

HOSTED BY



ELSEVIER



CrossMark

Available online at www.sciencedirect.com

ScienceDirect

International Soil and Water Conservation Research 3 (2015) 273–281

www.elsevier.com/locate/iswcr

Effects of rainfall patterns on runoff and soil erosion in field plots

Mohamad Ayob Mohamadi, Ataollah Kavian*

Department of Watershed Management, Sari Agricultural Sciences and Natural Resources University (SANRU), Sari, Mazandaran, Iran

Received 22 April 2015; received in revised form 7 October 2015; accepted 8 October 2015

Available online 14 November 2015

Abstract

Soil erosion processes during a storm are strongly affected by intra-storm variations in rainfall characteristics. Four storm patterns, each with a different rainfall intensity variation were separated. The storm patterns were: (1) increasing rainfall intensity (2) increasing then decreasing intensity (3) decreasing intensity (4) decreasing then increasing intensity. After each erosive rainfall (12 events), Runoff and suspended sediment samples were collected in each plot's tank which is located on hillslopes of the basin of Khamsan. Main storm characteristics and soil losses were plotted and equation of the line of best fit were selected. Analysis of variance (ANOVA) was used to determine response of runoff and soil erosion to storm patterns. Results showed that in lower rainfall intensities a linear function fits the relationship between soil loss and rainfall intensity whereas this function tends to be non-linear at higher intensities. Also a strong non-linear relationship was found between different quartiles of storm and soil loss. Statistical analysis revealed significant differences in total runoff, soil loss and sediment concentration across four storm patterns ($P < 0.001$) but no differences in the runoff coefficient. In particular, storms with increasing rainfall intensity yielded highest quantities of eroded sediments, total runoff and highest sediment concentrations followed by increasing then decreasing, decreasing then increasing and decreasing intensity, respectively.

© 2015 International Research and Training Center on Erosion and Sedimentation and China Water and Power Press. Production and Hosting by Elsevier B.V. This is an open access article under the CC BY-NC-ND license

(<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

Keywords: Storm patterns; Soil erosion; Rainfall intensity; Erosion plot

1. Introduction

Soil erosion is an extremely dynamic and complicated process. The spatial and temporal variability of this phenomena are very high within a catchment. Soil erosion is affected by many factors, among them topographic position of slope, vegetation and soil type have a momentous role on erosional behavior of soil (Morgan, 1986). The complexity of this process is not obvious. Soil loss from runoff plots on various soil types have shown different erosion rates under the same conditions of rainfall, topography and vegetal cover (Hussein, Kariem, & Othman, 2007). Acquired Data from erosion plots also contain large quantities of unexplained variability, which must be considered in experimental designs and to evaluate erosion models using erosion and runoff data (Gomez, Nearing,

*Correspondence to: Sari Agricultural Sciences and Natural Resources University (SANRU), Po. Box 737, Sari, Mazandaran, Iran. Tel.: +98 911 322 1326; fax: +98 1133882982.

E-mail addresses: M.ayobmohamadi@gmail.com (M.A. Mohamadi), a.kavian@sanru.ac.ir (A. Kavian).

Peer review under responsibility of IRTCES and CWPP.

<http://dx.doi.org/10.1016/j.iswcr.2015.10.001>

2095-6339/© 2015 International Research and Training Center on Erosion and Sedimentation and China Water and Power Press. Production and Hosting by Elsevier B.V. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

Giraldez, & Albert, 2001; Nearing, Govers, & Norton, 1999). This variability in soil erosion data is due to both natural variability and experimental design (Boix-Fayos et al., 2006). Generally, there is a demand for knowledge of the main sources of this variability and to understand interactions between factors affecting soil erosion. Meanwhile, the effect of rainfall characteristics as a major determining factor is crucial in order to deal with observed variability (Ran, Su, Li, & He, 2012). The effect of storms has been studied by many researchers (Parsons & Stone, 2006; Ran et al., 2012; Romkens, Helming, & Prasad, 2001). Among storm characteristics, rainfall intensity is a very important factor. The close relationship between water erosion and rainfall intensity is due to: (1) impact of raindrops on soil surface in high-intensity storms causes increased soil particle detachment (Van Dijk, Bruijnzeel, & Rosewell, 2002); and (2) higher rainfall intensity results in higher rates of infiltration excess runoff, and a much greater transport of suspended sediment load (Rose, 1993). Moreover, storms with the same average rainfall intensity likely do not have the same kinetic energy, since the relationship between rainfall intensity and its kinetic energy is not a linear relationship (Brodie & Rosewell, 2007; Petan, Rusjan, Vidmar, & Mikoš, 2010; Rosewell, 1986; Salles, Poesen, & Sempere-Torres, 2002; Van Dijk et al., 2002). It is kinetic energy that controls soil sealing and detachment of particles. But the effect of storms with the same average intensity on surface soil is different regardless of storm pattern effects (Parsons & Stone, 2006). Both spatiotemporal non-uniformity of rainfall (Marshall, 1983) and variation in rainfall intensity can affect soil erosion (de Lima, Tavares, Singh, & de Lima, 2009; Parsons & Stone, 2006). For example: Parsons and Stone (2006) studied the effect of storm patterns on runoff and erosion from three different soils. They found that, even if there are not differences between total runoff among different soils, storms with constant intensity yielded mean soil loss of 75% of storms with varying intensity. Kavian and Mohammadi (2012) found Storms with peak instantaneous intensity at the end yielded higher sediment loads and concentrations. Wei et al. (2007) conclude that different rainfall regimes have different effects on runoff and soil erosion. They showed that rainfall regimes which have such features as high intensity, short duration and high frequency produce more runoff and sediment. Huang, Ouyang, Li, Zheng, and Wang (2010) also observed different runoff and soil loss under different rainfall types. They found the quantities of runoff and soil loss under erosive rainfall type III were the most, followed by rainfall type II, IV and I. Flanagan, Foster, and Moldenhauer (1987) showed that storm patterns have considerable effect on total soil loss and runoff. Marques, Bienes, Pérez-Rodríguez, and Jiménez (2008) found that sediment production in high-intensive events is significantly greater than that produced in moderate-intensive events.

The aim of this study is to provide more insight and detail through: (1) determining the response of runoff and soil erosion to different storm patterns (2) statistical interpretation of how storms do affect soil erosion. The utilization of field erosion plots under natural rainfalls allows us to achieve the study objectives.

2. Material and methods

2.1. Site description

Two coupled watersheds (< 200 ha) with similar topography, relief, soil and vegetation were considered for comparison of soil conservation practices. The experimental watersheds are located in the basin of Khamsan, a province of Kurdistan, Iran (47°4'4.8"–47°10'36"E to 34°57'36.3"–35°1'34.4"N). The elevation of the catchment ranges from 1609 to 1820 m above sea level. The climate has a mean annual temperature of 14.1 °C and a mean annual rainfall of 473 mm (Nabiollahi et al., 2010). All experiments were performed using 18 plots which are located on six hillslopes within experimental watersheds (Figs. 1 and 2). In Fig. 2, the picture on the top shows distance between hillslope number 1 and the meteorological station. Also, one of 18 plots and its tank, and a view of three adjacent plots on hillslope number 5 are shown (Fig. 2).

2.2. Experimental design

A total of 18 erosion plots (22.1*1.83 m²) were placed on rangeland hillslopes with a mean slope of 18–23°. In each NW, S, W and East facing slope three erosion plots were installed except for a north facing slope with 6 plots (Fig. 1). To prevent runoff from adjacent areas, galvanized steel plates were buried 10–15 cm deep in the ground around the perimeter of each plot. Runoff and associated sediment were collected in a 750 liter tank at the lower end of each plot.

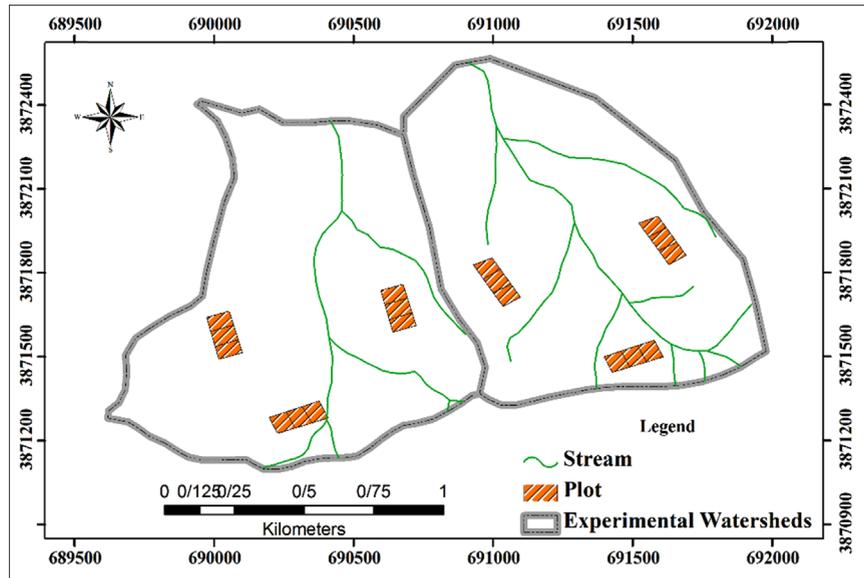


Fig. 1. Location of the study area on the map of Iran.

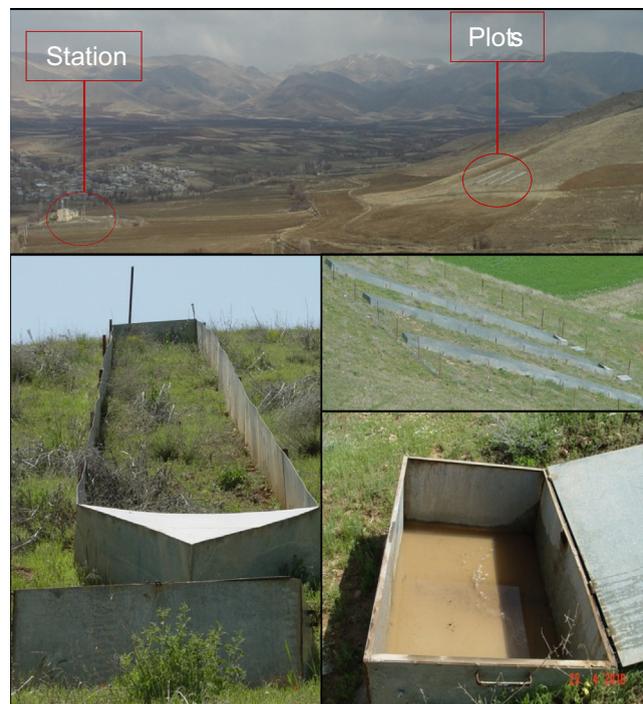


Fig. 2. Plots and station within experimental watershed.

2.3. Rainfall, runoff and soil loss measurements

Measurements of runoff were made during the rainy season of 2010–2011 from each plot's tank. During this period 12 erosive events occurred. After each storm causing runoff, the water level was measured in the tank, then the suspension (runoff and sediments) were mixed thoroughly and samples were taken to determine the weight of sediment load (Bargarello & Ferro, 2004; Hammad, Børresen, & Haugen, 2006; Polyakov & Lal, 2008). Finally, the

Table 1

Number of plots for each hillslope, total sample volumes, and mean runoff, soil loss and Sediment concentration for each hillslope.

Hillslopes	Total plots	Total runoff volume	Total sediment samples	Mean runoff (cm)	Mean soil loss (gr)	Mean sediment concentration (gr/liter)
1	3	36	36	1/952	11/453	0/366
2	3	36	36	1/778	12/29	0/43
3	3	36	36	2/151	19/598	0/55
4	3	36	35	1/86	11/788	0/394
5	3	36	36	2/747	24/423	0/552
6	3	36	33	2/068	20/99	0/533

total sediment in each sample was determined by the infiltration method of Seeger (2007) (Table 1). At the same time as runoff sampling, the amount of rainfall was measured at 10-min intervals using a recording rain gage which was installed at the meteorological station near the plots.

2.4. Data analysis

Thirteen maximum rainfall intensities were calculated and some of them are presented here as: maximum intensity in 10, 20, 30, 40, 50, 60 and 90-min. Storm quartiles (first, second, third and fourth quartile) was obtained by quantifying rainfall depth within each quarter of the storm duration. And the kinetic energy of storms was computed based on Eq. (1) proposed by Wischmeier and Smith (1978).

$$E = 210.3 + 89 \text{Log}_{10} I \quad (1)$$

where E is the storm kinetic energy in $\text{J m}^{-2} \text{cm}^{-1}$, and I is intensity in cm h^{-1} .

Storm characteristics were plotted against average soil loss of all 18 plots, then the best relationship and equation were selected in order to determine mechanisms of storm effects on sediment production. Storms were divided into four different patterns, based on intra-storm variation in rainfall intensity (Parsons & Stone, 2006). Increasing or decreasing trend in rainfall intensity were used to classify storm events. The storm patterns were: (1) increasing rainfall intensity (2) increasing then decreasing intensity (3) decreasing intensity (4) decreasing then increasing intensity. Finally, ANOVA was used to evaluate differences in runoff, soil loss and sediment concentration between storm patterns. The soil loss and runoff data used in this test were obtained in three repetitions.

3. Results and discussion

3.1. Effects of rainfall intensities on soil loss

During the experiment, 12 erosive rainfall events were recorded. Fig. 3 shows scatter plot graphs for the relationship between Maximum rainfall intensities and soil loss. The best regression equation was selected based on determination coefficients of the line of best fit.

The relationship between rainfall intensity and soil loss varied across intensities in a systematic way (Fig. 3). For maximum rainfall intensities in 10 (I_{10}) and 20-min (I_{20}), the dominant equations are in the form of a power function followed by logarithmic and exponential functions. And for I_{30} , I_{40} and I_{50} , this relationship tends to be logarithmic. Detailed analysis of scatterplot graphs (data are not shown), indicates From I_{25} to I_{40} , a logarithmic equation yields a determination coefficient higher than power and linear equations, respectively. And from I_{45} to I_{55} , the equation of the line of best fit tends to be in the form of a logarithmic equation followed by a linear equation. Finally, the highest R^2 belongs to a linear equation in the I_{60} and I_{90} graphs. Only the best equation is shown on each graph.

This result may indicate that in low-intensity events, the effect of storm on soil loss is linear. On the contrary, the effect of storm intensity on soil loss is non-linear in high-intensity events. Similarly Kandel, Western, Grayson, and Turrall (2004) found a non-linear effect of high intensity storms on runoff and erosion processes. Therefore, it is possible to conclude that highly intensity and short duration storms lead to greater soil losses. This confirms results

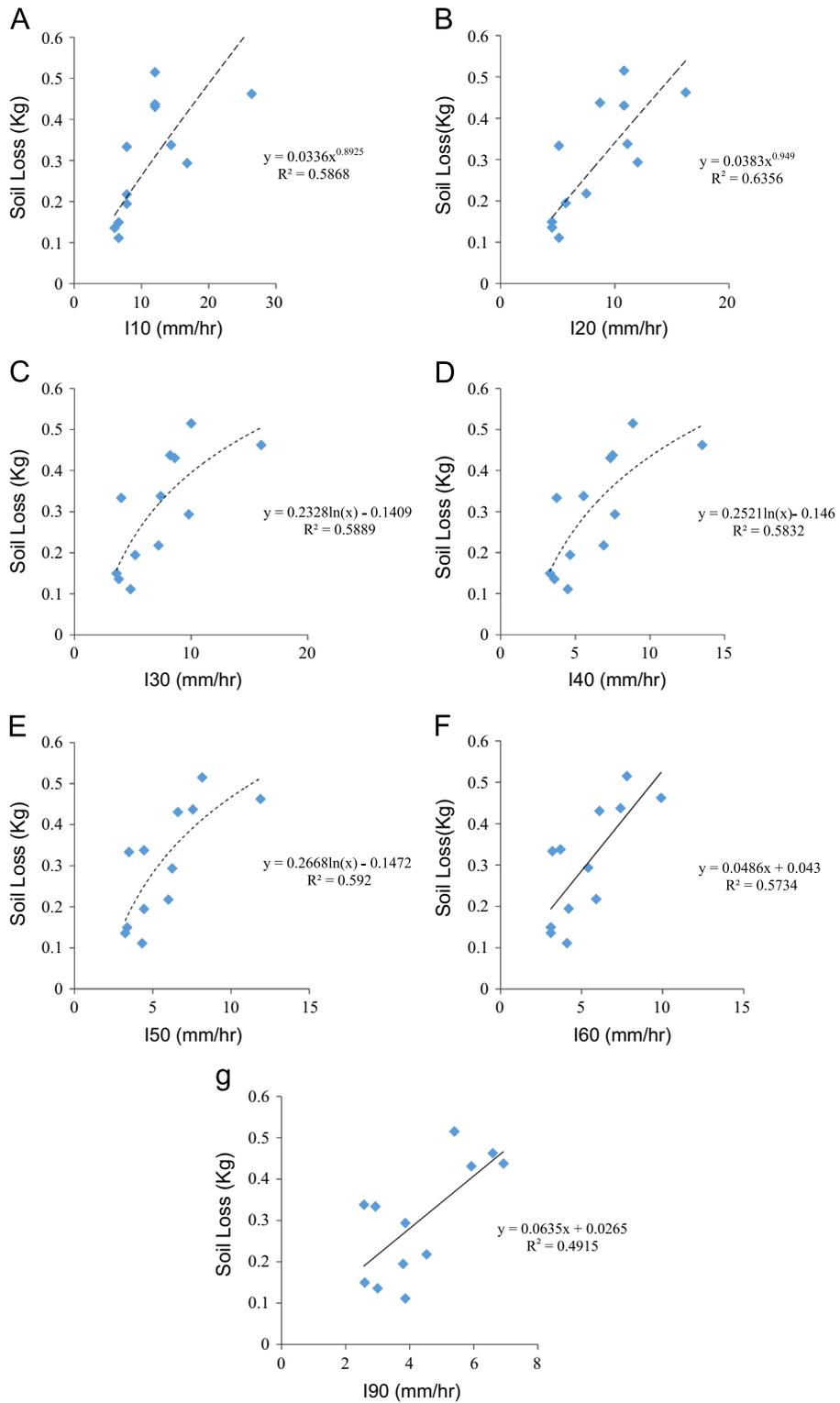


Fig. 3. Scatter plot graphs of maximum rainfall intensities and soil loss.

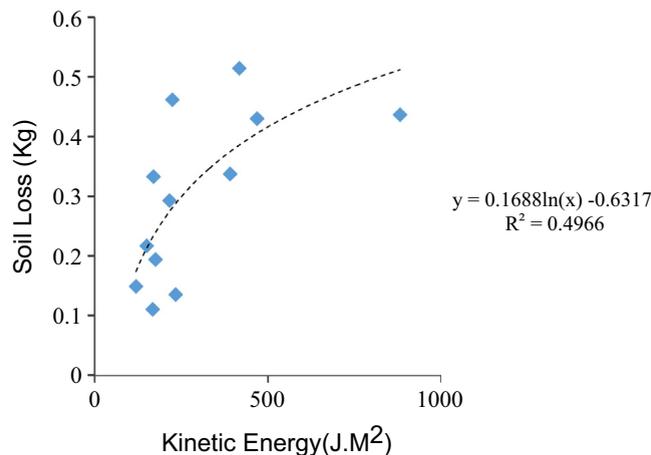


Fig. 4. Scatter plot graph of rainfall kinetic energy and soil loss.

from other investigations where high intensity storms increase soil erosion and sediment transport (Bracken & Kirkby, 2005; Jebari, Berndtsson, Bahri, & Boufaroua, 2008; Marques et al., 2008).

However, in Fig. 3 some points are scattered and lie far from the regression line, this indicates that the variability in the soil loss is not solely related to the intensity of the storm but there are also other factors involved in erosional processes (Arnaez, Lasanta, Ruiz-Flano, & Ortigosa, 2007).

3.2. Effects of rainfall kinetic energy on soil loss

Fig. 4 shows the relationship between kinetic energy of rainfall and soil loss. It shows that for this experiment, the relationship between kinetic energy and soil loss is a non-linear function.

3.3. Effects of storm quartiles on soil loss

The relationship between soil loss and storm quartiles is presented in Fig. 5. The logarithmic and power equations yield the highest determination coefficients, yielding a strong non-linear relationship between different quartiles of a storm and soil loss. The fourth storm quartile is strongly correlated with soil loss, consequently the least scatter is found around the regression line in the 4th quartile. These different effects across various storm patterns and their major role in soil erosion studies was also confirmed by Flanagan et al. (1987), Parsons and Stone (2006) and Wei et al. (2007).

Generally, non-linearity in hydrological processes is supported by Beven (2001), as he noted that hydrological systems are nonlinear and the implications of this nonlinearity should be taken into account in the formulation and application of distributed models.

3.4. Response of runoff, soil loss and sediment concentration to storm patterns

Table 2 and Fig. 6 present results of ANOVA and compare mean graphs. Table 2 reveals significant differences in total runoff, soil loss and sediment concentration across four storm patterns ($P < 0.001$), but no differences in runoff coefficients. In particular, the highest amounts of eroded sediment, total runoff and sediment concentration are related to storm with increasing rainfall intensity, followed by increasing then decreasing, decreasing then increasing and decreasing intensity, respectively (Fig. 6).

Increasing intensity storms, increasing then decreasing storms and decreasing intensity storms can be classified into separate groups regarding soil loss and total runoff (Fig. 6). However, decreasing then increasing intensity storms lie in the midst of decreasing and increasing then decreasing patterns. But, on the basis of sediment concentration only two different groups of storms are found. The first group with highest sediment concentration

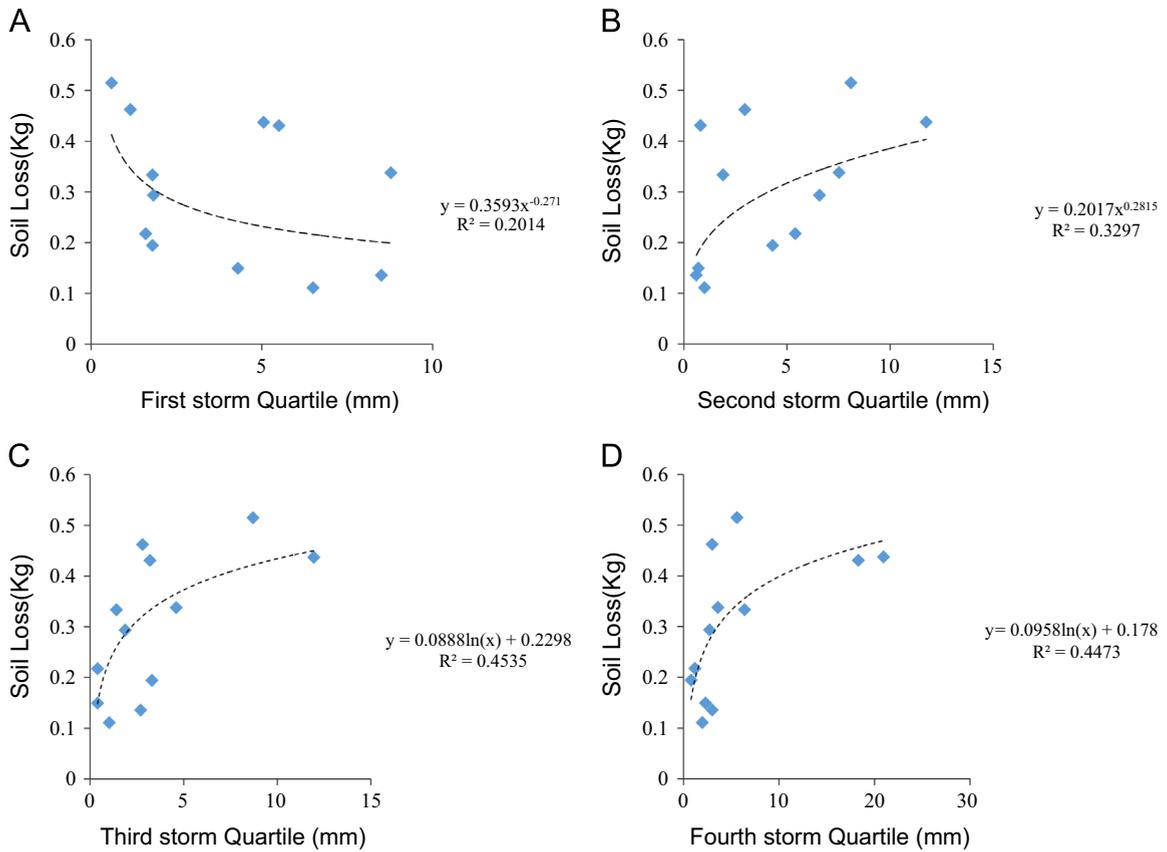


Fig. 5. Scatter plot graphs of storm quartiles and soil loss.

Table 2
One Way ANOVA's result.

	Storm pattern	Sample volume	Mean	F value	P value
Total runoff (liter)	Increasing	30	40.8	21.79	*** < 0.001
	Increasing–decreasing	24	27.95		
	Decreasing	6	18.4		
	Decreasing–increasing	12	21.29		
Soil loss (gr)	Increasing	30	24.21	14.75	*** < 0.001
	Increasing–decreasing	24	14.49		
	Decreasing	6	6.17		
	Decreasing–increasing	12	7.92		
Sediment concentration (gr/liter)	Increasing	30	0.586	11.91	*** < 0.001
	Increasing–decreasing	24	0.504		
	Decreasing	6	0.147		
	Decreasing–increasing	12	0.279		
Runoff coefficient (%)	Increasing	30	4.7	0.49	0.69 ^{ns}
	Increasing–decreasing	24	5.3		
	Decreasing	6	5		
	Decreasing–increasing	12	5.62		

*** $P < 0.001$; ns: non-significant.

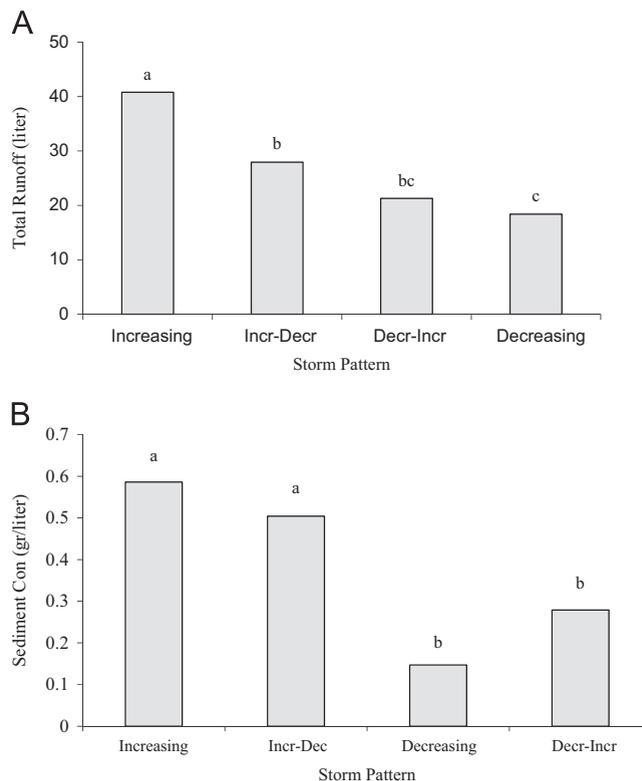


Fig. 6. Compare mean graph for runoff volume (a), sediment concentration (b), and soil loss (c) between all storm patterns.

includes increasing intensity and increasing then decreasing intensity. The second group with lowest sediment concentration includes decreasing intensity and decreasing then increasing intensity storms.

4. Conclusion

A detailed study of storm characteristics showed that relationship between soil loss and rainfall intensities can be characterized by two forms of function: (1) in low rainfall intensities a linear function is fitted to soil loss-rainfall intensity, and (2) in high rainfall intensities nonlinear functions are fitted to soil loss-rainfall intensity. Analysis of variance (ANOVA) indicated that no consistent differences in runoff coefficient was observed across all storm patterns but significant differences in total runoff, soil loss, and sediment concentration were found. In particular, storms with increasing rainfall intensity yielded the highest runoff, soil loss and sediment concentration.

References

- Arnaez, J., Lasanta, T., Ruiz-Flano, P., & Ortigosa, L. (2007). Factors affecting runoff and erosion under simulated rainfall in Mediterranean vineyards. *Soil & Tillage Research*, 93(2), 324–334.
- Bargarello, V., & Ferro, V. (2004). Plot-scale measurement of soil erosion at the experimental area of Sparacia (southern Italy). *Hydrological Processes*, 18(1), 141–157.
- Beven, K. (2001). How far can we go in distributed hydrological modeling?. *Hydrology and Earth System Sciences*, 5(1), 1–12.
- Boix-Fayos, C., Martínez-Mena, M., Arnau-Rosalén, E., Calvo-Cases, A., Castillo, V., & Albaladejo, J. (2006). Measuring soil erosion by field plots: Understanding the sources of variation. *Earth-Science Review*, 78(3–4), 267–285.
- Bracken, L. J., & Kirkby, M. J. (2005). Differences in hillslope runoff and sediment transport rates within two semi-arid catchments in southeast Spain. *Journal of Geomorphology*, 68(3–4), 183–200.
- Brodie, I., & Rosewell, C. (2007). Theoretical relationships between rainfall intensity and kinetic energy variants associated with stormwater particle washoff. *Journal of Hydrology*, 340(1–2), 40–47.
- de Lima, J. L.M. P., Tavares, P., Singh, V. P., & de Lima, M. I.P. (2009). Investigating the nonlinear response of soil loss to storm direction using a circular soil flume. *Geoderma*, 152(1–2), 9–15.

- Flanagan, D. C., Foster, G. R., & Moldenhauer, W. C. (1987). Storm pattern effect on infiltration, runoff and erosion. *Transactions of the American Society of Agricultural Engineers*, 31, 414–420.
- Gomez, J. A., Nearing, M. A., Giraldez, J. V., & Albert, E. E. (2001). Analysis of sources of variability of runoff volume in a 40 plot experiment using a numerical model. *Journal of Hydrology*, 248(1–4), 183–197.
- Hammad, A. H.A., Børresen, T., & Haugen, L. E. (2006). Effects of rain characteristics and terracing on runoff and erosion under the Mediterranean. *Soil Tillage Research*, 87(1), 39–47.
- Huang, Z., Ouyang, Z., Li, F., Zheng, H., & Wang, X. (2010). Response of runoff and soil loss to reforestation and rainfall type in red soil region of southern China. *Journal of Environmental Science*, 22(11), 1765–1773.
- Hussein, M. H., Kariem, T. H., & Othman, A. K. (2007). Predicting soil erodibility in northern Iraq using natural runoff plot data. *Soil & Tillage Research*, 94(1), 220–228.
- Jebari, S., Berndtsson, R., Bahri, A., & Boufaroua, M. (2008). Exceptional rainfall characteristics related to erosion risk in semiarid Tunisia. *Journal of the Open Hydrology*, 2, 25–33.
- Kandel, D. D., Western, A. W., Grayson, R. B., & Turrall, H. N. (2004). Process parameterization and temporal scaling in surface runoff and erosion modeling. *Journal of Hydrological Processes*, 18(8), 1423–1446.
- Kavian, A., & Mohammadi, M. A. (2012). Effect of rainfall type on runoff and sediment yield in plot scale. *Journal of Range and Watershed Management*, 65(1), 117–130.
- Marques, M. J., Bienes, R., Pérez-Rodríguez, R., & Jiménez, L. (2008). Soil degradation in Central Spain due to sheet water erosion by low-intensity rainfall events. *Journal of Earth Surface Processes and Landforms*, 33(3), 414–423.
- Marshall, R. J. (1983). A spatial-temporal model of storm rainfall. *Journal of Hydrology*, 62(1–4), 53–62.
- Morgan, R. P.C. (1986). *Soil erosion and conservation*. New York: Longman.
- Nabiollahi, K., Davoodpour, Zh., Rashidi, Z., Ghafori, S. F., Karimi, M., Mohammadpour, S. (2010). *Detailed study of the basin of khamsan-assessment of land capability* [In Persian].
- Nearing, M. A., Govers, G., & Norton, L. D. (1999). Variability in soil erosion data from replicated plots. *Soil Science Society of America Journal*, 63(6), 1829–1835.
- Parsons, A. J., & Stone, P. M. (2006). Effects of intra-storm variations in rainfall intensity on interrill runoff and erosion. *Catena*, 67(1), 68–78.
- Petan, S., Rusjan, S., Vidmar, A., & Mikoš, M. (2010). The rainfall kinetic energy–intensity relationship for rainfall erosivity estimation in the Mediterranean part of Slovenia. *Journal of Hydrology*, 391(3–4), 314–321.
- Polyakov, V. O., & Lal, R. (2008). Soil organic matter and CO₂ emission as affected by water erosion on field runoff plots. *Geoderma*, 143(1–2), 216–222.
- Ran, Q., Su, D., Li, P., & He, Z. (2012). Experimental study of the impact of rainfall characteristics on runoff generation and soil erosion. *Journal of Hydrology*, 424–425, 99–111.
- Romkens, M. J.M., Helming, K., & Prasad, S. N. (2001). Soil erosion under different rainfall intensities, surface roughness, and soil water regimes. *Catena*, 46(2–3), 103–123.
- Rose, C. W. (1993). Erosion and sedimentation. In: M. Bonell, M. M. Hufschmidt, & J. S. Gladwell (Eds.), *Hydrology and water management in the humid tropics*. Cambridge: Cambridge University Press.
- Rosewell, C. J. (1986). Rainfall kinetic energy in Eastern Australia. *Journal of Climate and Applied Meteorology*, 25(11), 1695–1701.
- Salles, C., Poesen, J., & Sempere-Torres, D. (2002). Kinetic energy of rain and its functional relationship with intensity. *Journal of Hydrology*, 257(1–4), 256–270.
- Seeger, M. (2007). Uncertainty of factors determining runoff and erosion processes as quantified by rainfall simulations. *Catena*, 71(1), 56–67.
- Van Dijk, A. I.J. M., Bruijnzeel, L. A., & Rosewell, C. J. (2002). Rainfall intensity-kinetic energy relationship: A critical literature appraisal. *Journal of Hydrology*, 261(1–4), 1–23.
- Wei, W., Liding, C., Bojie, F., Zhilin, H., Dongping, W., & Lida, G. (2007). The effect of land uses and rainfall regimes on runoff and soil erosion in the semi-arid loess hilly area, China. *Journal of Hydrology*, 335(3–4), 247–258.
- Wischmeier, W. H., & Smith, D. D. (1978). *Predicting rainfall erosion losses: A guide to conservation planning*. Washington D.C.: U.S. Department of Agriculture.