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Spatial modelling of gully erosion in Mazandaran Province, northern Iran

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ABSTRACT

Gully erosion is one of the most severe environmental problems in large areas of Iran. The spatial distribution of gully erosion and its susceptibility zonation was studied using different bivariate statistical models, such as frequency ratio (FR), weights of evidence (WofE), and index of entropy (IofE). For this purpose, 109 gully erosion locations were identified and divided into training (70%) and validating (30%) datasets. Effective factors, including elevation, slope aspect, slope degree, slope-length (LS), topographical wetness index (TWI), plan curvature, profile curvature, land use, lithology, distance from river, drainage density, and distance from road were selected to develop maps of gully erosion susceptibility. The spatial relationship between gully erosion and each effective factor was calculated by the mentioned models. The relative operating characteristic (ROC) curve was implemented for evaluating the accuracy of the applied predictive models. Results indicated that frequency ratio model had better performance (80.4%) than the weight of evidence (79.5%) and index of entropy (79%) models. The produced gully erosion susceptibility maps can be helpful to make decisions for soil and water planning and management and finally sustainable development in the Valasht watershed.

1. Introduction

Soil erosion and sediment yield are two main restrictions on sustainable management of soil and water resources. Large amount of materials washed from the land surface are deposited behind dams, inside craters, sea and oceans every year. Soil erosion and its consequences along with intensified exploitation of nature have imposed negative effects on vital ecosystems (Valentin et al., 2005). A large number of studies have been conducted on soil erosion process using various methods and models that have been carried out at either plot scale (Khaledi Darvishan et al., 2016; Sadeghi et al., 2016) or watershed scale (Spalevic et al., 2014).

Gully erosion is defined as an erosion process in which deep channels are created by accumulated runoff water removing topsoil to considerable depth (Desta and Adunga, 2012). It is one of the most destructive and complex types of water erosion, the mechanism of which can be started from a depression in land, scouring by waterfalls and extended through head-cut (Desta and Adunga, 2012; Dymond et al., 2016; Goodwin et al., 2017). It can cause numerous environmental and socio-economic problems, such as sedimentation, decreasing the expanse of agricultural land, depleting soil resources, and decreasing crop yield (Yitbarek et al., 2012; Frankl et al., 2013; Zgłobicki et al., 2015). In some cases, gully erosion can often be the cause of other natural hazard as landslides (Ionita et al., 2015), and debris flow (Ni et al., 2014). Gully initiation and development as two steps of gully erosion occurrence can be the results of different mechanisms such as incision, seepage or piping, fluting, tension crack development, mass wasting (Imeson and Kwaad, 1980; Gómez-Gutiérrez et al., 2015) and subsurface flow leading to dispersion and bank collapse (Rijkee et al., 2015). Gully erosion can also be derived from the development of rill erosion (Luffman et al., 2015; Ollobarren et al., 2016; Barnes et al., 2016; Dymond et al., 2016). Since gully erosion has reportedly been the main source of sediment yield in the watershed scale (Valentin et al., 2005) with an estimated total erosion contribution of 10–94% (Poesen et al., 2003), the gully networks must be considered in prediction of soil erosion at watershed scale (Shruthi et al., 2015). Therefore, there is a need to better understand gully erosion and its mitigation management to reduce its devastating effects by identifying and prioritizing gully erosion zones (Valentin et al., 2005). Numerous studies have prepared gully erosion susceptibility maps using various technologies/models, including GIS (Conforti et al., 2011; Dube et al., 2014; Rahmati et al., 2016a), logistic regression (Dewitte et al., 2015), and analytical hierarchy process (AHP) (Sela et al., 2012). Also, these techniques have been used to spatial modeling of other environmental subjects, including flood (Al-Abadi et al., 2016), debris flow (Chen et al., 2015), landslide (Hong et al., 2016; Motevalli

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et al., 2017), snow avalanche (Bühler et al., 2013), groundwater resources (Naghibi et al., 2015; Moghaddam et al., 2015), and water and sediment quality (Cormier et al., 2008; Bonnail et al., 2016). In addition, Frequency Ratio (FR), Weight of Evidence (WofE) and Index of Entropy (IofE) models were implemented by Ram Mohan et al. (2011); Manap et al. (2012); Mohammady et al. (2012); Regmi et al. (2013); Ozdemir and Altural (2013); Pourtaghi and Pourghasemi (2014) in their studies.

The study area (Valasht Watershed) is one of the main ecotourism sites in the northern province of Mazandaran that attracts many tourists each year. According to field surveys and existing reports (Mazandaran Province Governor, 2014), gully erosion and its sedimentation consequence is posing a great risk to the Valasht lake in this watershed by filling it over time. This subject has decreased the ecotourism value of Valasht watershed. Furthermore, reduction of water quality and the associated aquatic life are the consequences of gully erosion (Desta and Adunga, 2012; Goodwin et al., 2017). Therefore, the present study was aimed to evaluate the modeling of gully erosion susceptibility using FR, WofE and IofE models as simple and user-friendly techniques as well as comparing these models using ROC (Receiver Operating Characteristic) curve in the Valasht watershed. Lower cost, energy, time, etc. are the advantages of such simple models. In this regard, the use of simple models (if they have good accuracy) compared to advanced and complex models in appropriate decision making for land management is logical and affordable. Therefore, the ability of such statistical models to develop gully erosion susceptibility maps has been investigated in this study. Between these models, the IofE has not been applied for gully erosion susceptibility mapping, yet. In addition, given the tourist attractions of Valasht lake, such as mountaineering, sailing, swimming, fishing and also the consequences of filling lake by sediments from gully erosion make this study more important for sustainable water and soil resources management.

2. Materials and methods

2.1. Study area

The study area (Valasht watershed) with the area of 15.44 km^2 is located in Mazandaran Province of Iran (36°32′19″to 36° 34′ 39″ N and 51° 15′ 00″to 51° 19′ 26″E). The geographical location of study area and the spatial distribution of gullies are shown in Fig. 1. The area has great diversity of physiographic and topographic features, with an elevation ranging between 1006 and 1839 m (a.s.l.) and steep slopes. About 50% of the area is placed in slopes > 30°. In the study area, northern slope aspect has the most frequency. This watershed, as a part of the northern Alborz Mountains, is influenced by Mediterranean and continental polar air front that cause rainfall in autumn and winter, with a mean annual precipitation of 670 mm, which mainly concentrate in autumn, while summer is considered as a dry season. Mean annual temperature is 11.9 °C. Based on De Martonne aridity index, the climate of the area is semi-humid with a mean annual temperature of 11.9 °C (Safaei et al., 1997). The Valasht watershed is an approximately circular area. It has little time of concentration and high peak in hydrograph due to geometric features. The Valasht lake, created through a landslide when it moved into a steep valley, acts as a natural reservoir in this watershed. The initial depth of this lake was 50 m, based on the results of transverse and longitudinal profiles in topographic maps of 1:25000-scale, which has been reduced due to sedimentation that can pose risks to the environment as well as ecotourism of the area. Gully erosion has the highest contribution to sediment yield in this watershed, which necessitate its study.

2.2. Overview of methodological approach

The methodology (Fig. 2) used in this study includes 4 steps: (1) Gully erosion inventory mapping, (2) Selection of effective factors that influence on gully erosion, (3) Mapping the gully erosion susceptibility using FR, WofE and IofE models, and (4) Validation and comparison the accuracy of these models and selection of the best model.

2.2.1. Gully erosion inventory mapping

Since spatial distribution of gullies is required for mapping of gully erosion susceptibility, gully locations were mapped by Global Positioning System (GPS) during extensive and detailed field surveys, according to which the majority of gully types was linear with 5–50 m length and 0.5–1 m. Based on tracking, each gully erosion event was mapped as a polygon feature and all of watershed area and appropriate spatial distribution of gully erosion was considered.

2.2.2. Preparation a data base for effective factors

Since gully erosion occurs under the influence of certain factors, it is important to recognize these factors. Therefore, the preparation of spatial database for the effective factors was one of the most important parts of this research. Conditioning factors were selected according to previous studies (Rahmati et al., 2016a, 2017), data availability and geographical knowledge. Considered factors in the present study included: elevation, slope aspect, slope degree, slope-length (LS), topographical wetness index (TWI), plan curvature, profile curvature, land use, lithology, distance from river, distance from road, and drainage density.

Elevation is one of the effective factors in gully erosion susceptibility assessment. Gully erosion may occur in different elevation, depending on the gully erosion initiation and developing mechanisms. For developing this factor, Digital Elevation Model (DEM) was generated by digitizing a 1:25,000-scale topographical sheet of the study area and transformation of contour lines to DEM by using ArcGIS 9.3. The extracted elevation from DEM (Cell size: 10 m) was divided into four categories, viz. 1006–1220, 1220–1420, 1420–1620, and 1620–1839 m (Fig. 3a). Slope aspect, as an important factor with regards to microclimate and vegetation cover, was also extracted from DEM and divided into 9 categories in ArcGIS 9.3 (Fig. 3b). Usually, gully erosion occurs in certain slopes degree; so, this factor is frequently considered as an effective factor in gully erosion susceptibility mapping. Slope degree was also extracted from DEM and divided into 6 categories (< 5, 5–12, 12–20, 20–25, 25–30 and > 30) (Fig. 3c). LS factor is a parameter in Universal Soil Loss Equation (USLE) that influence on soil erosion. The LS factor (Fig. 3d) was calculated based on the following equation (Moore and Burch, 1986):

$$LS = (fa \times cellsize/22.13)^{0.4} \times (\sin \sigma/0.0896)^{1.3} \qquad (1)$$

where, *fa* is catchment's area and σ is slope in degrees. This index was calculated by SAGA-GIS. TWI, as an effective factor to determine the distribution of soil water content and dry and wet zones, was calculated based on the Eq. (2) (Beven and Kirkby, 1979):

$$TWI = \ln\left(\frac{\alpha}{\tan\beta}\right) \qquad (2)$$

where, α is the cumulative up-slope area from a point (per unit contour length) and β is the slope angle at the point (Fig. 3e). This index was calculated by SAGA-GIS. The lithological characteristics were extracted from geological map in scale of 1:100,000 (Fig. 3i), the detailed information of which is provided in Table 1. Land use map of study area was generated by Landsat 7/ETM$^+$ satellite images using a supervised classification. All steps for the development of land use map were handled in ENVI 5.1 software. The study area was covered by 6 land use classes (Fig. 3h), including forest, rangeland, dry farming, irrigation farming, orchard, and residential area. Distance from river was calculated by vector lines (Fig. 3j) and distance function in ArcGIS 9.3 software. Road lines, as a man-made factor, were obtained from a topographical map with 1:25,000-scale (Fig. 3l). The drainage density map of the Valasht watershed (Fig. 3k) was prepared using river