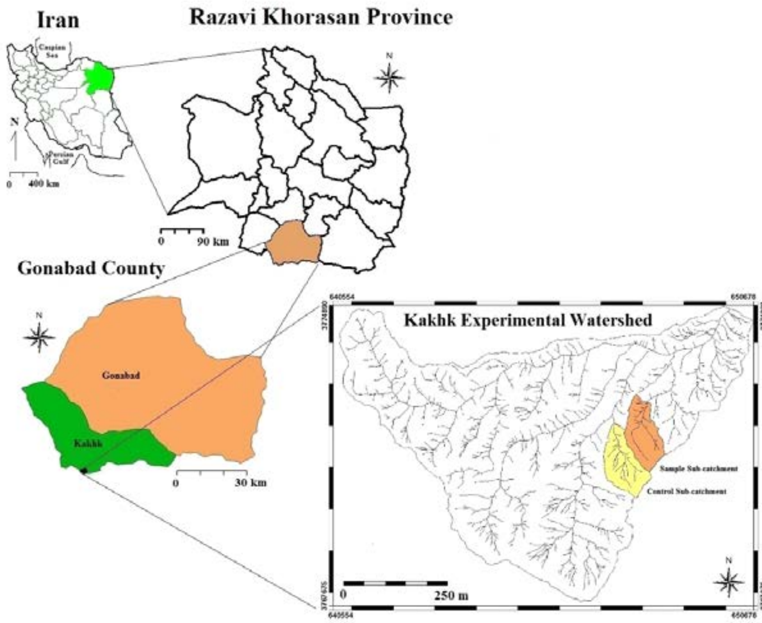


Fig. 1: Location of the study area

Table 1: Physical characteristics of the control and sample sub-catchments

| Characteristic | sub-catchments | |
|---|---|---|
| | Sub-catchment 1 (Sample) | Sub-catchment 2 (Control) |
| Area (km$^2$) | 1.065 | 1.106 |
| Perimeter (km) | 4.6 | 4.8 |
| Maximum altitude (m) above sea level | 2521 | 2623 |
| Minimum altitude (m) above sea level | 1997 | 2048 |
| Mean altitude (m) | 2171 | 2325 |
| Weighted average slope (%) | 52.9 | 55.4 |
| Main channel length (km) | 1.8 | 1.8 |
| Annual average precipitation (mm) | 243 | 243 |
| Distribution of rainfall (year) | Oct., Nov., Dec., Jan., Feb., Mar., Apr., May, Jun. (2008 – 2015) | |
| Mean annual temperature (ºc) | 14.2 | 14.2 |
| Annual evaporation (mm) | 1645 | 1645 |
| Climate condition | Semi-arid | Semi-arid |
| Dominant geological formations | Shemshak Js, Jsvb | Shemshak Js, Jsvb |
| Soil Texture | loamy sand, loamy | loamy sand, loamy |
| Dominant vegetation | Lactoca orientalis, Poa bulbosa, Seratulla orientalis, Ferula ovina- Gundelia tourneforti, Artemesia sp., Astragalus sp. | |

were established by a 0.2 m height surrounding cement and metal wall. The runoff and sediment load were directed into a tank with a capacity of 1 m$^3$ (Fig. 2). All 18 erosion plots were installed and equipped for determining the total runoff and total soil loss for each of the recorded precipitation events. Table 2 shows the characteristics of the erosion plots.

*Collection and analysis of data*

The study was carried out for natural rainfall events recorded from 2008 to 2015 (Table 3). At a later stage, runoff and soil loss were extracted from experimental erosion plots. For each of these rainfall events were calculated the volume of the total runoff and weight of the sediments which were collected from the surface

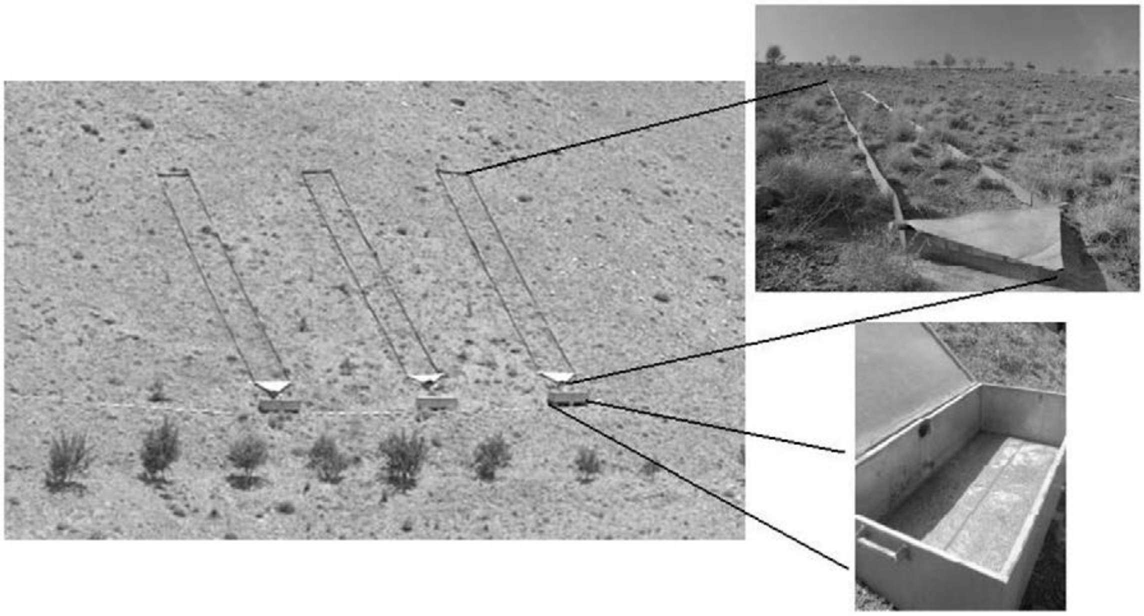

Fig. 2: Erosion plots established in Kakhk experimental watershed

Table 2: Physical characteristics of the installed erosion plots

| Site | Plot No. | Altitude (m) above sea level | Slope Aspect | Slope (%) | Mean infiltration Rate (mm/h.) | Soil Texture |
|---|---|---|---|---|---|---|
| A | 1<br>2<br>3 | 2065 | West | 37 | 3.3 | Sandy clay |
| B | 4<br>5<br>6 | 2112 | North | 45 | 3.1 | Sandy loam |
| C | 7<br>8<br>9 | 2115 | East | 60 | 3 | Sandy loam |
| D | 10<br>11<br>12 | 2160 | West | 54 | 3.2 | Sandy clay loam |
| E | 13<br>14<br>15 | 2105 | North | 37 | 2.3 | Sandy loam |
| F | 16<br>17<br>18 | 2085 | East | 45 | 2.8 | Sandy loam |

plots in the tanks. For the sediment content analysis conducted at each plot after each event, one litre of the sediment-water mixed was sampled and dried in an oven at 60ºC. The samples were then reweighed and the sediment concentration was determined for each sample. Also, in each event, the natural land covers of surface plots were calculated, which included canopy and litter. Table 4 shows the data obtained from rainfall events.

A statistical test was carried out significant difference analysis between classes of slope, aspect, soil texture and land covers (canopy and litter) factors and the produced runoff and soil loss. Than the significant difference analysis was calculated between land covers and runoff as well as land covers and soil loss, for the plots located in different classes of hill-slope steepness, slope aspect and soil texture. Table 5 shows the classes of factors used in this analysis.

## RESULTS AND DISCUSSION

Soil loss and runoff include a set of factors and processes that significantly influence the amount of the soil loss and runoff (Assouline and Ben-Hur, 2006; Leia *et al*., 2006). In this research, the maximum of runoff and soil loss have occurred at E site with amount of 15.6 mm and 140 g/$m^2$. Results showed thatsoil loss and runoffhave decreased with increase in amount of

Table 3: Characteristics of rainfall events (2008-2015)

| Event | Date event | Rainfall duration (h.) | Characteristics rainfall event | | |
|---|---|---|---|---|---|
| | | | Mean intensity (mm/h.) | Max intensity (mm/h.) | Total Precipitation (mm) |
| 1 | 31.Jan.2009 | 11 | 3.5 | 6 | 38.1 |
| 2 | 31.Mar.2009 | 16.5 | 6.7 | 127.2 | 110.1 |
| 3 | 11 April 2010 | 4 | 6.2 | 31.5 | 24.7 |
| 4 | 2 May 2011 | 4 | 3.7 | 38.4 | 14.7 |
| 5 | 2 February 2012 | 16 | 4 | 31.4 | 80.7 |
| 6 | 26 February 2012 | 18 | 3.3 | 33.3 | 60.1 |
| 7 | 17 April 2012 | 5 | 2.9 | 30 | 14.3 |
| 8 | 1.Feb.2013 | 10 | 13.3 | 15.7 | 40.5 |
| 9 | 4.Nov.2013 | 13 | 5.7 | 9.8 | 23.5 |
| 10 | 16.Mar.2014 | 19 | 3.7 | 6.1 | 22.8 |
| 11 | 5.Nov.2014 | 6.5 | 6.6 | 11 | 43.1 |
| 12 | 21.Feb.2015 | 18 | 5.7 | 15 | 100 |

Table 4: Mean data obtained from each site for rainfall events (2008-2015)

| Event | Characteristic | Site | | | | | |
|---|---|---|---|---|---|---|---|
| | | A | B | C | D | E | F |
| | Land covers (canopy and litter) (%) | 26 | 46 | 28 | 23 | 28 | 20 |
| 1 | Mean runoff depth (mm) | 2.2 | 8.6 | 11.9 | 3.4 | 4.3 | 8.5 |
| | Mean soil loss (g/$m^2$) | 0.1 | 0.1 | 0.4 | 0.3 | 0.4 | 0.2 |
| | Land covers (canopy and litter) (%) | 24 | 45 | 30 | 25 | 30 | 25 |
| 2 | Mean runoff depth (mm) | 5.9 | 6.8 | 5.4 | 2.9 | 5.9 | 7.8 |
| | Mean soil loss (g/$m^2$) | 0.2 | 0.2 | 0.5 | 0.2 | 0.4 | 0.8 |
| | Land covers (canopy and litter) (%) | 25 | 42 | 26 | 24 | 32 | 22 |
| 3 | Mean runoff depth (mm) | 4.4 | 5.2 | 4.0 | 5.4 | 3.8 | 6.4 |
| | Mean soil loss (g/$m^2$) | 0.2 | 0.3 | 0.2 | 0.3 | 0.1 | 0.2 |
| | Land covers (canopy and litter) (%) | 29 | 45 | 40 | 27 | 19 | 19 |
| 4 | Mean runoff depth (mm) | 4.6 | 4.0 | 8.4 | 4.9 | 6.7 | 9.4 |
| | Mean soil loss (g/$m^2$) | 2.2 | 2.4 | 3.1 | 4.9 | 10.1 | 13.1 |
| | Land covers (canopy and litter) (%) | 12 | 28 | 15 | 12 | 12 | 14 |
| 5 | Mean runoff depth (mm) | 7.1 | 14.5 | 5.1 | 13.3 | 15.8 | 11.9 |
| | Mean soil loss (g/$m^2$) | 2.9 | 18.8 | 4.0 | 14.8 | 140.3 | 11.3 |
| | Land covers (canopy and litter) (%) | 12 | 28 | 15 | 12 | 12 | 14 |
| 6 | Mean runoff depth (mm) | 2.4 | 4.8 | 1.9 | 5.2 | 5.2 | 5.3 |
| | Mean soil loss (g/$m^2$) | 1.0 | 6.3 | 1.4 | 6.0 | 46.8 | 3.2 |
| | Land covers (canopy and litter) (%) | 22 | 40 | 20 | 18 | 20 | 22 |
| 7 | Mean runoff depth (mm) | 1.5 | 1.1 | 1.0 | 1.4 | 2.6 | 1.9 |
| | Mean soil loss (g/$m^2$) | 1.9 | 2.0 | 1.2 | 1.8 | 16.2 | 2.0 |
| | Land covers (canopy and litter) (%) | 14 | 25 | 12 | 14 | 15 | 12 |
| 8 | Mean runoff depth (mm) | 3.5 | 3.5 | 3.9 | 6.7 | 5.4 | 7.5 |
| | Mean soil loss (g/$m^2$) | 1.2 | 2.1 | 0.7 | 26.7 | 10.7 | 7.6 |
| | Land covers (canopy and litter) (%) | 15 | 32 | 15 | 10 | 14 | 12 |
| 9 | Mean runoff depth (mm) | 1.3 | 1.1 | 1.2 | 1.0 | 1.7 | 2.2 |
| | Mean soil loss (g/$m^2$) | 0.8 | 0.5 | 2.0 | 2.8 | 2.2 | 1.1 |
| | Land covers (canopy and litter) (%) | 15 | 30 | 15 | 12 | 15 | 14 |
| 10 | Mean runoff depth (mm) | 1.6 | 2.4 | 2.0 | 3.1 | 2.2 | 2.8 |
| | Mean soil loss (g/$m^2$) | 1.0 | 5.0 | 3.2 | 13.4 | 12.1 | 6.1 |
| | Land covers (canopy and litter) (%) | 15 | 35 | 16 | 12 | 15 | 12 |
| 11 | Mean runoff depth (mm) | 3.8 | 3.2 | 4.5 | 2.2 | 1.5 | 7.8 |
| | Mean soil loss (g/$m^2$) | 5.6 | 3.9 | 12.6 | 3.7 | 3.0 | 15.4 |
| | Land covers (canopy and litter) (%) | 10 | 25 | 12 | 10 | 12 | 14 |
| 12 | Mean runoff depth (mm) | 8.0 | 7.2 | 8.6 | 10.7 | 6.6 | 10.1 |
| | Mean soil loss (g/$m^2$) | 1.8 | 0.0 | 0.0 | 2.4 | 2.6 | 1.2 |

Table 5: The classes of each factor

| Classes | Sub factors | Factor |
|---|---|---|
| 1 | North | Hill-slope aspect |
| 2 | East | |
| 3 | West | |
| 1 | <50 | Slope % |
| 2 | 50 < | |
| 1 | Sandy clay | |
| 2 | Sandy loam | Soil texture |
| 3 | Sandy clay loam | |
| 1 | <15 | Land covers % |
| 2 | 15-30 | (canopy and |
| 3 | 30< | litter) |

Table 6: The results of Kruskal-Wallis test slope, aspect, land covers and soil texture with runoff and soil loss

| | Factors | df | p |
|---|---|---|---|
| Runoff | Site | 5 | 0.344 |
| | Slope | 1 | 0.43 |
| | Aspect | 2 | 0.297 |
| | Land covers | 2 | 0.212 |
| | soil texture | 2 | 0.283 |
| Soil loss | Site | 5 | 0.163 |
| | Slope | 1 | 0.986 |
| | Aspect | 2 | 0.705 |
| | Land covers | 2 | 0.012* |
| | soil texture | 2 | 0.166 |

* is significant difference at 0.05

Table 7: The results of Kruskal-Wallis test on land cover sand runoff and soil loss in each slope class

| | Land covers | Df | p |
|---|---|---|---|
| Runoff | <50 | 2 | 0.282 |
| | 50 < | 2 | 0.156 |
| Soil loss | <50 | 2 | 0.037* |
| | 50 < | 2 | 0.212 |

* is significant difference at 0.05
** is significant difference at 0.01

Table 8: The results of Kruskal-Wallis test on land covers and runoff and soil loss in each aspect class

| | Land covers | Df | p |
|---|---|---|---|
| Runoff | North | 2 | 0.474 |
| | East | 2 | 0.383 |
| | West | 1 | 0.118 |
| Soil loss | North | 2 | 0.026* |
| | East | 2 | 0.638 |
| | West | 1 | 0.005** |

* is significant difference at 0.05
** is significant difference at 0.01

land covers (canopy and litter) and the line gradient is steeperfor soil loss reduction than runoff. The line gradient is -6.0 for soil loss but for the related runoff, it is -0.7 (Fig. 3).

Normality test was performed on the data by Kolmogorov-Smirnov test, which showed that the data were not normal. Kruskal-Wallis test showed no significant difference between six sites, slope, aspect and soil texture with the runoff and soil loss in six sites but a significant difference was obtained between land covers and soil loss (p=0.012). Table 6 shows the results from Kruskal-Wallis test in SPSS. The result especially characterizes the role of land covers on soil loss. Focus on effects of land covers on soil loss and runoff generation showed that there is no significant difference between slope classes and runoff, but a significant difference was observed between "less than 50 percent" class of slope and soil loss (p=0.037). In slope class of "more than 50 percent" class of slope no significant differences were found between soil loss and land covers classes (Table 7). Aghabeigi Amin *et al.,* (2014) showed that slope changes have strongly and significantly affected runoff and sediment yield. It seems that the slope class of "more than 50 percent" has a dominant effect on soil loss. Koulouri and Giourga, (2007) showed that where the slope is extremely steep (40%), soil loss remains at the similarly high levels even after cultivation. Because slope is the dominant factor and controls the soil loss, although vegetation characteristics are changing.

No significant difference were found between aspect classes and runoff but a significant difference was observed between north aspect and soil loss (p=0.026) as well as west aspect and soil loss (p=0.005).Table 8 shows the results of Kruskal-Wallis test (in SPSS) between aspect classes and runoff and soil loss. Aghabeigi Amin *et al.,* (2014) have concluded that the effect of aspect on runoff in different vegetation type is same.

The northern slopes receive less solar radiation in the area. But the western slopes are exposed to the sun shine more than two other aspects. This has led that the northern slopes contain more soil moisture content than western slope. This would cause that erosion potential will be more in the northern slope than western slope. Based on these results land cover has a significant effect on soil loss but this effect is characterized in the highest and lowest conditions of erosion potential.

Gabarrón-Galeote *et al.,* (2013) stated that soil moisture content had been an important factor,

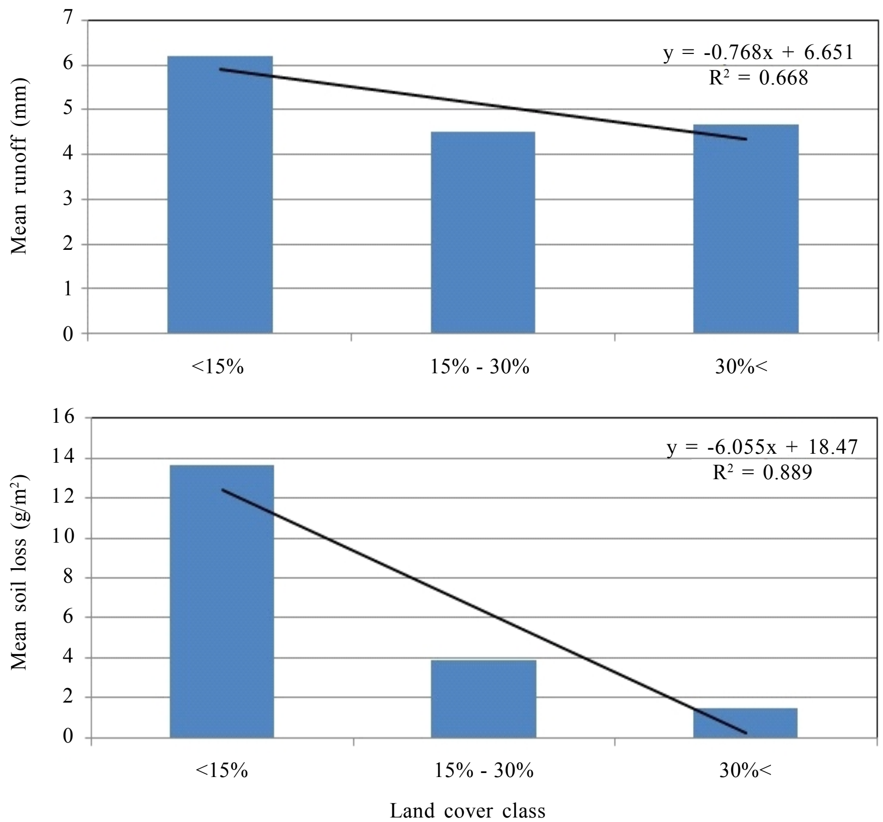


Fig.3: Mean soil loss and runoff in each class of land covers (canopy and litter)

Table 9: The results of Kruskal-Wallis test on land covers and runoff and soil loss in each soil texture

| | Land covers | df | P |
|---|---|---|---|
| Runoff | Sandy clay | 1 | 0.174 |
| | Sandy loam | 2 | 0.382 |
| | Sandy clay loam | 1 | 0.465 |
| Soil loss | Sandy clay | 1 | 0.349 |
| | Sandy loam | 2 | 0.068 |
| | Sandy clay loam | 1 | 0.018* |

*Significant difference at 0.05
**Significant difference at 0.01

especially in the northern slopes. They demonstrated the especial influences of vegetation in the southern slopes because of lower soil moisture content. Southern and western slopes are almost equal in terms of soil moisture conditions under the influence of solar radiation in the study area (Eshghizadeh *et al.*, 2015).

No significant difference were found between soil texture classes and the runoff, but a significant difference was observed between sandy clay loam and soil loss (p=0.018). Table 9 shows the results taken from Kruskal-Wallis test in SPSS between soil texture classes and runoff as well as soil loss.

Runoff and soil loss are influenced by small change in soil texture. Soil texture affects the rate of infiltration to the soil. Also, it determines the stability of the soil. A soil with a high percent of sand has a high rate of infiltration, producing the least rate of runoff. As the percent of clay increases in a soil, the size of the particles decreases. Therefore, the rate of infiltration reduces and the amount of runoff increases. Soils with a low percent of clay are less cohesive and are less stable. These soils are at greater risk of erosion (Environment Agency 2007). Thus, sandy clay loam-textured tend to be less erodible than sandy clay and sandy loam textures. As a result, due to lower potential for erosion, a significant difference has been observed in land cover classes. The result showed that the effect of land covers is clearer on soil loss than runoff. Sole-Benet *et al.* (1997) were resulted that stems, leaves and plant residues have a smaller effect on runoff.

The results of this research emphasizes that increase in land covers reduces the soil loss. It can result in of increase in permeability due to increase in canopy and litter. With increase in permeability the runoff and soil loss are reduced. Field observations pointed out that increasing canopy of plants increased infiltration and reduced both runoff and soil loss (Moreira *et al*., 2008; Aghabeigi Amin *et al.,* 2014). Increase in canopy caused a considerable decrease in sediment production, which confirmed previous studies. Litter and plant cover cause overland flow velocity reduction, surface roughness increase, enhancing soil infiltration through greater macro-pore density and improving soil structure by contributing organic matter. Vegetation cover protects soil surface from splash, increases surface roughness and enhances soil structure and macro-porosity (Moreira *et al*., 2008; Joshi and Tambe 2010).

## CONCLUSION

This study used the monitored data that obtained from plots under natural conditions on a hill-slope in an Iranian semi-arid region. Initial result showed high degree of spatial variability in runoff and soil loss on hill-slope at the small scale. So the runoff and soil loss processes, even in a small plots, were quite complex. Constant conditions in the plots significantly affected soil loss from event to event.

The results of this study showed that the effect of cover (canopy and litter) on runoff and erosion is strongly related to runoff generation and soil loss potential of the surface. Also, small variation in cover percentage (canopy and litter) will have small effects on runoff and soil loss if apart from the cover, dominant factor affect runoff generation and soil loss. No significant difference between runoff changes and slope, aspect, land covers and soil texture classes can be due to dominant factors such as intensity and amount of precipitation. When the slope or soil texture is the dominant factor on runoff and soil loss, the difference will not be significant between soil loss and cover. The obtained results highlighted the role of land covers (canopy and litter) on soil loss. Vegetation had an important effect on infiltration and interception and enhanced both soil infiltration and soil water storage capacity. Also, litter accumulated on soil surface kept it against raindrop impact and increased water storage. Identification of the importance of land covers that influence on runoff and soil loss is necessary in management strategies.

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## CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

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