Computational Mapping of Landslide Susceptibility Zones Using Satellite and Field Data

A Thesis submitted

in accordance with the requirements

for the degree of

Doctor of Philosophy

By

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"If a landslide comes as a surprise to the eyewitnesses, it would be more accurate to say that the observers failed to detect the phenomena which preceded the slide"

Karl von Terzaghi (1883-1963)

Dedicated to

My Tau Ji, My Parents, My Wife, My Brother, My Sisters

&

Three Cute Kids - Kanha, Guddan, and Aadu

Abstract

Landslides accounted for around 4.89% of the globally occurring natural disaster events during the last two decades. These are very prevalent in the Himalayan region, mainly due to varying lithology, changing weather, extreme precipitation, the density of drainage, tectonic activities, orography, topography, anthropogenic activities, and ongoing Seismicity. It is essential to identify such areas that are susceptible to landslides so that proper infrastructure management and develeopment activities could be carried out. Thus, landslide susceptibility mapping (LSM) and its inventory preparation are important steps towards disaster management. LSM is the division of hill or mountainous areas into homogeneous spatial regions in accordance to their degrees of actual or potential susceptibility. It depends on various terrain attributes and subsurface properties called causative or conditioning factors and various triggering factors and their interrelations. Although several methods are in use for LSM around the globe, due to different landslide processes, no single method can efficiently identify, map and verify the susceptibility of a region.

Generally, the heuristic approach, where experts in the domain determine the weight of causative factors, is mostly applied in the Indian scenario. However, an expert-based approach induces subjectivity in susceptibility maps. This thesis presents a methodology for selecting the weights of causative factors in the preparation of susceptibility maps. The weights of the factors are determined based on the distribution of landslide and the intrinsic properties of data, which are used for LSM. Further, the selection of causative factors depends on the characteristics of the study area and spatial scale of analysis. To study the effect of scale and mapping units in LSM, the study area is divided into several sub-basins and micro-watersheds using grid-cells with geo-hydrological subdivisions (GCHU). This study recommends the use of sub-basin analysis as a representative of the susceptibility of a basin. The causative factors used in susceptibility mapping could be discrete (e.g., lithology) or continuous (e.g., slope gradient) in nature. A comparative analysis of susceptibility maps prepared using discrete and continuous factors is carried out. It is found that the factors represented by continuous data provide homogeneous susceptibility zone boundaries.

Furthermore, there are various approaches for LSM, namely distribution analysis, geomorphic or heuristic, statistical methods, deterministic approach, probabilistic approach, and distribution free or machine learning methods. The machine learning methods are widely used in LSM, but they require a large amount of training data. However, the landslides do not occur everywhere (there are also areas that are non-susceptible to landslides), and the number of landslide occurrences is limited in an area. This physical phenomenon creates an imbalance between landslide locations and non-landslide locations in the data. Hence, in this thesis the landslide susceptibility mapping is considered as an imbalanced learning problem. It is suggested to use informed under-sampling methods, namely Easy Ensemble and Balance Cascade, instead of random undersampling for balancing the data. Several methods, namely Fisher discriminant analysis, logistic regression, feed-forward neural network, cascade forward neural network, and support vector machine has been used for the preparation of landslide susceptibility maps in the thesis. Several accuracy measures such as precision, recall, receiver operating characteristics, f-score, geometric mean, and Heidke skill score are used to validate the susceptibility maps. The significance of the present work lies in the fact that it attempts to solve a few important issues such as subjectivity in weightage selection, subjectivity in selection of scale and study area, subjectivity in selection of factors, and finally problems associated with data imbalance in the general practice of landslide susceptibility mapping.

Keywords: Landslide susceptibility mapping; Scale dependency; Landslide causative factors; Data imbalance; Indian Himalayas

Declaration

I hereby declare that the entire work embodied in this Thesis is the result of investigations carried out by me in the **School of Engineering**, Indian Institute of Technology Mandi, under the supervision of **Dr. Dericks P. Shukla**, and that it has not been submitted elsewhere for any degree or diploma. In keeping with the general practice, due acknowledgements have been made wherever the work described is based on finding of other investigators.

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Declaration by Research Advisor

I hereby certify that the entire work in this Thesis has been carried out by **Mr. Sharad Kumar Gupta** (Scholar No: D15015), under my supervision in the **School of Engineering**, Indian Institute of Technology Mandi, and that no part of it has been submitted elsewhere for any Degree or Diploma.

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Sharad Kumar Gupta

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