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

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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.

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,

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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 m^2) 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.