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GIS-Based Logistic Regression for Landslide Susceptibility Analysis in Western Washington State

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ABSTRACT

The Oso landslide, one of the most recent disasters, occurred on March 22nd, 2014 in western Washington State. It caused significant property damage and killed over 40 people. As a result, a renewed interest has emerged for creating more accurate landslide susceptibility maps for this region. Research addressing landslide susceptibility within the north Puget Sound region of western Washington is lacking; therefore, this study develops a probabilistic GIS-based landslide susceptibility model for the north Puget Sound region. Multivariate logistic regression was utilized to create a landslide susceptibility map of Whatcom, Skagit, Snohomish, and King Counties. To predict probable areas of landslide occurrence, a landslide inventory map was prepared and fourteen topographic, geologic, environmental, and climatic predictor variables were considered. This research aims to assist in restructuring western Washington's landslide policies, and could serve as the first step in producing more accurate landslide susceptibility maps for the region.

KEYWORDS

Landslide Density, Multivariate, Oso Landslide, Predictor Variables, Probabilistic Model, Puget Sound, Quantitative, ROC Analysis

INTRODUCTION

Natural disasters are usually not randomly distributed and occur in different regions of the world due to climatic patterns, topography, or tectonic activity. Droughts, floods, and hurricanes are prominent examples of natural disasters but there are also other, lesser reported disaster occurrences, that effect most nations: landslide activities (Sidle and Ochiai, 2006). In the United States, landslides occur or have occurred in all fifty states (Highland, 2004). The primary regions of landslide occurrences are the Intermountain West, mountainous and hilly regions of the eastern U.S., and the mountainous and coastal areas of the West Coast (Highland, 2004). The State of Washington experienced hundreds of landslides during the winters of 1995, 1996, and 1997 due to record rainfall, and these slides caused significant property damage and disrupted transportation networks (Baum et al., 2005). Devastating to the local economy, these severe slides stimulated renewed interest in identifying areas prone to slope failure (Baum et al., 2005). Recently, the town of Oso in western Washington experienced a tragic landslide resulting in significant home destruction, the death of 43 people, and major damage to state Highway 530 (Stromberg, 2014). Identifying potential landslide areas has once again been revived in western Washington (Stromberg, 2014).

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In order to minimize potential adverse impacts of landslides, Geographic Information Systems (GIS) have been used to map landslide susceptibility (Dahal et al., 2007). Many techniques have been developed and applied in the literature to produce susceptibility maps (Kavzoglu et al., 2014). Landslide susceptibility is assessed through qualitative and quantitative approaches (Dahal et al., 2007). Qualitative approaches rely entirely on expert opinion, and susceptible areas are often categorized by such terms as "very high" or "very low" (Castellanos Abella and Van Westen, 2008). The two types of quantitative approaches utilized for landslide susceptibility mapping are deterministic and statistical (Yalcin et al., 2011). Deterministic methods are primarily based on slope stability studies and are only applicable when ground conditions are uniform across the entire study area (Dahal et al., 2007; Yalcin et al., 2011). The statistical approach is an indirect susceptibility mapping methodology, which involves analyzing the historical link between landslide-controlling factors (i.e. independent variables) and the distribution of landslides (dependent variable) (Atkinson and Massari, 1997; Dahal et al. 2007; Yalcin et al., 2011). The most widely used statistical approaches in landslide susceptibility mapping include bivariate and multivariate statistical techniques such as logistic regression (Devkota et al., 2013). Other quantitative approaches include data mining models such as support vector machine, decision tree methods, artificial neural networks, etc. (Devkota et al., 2013).

Most published literature on landslide susceptibility mapping involves comparing known landslide susceptibility approaches, or adjusting universally accepted methodologies in order to produce more accurate maps. Many studies have also used repeated methodologies from prior literature but at different geographic locations or scales. The purpose of this research is to quantitatively identify high risk areas to landslide occurrence within western Washington by developing a GIS-based landslide susceptibility model. Multivariate logistic regression was utilized as the statistical methodology. In addition, this paper addresses the level of risk associated with the Oso landslide. This research aims to aid western Washington land-use managers in identifying areas prone to landslides in order to save lives and mitigate environmental and economic costs.

STUDY AREA

The Puget Sound region is a 35,483 km^2 basin that drains to the Sound and adjacent oceanic waters (USGS, 2013). This region encompasses an abundance of diverse landforms representative of lowland and mountainous terrains: valleys, mountains, lakes, canyons, rivers, flats and estuaries (Kruckeberg, 1992). The unique and dynamic landscapes of Puget Sound are constantly evolving due to geologic and climatic processes such as earthquakes, volcanic eruptions, landslides, water, and wind (Kruckeberg, 1992). The climate of this region is characterized as maritime—mild and wet (Kruckeberg, 1992). Summers are typically cool and dry, and winters are usually wet and cloudy. Average temperatures are approximately 10.5^0 C, and annual precipitation in western Washington ranges from 50 to over 380 cm (WRCC, 2014). Elevation ranges from sea level to approximately 3,261 meters.

The basin's borders are naturally bounded to the east by the Cascade Range and to the west by the Olympic Mountains. The northern extent of this region reaches the U.S. and Canada border, while the southern extent ends at the base of the Coastal Range near Olympia (Kruckeberg, 1992). The Puget Sound region includes thirteen western Washington counties. This research focusses on the counties of North Puget Sound—King, Snohomish, Skagit, and Whatcom (Figure 1). These four counties cover approximately 18,130 km^2 of the Puget Sound region. In addition, the small town of Oso affected by the 2014 landslide resides in Snohomish County.