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Evaluating the influence of geo-environmental factors on gully erosion in a semi-arid region of Iran: An integrated framework

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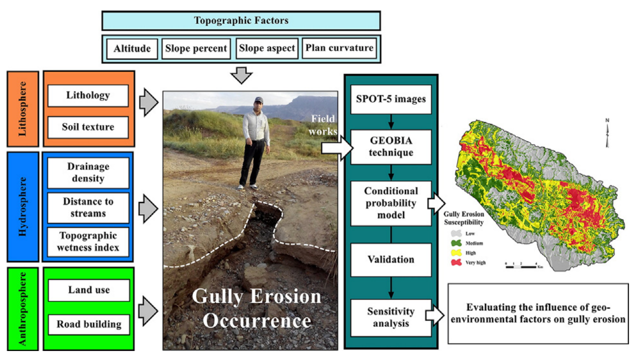
GRAPHICAL ABSTRACT



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ABSTRACT

Despite the importance of soil erosion in sustainable development goals in arid and semi-arid areas, the study of the geo-environmental conditions and factors influencing gully erosion occurrence is rarely undertaken. As effort to this challenge, the main objective of this study is to apply an integrated approach of Geographic Object-Based Image Analysis (GEOBIA) together with high-spatial resolution imagery (SPOT-5) for detecting gully erosion features at the Kashkan-Poldokhtar watershed, Iran. We also aimed to apply a Conditional Probability (CP) model for establishing the spatial relationship between gullies and the Geo-Environmental Factors (GEFs). The gully erosion inventory map prepared using GEOBIA and field surveying was randomly partitioned into two subsets: (1) part 1 that contains 70% was used in the training phase of the CP model; (2) part 2 is a validation dataset (30%) for validation of the model and to confirm its accuracy. Prediction performances of the GEOBIA and CP model were checked by overall accuracy and Receiver Operating Characteristics (ROC) curve methods, respectively. In addition, the influence of all GEFs on gully erosion was evaluated by performing a sensitivity analysis model. The validation findings illustrated that overall accuracy for GEOBIA approach and the area under the ROC curve for the CP model were 92.4% and 89.9%, respectively. Also, based on sensitivity analysis, soil texture, drainage density, and lithology represent significantly effects on the gully erosion occurrence. This study has shown that the integrated framework can be successfully used for modeling gully erosion occurrence in a data-poor environment.

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1. Introduction

Gully erosion is one of the most destructive forms of erosion in arid and semi-arid areas. It is known as an important signature of land degradation and forming as well as source of sediment in a range of environments (Valentin et al., 2005). Based on the observed damages caused by gully erosion, this hazard known as threatens the sustainability of aquatic/terrestrial ecosystems and economic stability (Van Oost et al., 2007; El Maaoui et al., 2012; Ionita et al., 2015; Ibáñez et al., 2016). They often have severe environmental and economic consequences worldwide such as destroying soil, damaging agricultural fields, undermining infrastructure, altering transportation corridors, and degradation of surface water quality, which can be difficult to reverse (Takken et al., 2008; Chen et al., 2016). Gullies are also considered one of the most useful indicators of desertification (UNEP, 1994; Lal, 2001) and are generally defined by their channel depth, which can range from 0.5 to 30 m (Soil Science Society of America, 2001). Kelsey (1980), and Costa and Bacellar (2007) demonstrated that gully erosion considerably affects flux rates and sediment budgets, and influences flow pattern and stream dynamics.

Similar to other natural hazards such as flood inundation, landslides, debris flows, avalanches, and earthquakes, it is usually hard to predict gully erosion features. They require monitoring and mapping since they have potentially harmful consequences for environment and people (Shit et al., 2015). In order to gain a better understanding of the gully erosion mechanism, it is required to obtain the gully erosion inventory database and to predict the gully erosion susceptibility map (Conoscenti et al., 2013). Technically speaking, topography, drainage pattern, lithology, rainfall, land use, and soil characteristics have been reported as the relevant Geo-Environmental Factors (GEFs) controlling critical conditions for gully erosion occurrence and development (Poesen et al., 2003; Valentin et al., 2005; Nazari Samani et al., 2010; McCloskey et al., 2016). From the gully occurrence mitigation and sustainable development viewpoints, there are GIS-based models that allow to delineate gully-susceptible areas and produce gully erosion susceptibility maps by defining statistical relationships between gully conditioning factors and the spatial distribution of gullies (Martínez-Casasnovas et al., 2004; Märker et al., 2011; Gómez-Gutiérrez et al., 2015). However, Gully Erosion Inventory Map (GEIM) and Gully Erosion Susceptibility Map (GESM) are essential for soil and water conservation and evaluating the relationship among gully occurrence and the GEFs (Conforti et al., 2011; Lucà et al., 2011).

In comparison with other soil erosion measurements, gully erosion monitoring and construction of the GEIM using remote sensing techniques are considered the least expensive method of data collection (Pradhan et al., 2011; Momm et al., 2015). Gully detection and the assessment of the gulling process by remote sensing technology is based on the analysis of spatial, spectral, and temporal information. Identifying existing gullies and performing a continuous monitoring, especially for larger areas with extensive gullying, cannot be based on aerial photographs and pixel-based approaches, which only consider on visual image interpretation and pixel values alone, respectively. However, a semi-automatic procedure in combination with field observations and knowledge-based processes may be a viable approach for mapping the gully features. According to literature, Geographic Object-Based Image Analysis (GEOBIA), also commonly known as Object Oriented Analysis (OOA) or Object-Based Image Analysis (OBIA), is becoming more popular and has significantly higher accuracy compared to traditional pixel-based image analysis (Blaschke and Strobl, 2001; Stumpf and Kerle, 2011). al Khudairy et al. (2005) stated that the GEOBIA technique improves the quantitative analysis of changes in urban features, especially when high-resolution satellite data are available. OBIA is a knowledge-driven approach in which a range of diagnostic features for a particular object can be integrated on the basis of expert knowledge. This approach aims to represent the content of a complex scene in a manner that best describes the imaged reality, by mimicking human perception (Blaschke et al., 2014). One of the advantages of GEOBIA is that it can extract information from image objects delineated at several scale values (Blaschke, 2010). Identification of gully erosion patterns and susceptible areas are important issues to understand the gullying process, whereas preparation of gully erosion inventory database remains a challenging and time-consuming task (Martínez-Casasnovas et al., 2004). A number of studies have been conducted to identify gully erosion features through aerial photographs and field investigations (Ries and Marzolff, 2003; Vandekerckhove et al., 2003) and distinguish gully conditioning factors using traditional approaches (Nyssen et al., 2002). However, Seutloali et al. (2016) stated that these traditional methods of gully erosion monitoring are expensive, time-consuming, labour intensive works, and more importantly lack spatial representation, despite being regarded as accurate. Importantly, new aerial platforms such as unmanned aerial vehicles, and high spatial resolution imagery data today provide the necessary level of detail. Development of rule-based, semi-automated classifications include spatial location and context as key components of its analysis, which this capability is particularly useful for gully erosion studies that attempts to detect fine-scale features among vast areas of continuous landscapes, as has already been reported by Powers et al. (2015). Recently, Martha et al. (2013) demonstrated that preparation of landslide inventory-set using GEOBIA technique is fast, unbiased, visually consistent and data driven in comparison to manual procedures. Shruthi et al. (2011) successfully mapped gully features in North West Morocco with the GEOBIA technique based on Ikonos-2 and GeoEye-1 data. However, these studies were limited to high resolution satellite images which are not easily accessible in developing countries mainly due to financial restrictions (Ananda and Herath, 2003).

Literature review indicates that quantifying the impact of GEFs on gully erosion has not yet been investigated fully in a semi-arid region based on Conditional Probability (CP) model. However, little is known regarding the GEIM and gullies spatial extent in Iran, especially at a regional scale. The traditional approaches for determining the spatial extent of gullies in field surveys at regional scales is extremely costly and time-consuming (Seutloali et al., 2016). The Kashkan-Poldokhtar Watershed in Iran is always exposed to gully erosion hazard because of semi-arid climate and physiographic conditions. In policy terms, a need was identified by the Department of Natural Resources Management in the Kashkan-Poldokhtar Watershed, Iran, to produce the GEIM and GESM. For this reason, the aim of the current study was to develop an integrated framework for modeling gully erosion occurrence in semi-arid condition. The specific objectives of this study are to: (1) - explore the capability of GEOBIA for gully erosion inventory mapping (2) evaluate the influence of GEFs on gully erosion, and (3) delineate gully-susceptible zones based on statistical conditional probability analysis. The simultaneous assessment of the applicability of GEOBIA technique and accurate field measurements, along with the implementation of a sensitivity analysis to contribution evaluation of different GEFs in gully erosion occurrence provide novelty to this study. Gully erosion susceptibility analysis will assist in understanding gully erosion formation and spatio-temporal evolution; as well as promote the development of strategies for the sustainable management of soil and water resources.

2. Study area

The Kashkan-Poldokhtar Watershed is situated between the Ilam and Lorestan Proviences in Iran. This area is located between 33° 2′ and 33° 13′ north latitude, and 47° 23′ and 47° 37′ east longitude (Fig. 1). It covers an area of 245 km^2. According to the climatic classification in Iran (IDWRM, 2013), the study area is classified as semi-arid (mean annual rainfall of 385 mm). In winter, the temperature ranges from −5 °C to 11 °C, while in summer it varies from 25 °C to 48 °C (IDWRM, 2013). The absolute elevation in the study area ranges from about 461 to 2191 m, with a mean elevation of 706 m a.s.l. There is a

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