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Effects of land use change on soil splash erosion in the semi-arid region of Iran

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A B S T R A C T

Land use change may escalate the process of splash erosion as the primary mechanism causing water erosion. The objective of this study was to investigate the impacts of different management practices and land uses on splash erosion in a semiarid region in Iran. The major land uses in the area were pasture, degraded pasture, dry land farming, and irrigated farming. For the purposes of this study, soil properties including organic matter, $CaCO_3$, surface shear strength (SSS), particle size distribution, mean weight diameter (MWD), and the topographic attributes were measured. Soil splash erosion was measured at 80 different locations under the following four conditions comprising different values of slope (S:%) and rainfall intensity ($RI{:}mm \cdot h^{-1}$): 5–50, 5–80, 15–50, and 15–80, respectively, using the multiple splash sets (MSS) especially designed and tailored for the purposes of this study. A completely randomized design was used in which soil texture and the land use systems were independently analyzed. The fuzzy linear regression (FLR) was used and compared with the multiple-linear regression (MLR) analysis. It was found that the splash erosion in the study region was mainly influenced by landuse and soil management practices rather than by intrinsic soil properties like tested textures. The average splash erosion values among landuse types are: degraded pasture > cultivated farming > pasture; this is claimed to be associated with the lower organic matter content and shear strength due to overgrazing and untimely grazing. The FLR models outperformed the MLR ones ($p > 0.01$). MWD and SSS attributes were the most effective variables in estimating soil splash, indicating the structural susceptibility of the soils to management practices. Based on the results obtained, MWD and SSS may be regarded as important indices of splash erosion.

1. Introduction

Soil erosion is one of the most serious environmental problems threatening many ecosystems in (semi-)arid regions of the world. More specifically, disturbed areas in these regions exhibit a greater potential for soil detachability and transportability (Saygın et al., 2011). The main impacts of these disturbances include reduced vegetation, loss of surface cover by decaying vegetation, and soil compaction (Ravi et al., 2009). Disturbed lands in Iran include forests and pastures that have been disturbed by such human activities as overgrazing, untimely grazing, shrub burning, and tillage (Khalilmoghadam et al., 2009). Soil erosion rate in Iran is estimated at 25 Mg per hectare per year which is four times greater than its world average (Abbaszadeh Afshar et al., 2010; Jalalian et al., 1996). What adds to this undesirable situation is the high rate of land use change from pasture to dry land farming which is estimated at 400 m^2 per second (Abbaszadeh Afshar et al., 2010).

Land use/cover affects the occurrence and the intensity of runoff and soil erosion (Chen et al., 2001; Wei et al., 2007). Proper management of land use/land cover patterns may greatly improve soil properties, leading to reduced soil erosion to the recommended threshold limits (Fu, 1989; Chen et al., 2003). Improved physical soil properties can also positively affect the establishment of vegetation (Kosmas et al., 2000). Different land uses and/or cover systems might lead to changes in a number of soil properties and soil erosion processes (Costa et al., 2003). Different models have been widely used to study and simulate the effects of landuse changes on surface runoff and sediment yield (Wendt and Corey, 1980; Lorup et al., 1998; Raclot and Albergel, 2006; Yuan et al., 2007; Yu et al., 2009; Xiaoming et al., 2010). Schiettecatte et al. (2008) showed that spatial differences in erosion rates within the watershed are mainly caused by differences in topography and landuse. Wei et al. (2007) reported that the runoff coefficient and erosion modulus of shrubland were lowest followed by grassland and woodland in an increasing order. Pastureland was found to have an adverse effect on erosion control, which was slightly weaker than cropland but far greater than the other three land use types.

The absence of vegetation cover in disturbed lands accelerates splash erosion rates by as much as several folds compared to undisturbed sites (Lal, 2001; Thomaz and Luiz, 2012). The detachment of soil particles by splash depends on several raindrop characteristics,

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including raindrop size and mass, drop velocity, kinetic energy, and water drop impact angle (Sharma et al., 1993; Singer and Le Bissonnais, 1998; Cruse et al., 2000; Bhattacharyya et al., 2010). Detachment rate is strongly influenced by soil properties, including soil texture and thickness of the water layer at the soil surface (De Ploey and Savat, 1968; Moss and Green, 1983; Sharma et al., 1991; Kinnell, 1991; Jomaa et al., 2010), soil strength, bulk density, cohesion, soil organic matter content, moisture content, infiltration capacity (Nearing et al., 1988; Owoputi, 1994; Morgan et al., 1998; Planchon et al., 2000; Ghahramani et al., 2011), soil initial water content, surface compaction and roughness (Planchon et al., 2000), the nature of soil aggregates and crust, porosity, capacity of ionic interchange, and clay content (Poesen and Torri, 1988). Several studies have shown that splash detachment rate is mainly related to surface rock fragments in soils with sparse vegetation cover (Jomaa et al., 2012).

Soil particle size distribution plays an important role in splash erosion (Woodburn, 1948) as smaller particles are splashed over longer distances than larger ones and fine sands have a higher detachability than coarse sands (Poesen and Savat, 1981). Wainwright (1996) observed that soil conditions before a rainfall event and their changes during the event might control splash conditions. Le Bissonnais (1996) classified 17 Mediterranean soils into two groups and found that seal formation was the main factor involved in splash and wash erosion. Luk (1979) and Ekwue (1991) showed that large aggregate sizes and high organic matter content (OM) protect soils against splash detachment. Singer and Le Bissonnais (1998) observed that differences in OM among the three soils they studied were small, and that the differences in soil texture did not lead to significant differences in splash. Legout et al. (2005) observed that the size distribution of splashed fragments was comparable to the size distribution of fragments resulting from aggregate breakdown rather than the original soil matrix. They concluded that the size distribution of splashed fragments depended indirectly on the size distribution of aggregate breakdown products but directly on their size.

The multiple-linear regression (MLR) method (Mayr and Jarvis, 1999; Tomasella et al., 2000) and the fuzzy linear regression (FLR) (Tran et al., 2002) are the two most common methods used for developing soil spatial prediction functions (SSPFs) and pedo-transfer functions (PTFs). Compared to MLR, the FLR method might be more appropriate when: 1) data are not sufficient to perform the statistical regression; 2) the assumptions about the statistical distribution cannot be justified; 3) the relationship between input(s) and output is vague; and 4) imprecise human judgments are involved (Tran et al., 2002). Since its development by Zadeh (1965), the fuzzy set theory has been successfully used in solving problems dealing with vague expert knowledge, uncertainty, or imprecise/insufficient data. Recently, there has been a variety of studies applying the theory to different areas of soil and soil erosion studies (Mitra et al., 1998; Changying and Junzheng, 2000; Kumar et al., 2000; Lark, 2000; Oberthur et al., 2000; Jian-guo et al., 2001; Ahamed et al., 2000; Tayfur et al., 2003; Hodza, 2010).

Although most previous studies on splash erosion have focused on impacts of soil, climate, topography, and ground cover characteristics, to the best of the authors' knowledge, no study has of yet been reported on the effects of different management systems and land use changes on soil splash erosion. Therefore, this study was conducted in the central Zagros region, Iran: i) to investigate the impact of different management systems and land use changes from pasture to degraded pasture and cultivated lands on soil splash erosion, and ii) to compare the predictive power of the fuzzy linear regression (FLR) and that of multiple linear regressions (MLR) in estimating soil splash erosion.

2. Materials and methods

2.1. General site description

This study was conducted in part of the central Zagros, Iran (50°15′–51°51′ N and 31° 20′–32°53′ E) covering an area of approximately 27,500 ha (Fig. 1). The region is characterized by a long term average rainfall of 600 mm, a mean temperature of 14 °C, an elevation of 1870 to 1980 m above mean sea level, and a hilly topography. Within the study area, there are seven geological units: Asemari formation (M_{as}^{lm}), Agha-Jari formation (M_{aj}^{c}), Alluvial Fan and old terrace (Q_1^t), Alluvial Fan and new terrace (Q_2^t), silt and clay flats (Q_3^t), Mishan formation (M_{mn}^{m}), and Gachsaran formation (M_{gs}^{mg}) with moderate weathering and sensitivity to erosion (Iranian Geological Organization, 2006). The soils include *Calcic Haploxerolls*, *Typic Calciaquolls*, *Pachic Calcixerolls*, *Calcic Haploxeralfs*, *Calcic Haploxeralfs*, *Fluventic Haploxerepts*, and *Typic Calcixerepts* (Soil Survey Staff, 2010) as well as *Haplic Fluvisols*, *Haplic Calcisols*, *Fulvic Cambisols*, *Calcic Luvisols*, *Luvic Calcisols*, *Calcic Kastanozems*, and *Luvic Calcic Kastanozems* (World soil resources reports, 2006). The major land uses are pasture (*Astragalus* sp. and *Bromus* sp.), degraded pasture (*Bromus* sp.), dryland farming, and irrigated farming. Winter wheat (*Triticum aestivum*) is mostly cultivated on the dry farmed lands and clover (*Trifolium resupinatum*) is generally cultivated on irrigated fields. Conventional tillage (i.e., moldboard plowing and disking by MF285 tractors) is used in dryland and irrigated farming. The degraded pasture area was under intensive sheep overgrazing (i.e., four to eight times greater than its normal capacity) during late May to early September. All the cover crops (*Bromus* sp.) on the degraded pasture lands are consumed by livestock during grazing.

2.2. Experimental design

The study area was initially divided into similar Land Unit Tracts (LUT). LUT is defined as an area of land where the attribute values are sufficiently uniform and distinct from those of the neighboring areas to justify its delineation in a map or an image (Gunn and Aldrick, 1988). The attributes included soil, geology, topography, and land use attributes. The stratifying procedure was conducted using a geology map with a resolution of 1:100,000, a topography map at 1:50,000, a land use map at 1:250,000, and a land capability map at 1:250,000. GIS9.3 environment was used for analyzing the data and for producing the thematic map layers so that a total number of 25 LUT layers was generated. Supervised random sampling was used to collect samples in every land unit. A total number of 80 samples was collected in order to produce a measure of diversity in soil properties within each LUT (13 from pasture lands, 13 from degraded pasture lands, 30 from dry land farms, and 24 from irrigated farms) from the A horizons of the soil. The positions of the points were identified by GPS for reference purposes.

2.3. Soil attributes

Particle size distributions of the soils were determined by sieving and sedimentation (Gee and Bauder, 1986), the organic matter and calcium carbonate contents were measured using the Walkley–Black procedure (Nelson and Sommers, 1986), titration was accomplished using NaOH (Nelson, 1982) and aggregate stability was determined by the wet sieving method (Chepil, 1962). A shear vane was used to make shear strength measurements in the saturation condition. The procedure used in this study was to push the vane into the soil surface until the blades were covered (about 8 mm deep), and a clockwise rotation rate was then applied to ensure that failure developed within 5 to 10 s. The maximum stress value was recorded on a dial at the top of the vane driver. Vanes with a stress range between 0 and 100 kPa were used in all the cases to induce shear failure. A non-return pointer assisted readings.

2.4. Topographic attributes

A 10-m by 10-m DEM (National Cartographic Center, 2009) was used to characterize the topographic attributes of slope, wetness