Developing an erodibility triangle for soil textures in semi-arid regions, NW Iran

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A B S T R A C T
There is a strong need to develop a simple method for rapid estimation of erodibility using readily available data. In this study, soil erodibility was measured using eleven soil textures at the plot scale (60 cm × 80 cm) on a slope of 9% in a semi-arid region. A total of 110 soil erosion experiments were conducted using ten simulated rainfalls (50 mm h⁻¹ for 30 min). A regression model was developed based on silt and clay content (R² = 0.82, p < 0.001) and was applied to estimate erodibility for 231 soils in the textural triangle. Kriging was used to spatially interpolate erodibility using these data to unknown soils on the textural triangle. A soil erodibility triangle was developed using kriging technique and its accuracy was evaluated using seven other soils. The technique showed a 5.4% error and allowed the prediction of soil erodibility in semi-arid areas by using the soil erodibility triangle.

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1. Introduction
Soil erodibility expresses the soil’s susceptibility to erosional processes and is conceived of as the ease with which soil is detached by splash during rainfall and/or surface flow (Renard et al., 1997). It is generally considered as an inherent soil property with a constant value which reflects the fact that different soils erode at different rates when the other factors that affect erosion are the same (Kirkby and Morgan, 1980; Brevik et al., 2015). This soil property is a result of the integrated effect of processes that regulate rainfall acceptance and the resistance of the soil to particle detachment and subsequent transport (Lal, 1994). It is an important factor in determining the rate of soil loss (Zhang et al., 2004), therefore it is widely adopted as an important factor in soil erosion prediction models such as the Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978) and the Revised USLE (RUSLE) (Renard et al., 1997). Thus, knowledge of soil erodibility is an essential requirement for conservation planning and the assessment of sediment related environmental effects of watershed agricultural practices (Wang et al., 2013b). Soil erodibility is also a key factor in understanding pedon and slope erosional processes as well as landforms and landscape evolution (Bryan, 2000; Cammeraat, 2002; 2004). Soil erodibility research contributes to understanding human impacts on soil properties and thus on soil and water losses (Cammeraat and Imeson, 1998; Cerdà and Doerr, 2007; Brevik et al., 2015; Ochoa Cueva et al., 2015; Liu et al., 2015). The impact of the humankind by means of forest fires (Cerdà and Doerr, 2005), grazing (Palacio et al., 2015), ploughing (Zhao et al., 2015), and herbicides (Cerdà et al., 2009) affects soil erodibility. Moreover, research on soil erodibility can help to better understand soil formation and soil degradation processes (Cammeraat et al., 2002; Cammeraat and Risch, 2008; Cerdà and Doerr, 2010), the impact of water (Ziadat and Taimeh, 2013) and wind (Wang et al., 2013a; Borrelli et al., 2015; Colazo and Buschiazzo, 2015) on soil particle detachment, and also identify soil quality (Brevik, 2009; Zhao et al., 2015) and watershed erosion (Keesstra et al., 2014). The concept of erodibility and how to assess it are complicated since the susceptibility of the soil to erosion is influenced by a large number of properties such as physical, chemical, rheological, mineralogical and biological properties, not to mention soil profile characteristics such as the depth of the soil and its influence on vegetative growth (Morgan, 1995; Veibe, 2002). Several attempts have been made to devise a simple index of erodibility based on the properties of the soil determined either in the laboratory or field. For the first time, a nomograph was developed by Wischmeier et al. (1971) to estimate soil erodibility from measurable soil properties in the early 1970s from long-term soil erosion plots under natural rain and rainfall simulation experiments (Auerwald et al., 2014). In this method, soil erodibility was originally derived from five variables, namely the silt plus, the very fine sand content, clay content, organic matter content, an aggregation index, and a permeability index (Wischmeier et al., 1971). Later, a sixth variable, namely...
is currently used as a tool for quantifying the soil susceptibility to erosion worldwide. Attempts to simplify the K evaluation procedure have been carried out in the past and simplified relationships have been proposed for predicting K values of soils for which data are limited (Römken et al., 1986; Römken et al., 1997; Verstraeten et al., 2002; Bagarello et al., 2009). Early Borselli et al. (2012) attempted on alternative ways in order to infer the range of uncertainty of K-values associated to every combination of climate and of input soil properties. They developed a special software (KUERY from “query” and K) to calculate the most probable soil erodibility for the given climate group using soil properties: Dg (geometric mean of the particle-size distribution), Sg (geometric standard deviation), organic matter and percentage rock fragments. The KUERY calculates the interpolated cumulative distribution curve of the K-value for any given Dg, Sg, organic matter and percentage rock fragments. However, reducing the number of input variables in the evaluation procedure of soil erodibility can be practically attractive for limiting laboratory analyses and resulting costs (Bagarello et al., 2011). Therefore, there is a strong need for developing a simple method to estimate soil erodibility based on readily-available soil properties in the semi-arid regions. This study was designed based on field measurements of soil loss in soils with different textures using simulated rainfall events in order to find soil textures susceptible to water erosion, determine soil properties influencing erodibility, and develop a simple technique for estimating soil erodibility in these areas.

2. Materials and methods

2.1. Study site

In order to quantify soil erodibility in semi-arid regions, soil sampling was carried out at different sites in Zanjan Province in early March 2012. This area is one of the semi-arid regions located in the north west of Iran with a mean annual precipitation of 298 mm and a mean annual temperature of 11 °C. Soils are often calcareous and are mostly classified as Typic Calcixerepts according to the Soil Taxonomy classification system (Soil Survey Staff, 2010). The soils usually have little vegetation cover especially during early springs when rainfalls are severe and frequent (Hasanzadeh et al., 2013). It is estimated that this area has the potential to produce 15 Mg ha\(^{-1}\) of sediment per year, mostly around the Qezel Owzan river, the longest river in the Sefid Roud basin in NW Iran (Fig. 1). It seems soil erodibility is a critical erosion factor particularly in unprotected sloped lands (rainfed lands and rangelands) in the area.

2.2. Soil sampling

Soil samples were collected from 0 to 20 cm depth and were initially analyzed to determine particle size distribution in the lab. Finally, soils consisting of eleven soil textures according to the U.S. Department of Agriculture (USDA) system (Soil...