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Application of GIS-Based Knowledge-Driven and Data-Driven Methods for Debris-Slide Susceptibility Mapping

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ABSTRACT

Debris-slides are fast-moving landslides that occur in the Appalachian region including the Great Smoky Mountains National Park (GRSM). Various knowledge and data-driven approaches using spatial distribution of the past slides and associated factors could be used to estimate the region's debris-slide susceptibility. This study developed two debris-slide susceptibility models for GRSM using knowledge-driven and data-driven methods in GIS. Six debris-slide causing factors (slope curvature, elevation, soil texture, land cover, annual rainfall, and bedrock discontinuity), and 256 known debris-slide locations were used in the analysis. Knowledge-driven weighted overlay and data-driven bivariate frequency ratio analyses were performed. Both models are helpful; however, each come with a set of advantages and disadvantages regarding degree of complexity, time-dependency, and experience of the analyst. The susceptibility maps are useful to the planners, developers, and engineers for maintaining the park's infrastructures and delineating zones for further detailed geo-technical investigation.

KEYWORDS

Data-Driven Method, Debris-Slide, Frequency Ratio, Great Smoky Mountains National Park, Knowledge-Driven Method, Receiver Operating Characteristic (ROC) Curve, Susceptibility, Weighted Overlay

INTRODUCTION

Mass movements are one of the most important geological processes for shaping up the morphology of the mountainous highland slopes. A slope becomes unstable when the acted force on the surface of the slope exceeds the shear strength of the slope forming materials. Most highlands have experienced at least one type of slope failure under critical landslide causing conditions and triggering factors such as rainfall and earthquake (van Western, 1993). Debris-slide and debris-flow are the predominant forms of slope failure in the Appalachian region. Debris-slide takes place when broken rock fragments mixed with plant debris, soil and water move downslope due to gravitational pull and might turn

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into a debris-flow with increase in the water content. More than 3000 rapidly moving slides have been recorded in the southern Appalachian Highlands, which have directly caused nearly 200 deaths since 1940 (Pariseau & Voight, 1979; Scott 1972; Wooten et al., 2016), and posed serious damage to houses, road networks, and federal properties.

Debris-slides in the Appalachian region are mainly triggered by torrential rainfall associated with severe storms (Wieczorek, et al., 2000) that increases pore water pressure in the soil cover and rock discontinuities (Eshner & Patric, 1982; Hupp, 1983), which facilitates the movement of the materials. Slope movements in the Great Smoky Mountain National Park (GRSM) area initially starts as slides at the scar head and flowage becomes the main mechanism as it moves rapidly along the drainage system towards the lower reaches of the mountains (Bogucki, 1970). For debris-slide risk assessment, it is important to identify potential slides initiation areas. One of the effective ways to identify such areas is to create a debris-slide susceptibility map. Debris-slide is a complex geological phenomenon that depends on several factors such as elevation, lithology, topographical slope angle, soil type, hydrological condition etc. in varying degree of influence (Ghosh et al., 2013). Therefore, it important to understand the interrelationship between occurrences of debris-slide and associated causative factors. The role of these causative factors, also known as geo-factors, can be determined by examining the areas where debris-slides have taken place repeatedly in past (Jones, 1992). Debris-slide susceptibility map predicts the spatial extent of future debris-slide with the assumption that the factors, which have caused debris-slides in the past, will cause sliding in the future under critical geo-environmental conditions (Carrara et al., 1995; Guzzetti et al., 1999). This makes debris-slide or any form of slope failure to be a predictable geo-hazard (Jones, 1992). Nevertheless, effective role of the geo-factors can change considerably based on the physical and geological condition of an area (Ghosh et. al, 2013).

Different methodologies for landslide susceptibility are well documented in literature, which are mainly of three categories: (i) Heuristic or knowledge-driven (ii) Empirical or data-driven and (iii) Deterministic approach. With the advancement of Geographic Information System (GIS), creating debris-slide maps for a large study area as a function of different geo-factors has become a popular practice worldwide. For predictive mapping of debris-slide susceptibility, heuristic and empirical methods are broadly used by employing GIS technology. The heuristic or knowledge-driven methods are of two types: (i) direct and (ii) indirect. A direct heuristic method involves field investigations by using direct geomorphological, geological and hydrological mapping (Brabb, 1984) to evaluate the interrelationship between these factors with landslides. This exercise is performed by the experts, based on their previous experiences of dealing with such situations in similar conditions (Aleotti and Chowdhury, 1999). The accuracy of such assessment heavily relies on the experience of the experts, precision of data collection, and proper execution of the methodology. Direct processes are often difficult and time consuming. While in indirect heuristic method, experts assign numerical weights or rankings to geo-factors, based on their experience or observation about the relative influence of the geo-factors on the area's slope stability (Soeters and Van Westen, 1996). Subjectivity involved in the selection of geo-factors and assigning numerical weights is one of the main constraints of heuristic models. Empirical or knowledge-driven models calculate interrelationship between the geo-factors and occurrence of landslides using statistical/mathematical equations. Application of data-driven models gained popularity in early eighties, with the development of GIS technology. Currently, GIS provides powerful tools to formulate and execute advanced data-driven models for creating landslide susceptibility maps. In this process landslide inventory data are integrated with the geo-factors to model the relationships in the form of numerical expressions. Data-driven models can be either bivariate or multivariate. Bivariate models calculate interrelationship between individual classes of the geo-factors and occurrence of landslides. In most of the cases, bivariate models calculate the density of landslides within the individual classes of the geo-factors by applying different statistical methods. Multivariate methods involve simultaneous calculation of interrelationship between the geo-factors