学 位 論 文 要 約

Dissertation Summary

氏名（Name）　MATEBIE METEN ENDALEW

論文名(Dissertation Title)　GIS-based Landslide Susceptibility Modeling in the Blue Nile Gorge, Jema River Gorge and Debre Sina areas of the Central Ethiopian Highlands.

Landslide problems are recurrent phenomena in the Ethiopian highlands where the topography is rugged and mountainous with steep slopes coupled with fragile rock types, river incision, presence of faults, deforestation (land clearing) etc. This is facilitated by triggering factors like heavy rainfall that occurs from June to the end of September and by earth quakes from the Afar Rift, Main Ethiopian Rift, and Rift Margin zones. In this study three areas (Blue Nile Gogre, Jema River Gorge and Debre Sina area) were selected based on the frequent landslide incidences. GIS can be used to retrieve, handle, process analyze and present the data and results in a meaningful way.

Landslide susceptibility modeling is an important tool for disaster management and development activities such as planning of road infrastructure, settlement, and agriculture. This requires landslide inventory data and a set of landslide influencing (conditioning or causative) factors. The methods used in landslide susceptibility modeling (mapping) include heuristic, statistical, and deterministic models. In heuristic models expert opinion is used to assess the susceptibility. These models combine the mapping of landslides and their geomorphologic setting as the main input factors. Heuristic models have drawbacks in that the weight determination for each class is biased. The statistical or probabilistic approach is based on the observed relationship between each factor and the distribution of past landslides. This approach usually involves the mapping of existing landslides, a set of factors that are supposed to be directly or indirectly related to the stability of the slopes and the establishment of the statistical relationships between these factors and the instability process. Hence susceptibility is conducted in an objective manner whereby factors and their inter-relationships with a landslide are evaluated on a statistical basis. Limitations of the statistical models come from data quality such as errors in mapping, incomplete inventory, and poor resolution of some datasets as the models are essentially data trained. Deterministic methods on the other hand apply the classical slope stability theory and principles such as infinite slope, limit equilibrium, and finite element techniques. These methods require standard soil parameter inputs such as soil thickness, soil strength, groundwater pressure, slope geometry etc. that will result in an average factor of safety map. This method has a problem of oversimplification of the geological and geotechnical model and difficulties in predicting groundwater pore pressures and their relationships to rainfall.

From the three models discussed above, we preferred to apply the statistical ones that include the frequency ratio, logistic regression, weights of evidence, fuzzy logic and rock engineering system (RES). This is because these models have a comparative advantage in avoiding bias in weight calculation and many data input requirements like geotechnical and groundwater pore pressures, which are difficult to find over large areas. All the statistical models undergo at least five major steps to produce a landslide susceptibility map of a certain area. These include the data collection phase (i.e., from field survey or secondary data source), GIS database construction Phase (digitizing lithologic map, land use map, river networks and geologic structures, generate topographic attributes like slope, aspect, profile curvature, plan curvature, elevation etc from DEM), training phase in which weights for all factor classes are determined from the relationships of training landslides and landslide conditioning (causative) factor, output phase whereby all the weight assigned factors are combined to produce the landslide susceptibility map based on applied model rules and the validation phase in which the produced landslide susceptibility is verified for its validity. In frequency ratio model, the frequency ratio values (weights) of all the classes in a specific factor were calculated by dividing landslide ratio to area ratio in each factor class and assigned to the respective reclassified raster map of a factor. Then all the frequency ratio raster maps of the factors were summed on a pixel by pixel basis to make the landslide susceptibility index map. This model is simple and the process of input, calculation, and output can be easily understood. Moreover, its ratio values can be used as a rating without converting the database into another format. A huge amount of data can be processed so quickly and easily, unlike logistic regression model, which require sample selection in case of big areas. Logistic regression is the most commonly used multivariate method, which allows forming the best fit model to describe the relationship between a dependent variable and a set of independent variables. The dependent variable is coded as "1" and "0" representing the presence and absence of a landslide respectively. In this method, the study area is divided into two parts: landslide and non-landslide area. Then these areas are rasterized and converted into point data format in GIS. These points are in turn used to extract the values of individual frequency ratio maps for each landslide factor considered in this study. These points were saved in SPSS statistical software for logistic regression analysis so as to determine the coefficients of each independent variable. If the coefficient of a certain factor is high, then its contribution to landsliding will be high. After a linear relationship is established between landslide and the landslide factors, this equation is inserted in the existing probabilistic equation for logistic regression.

The weights of evidence model follows the Bayesian probability approach and was originally designed for mineral potential assessment. Recently this has been used for landslide susceptibility mapping in the past decade. This model calculates the positive and negative weights of the respective factor classes based on the probability ratios of Bonham- Carter (2002). A positive weight (W_i^+) indicates presence of a causative factor in the landslide and the magnitude of this weight is an indication of the positive correlation between presence of the causative factor and landslides. A negative weight (W_i^-) indicates an absence of the causative factor and the magnitude indicates negative correlation. The difference between the two weights is known as the weight contrast ($C = W_i^+ - W_i^-$) and the magnitude of contrast reflects the overall spatial association between the causative factor and landslides (Dahal et al., 2008). If the weight contrast is positive, the factor is favorable for landsliding and if it is negative, it will be unfavorable. If it is close to zero, this indicates that the factor shows little relation to landsliding. In this model, all the factors should be conditionally independent among each other and with the landslides.

In fuzzy logic (FL) model, the fuzzy membership values were calculated by normalizing the frequency ratio values of each factor's class in a range between 0 and 1. Then, the fuzzy membership values were combined by fuzzy AND, fuzzy OR, fuzzy gamma, fuzzy sum and fuzzy product operators. A total of twelve landslide susceptibility maps were produced and the best map was chosen based on area under the curve (AUC) of the receiver operating characteristic (ROC) curve and the highest difference between minimum and maximum susceptibility index values. Based on these criteria, the landslide susceptibility map produced using fuzzy gamma ($\gamma = 0.8$) operator was selected. Rock engineering system (RES) is a semi-quantitative method which assigns each factor's classes a value between 0 and 4 based on the principles of Hudson (1992) and uses an interaction matrix through a coding system of five values in previous researches but a coding system of nine values has been used in this study in order to provide a wider range of values for interactions among each pair of landslide factors and each landslide factor with a landslide. Unlike other methods, RES has a freedom to evaluate and assign each interaction based on expert's knowledge and experience. But it also bears the problem of subjectivity in assigning the interaction values. On the other hand, FL is completely data driven and doesn't show any subjectivity in assigning values for each factor class.

In the Blue Nile Gorge, the effect of combining different factors has been shown by the different values of prediction accuracies from AUC values of ROC curves and the best combination was selected based on the highest prediction accuracy and higher difference between the maximum and minimum susceptibility index values. Similarly the weights of evidence and logistic regression modeling were also undertaken in this area. The former model showed a prediction accuracy of 88.4%. The later was intended to find the best combination of landslide and non-landslide points (i.e., all landslides and 80% of the non-landslide points) showing the highest prediction accuracy of 88.2%. In the Selelkula area of the Lower Jema River gorge, FL and RES were applied and the result shows that RES is slightly better than FL. In the Debre Sina area, the frequency ratio and logistic regression models were implemented and the result shows that the later is slightly better than the former model. In general, the application of statistical models has highlighted the landslide prone areas in the study areas, which can be very important to decision makers who are engaged in land use planning, disaster prevention and mitigation.