LANDSLIDE HAZARD MAPPING USING BAYESIAN APPROACH IN GIS – CASE STUDY IN YANGSAN AREA, KOREA

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ABSTRACT

Landslide hazard mapping is essential for land-use activities and management decision-making in mountainous areas. This research gives a view of landslide characteristics on natural terrain of YangSan area, Korea and developing a Geographical Information Systems (GIS) approach to modeling slope instability. The relations between landslide distributions with the physical parameters such as lithology, elevation, slope gradient, slope aspect, lineament, drainage, vegetation, and land use were analyzed by Bayesian statistical model. A susceptibility map is modeled by incorporating these parameters in a weight of evidence model using Bayesian approach.

1 INTRODUCTION

The study area (figure 1) is located in the southern part of Taebaeg Mountain Range, nearby the eastern coast of the Korean Peninsula and it covers an area of approximately 340km^2. Landslide is the most common natural phenomenon in the area and it is usually triggered by heavy rainfall. Although there are few active landslides, they have represented a serious threat to human activity and the fairly numerous infrastructures.

Landslide hazard mapping is essential for land-use activities and management decision-making in mountainous areas. The present work aims at contributing to further understanding on the predisposing factors to landslides as well as proposing a method that allows us to weigh up the influence of various factors on landslides in order to construct a realistic map of potential landslide hazards. Analysis of landslide hazard requires evaluation of the relationships between various terrain conditions and landslide occurrences. In the quantitative approach, several maps representing the spatial distribution of those physical parameters are combined into a hazard map at a higher degree of objectivity.

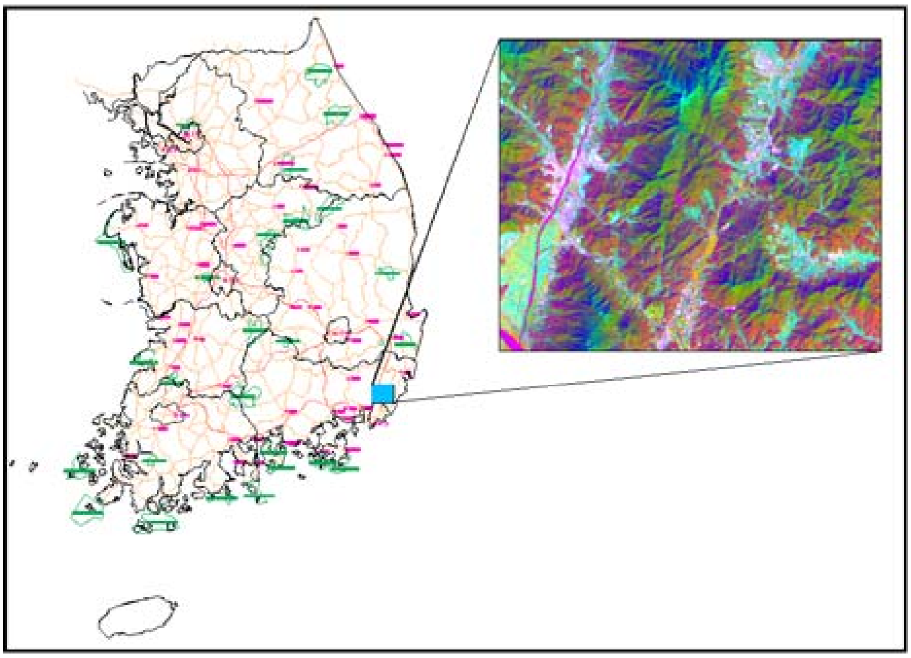


Figure 1. Study area.

2 METHODOLOGY

As slope instability processes are the product of local geomorphic, hydrologic and geologic conditions (Soeters and van Westen, 1996), several different methods for assessing landslide hazard were proposed or implemented by consider physical parameters that may affect probability of landslide occurrence. In this study, the relative importance of each terrain parameter as a determining factor of slope instability was quantitatively determined by weights-of-evidence (WofE) method.

Weights-of-evidence is a quantitative data-driven method used to combine datasets (Bonham-Carter, 1994; Carranza, 2002). It uses a log-linear form of the Bayesian probability model to estimate the relative importance of evidences by statistical means. This method was developed at the Canadian Geological Survey (Bonham-Carter et al, 1990) and was applied to the mapping of mineral potential. In the Bayesian approach, prior and posterior probabilities are amongst the most important concepts.

Given an area of study that contains certain number of landslides, the prior probability that a landslide occur per unit area is calculated as the total number of landslides over the total area.

$$P\{D\} = N\{D\}/N\{T\} \qquad (1)$$

This initial estimate can be later increased or diminished in different areas by the use of other evidences.

If a binary map, representing new evidence, B, is also present, the probability of finding a new deposit given the presence of the new evidence can be expressed as a conditional (or posterior) probability:

$$P\{D|B\} = \frac{P\{D \cap B\}}{P\{B\}} = P\{D\}\frac{P\{B \cap D\}}{P\{B\}} \tag{2}$$

Conversely, the posterior probability of a deposit given the absence of the new evidence can be expressed as:

$$P\{D|\overline{B}\} = P\{D\}\frac{P\{\overline{B} \cap D\}}{P\{\overline{B}\}} \tag{3}$$

Probability (P) can be expressed as odds (O) or vice versa using the equation:

$$O = P/(1-P) \tag{4}$$

Therefore, equations (2) and (3) can be expressed, respectively, in an odds formulation as:

$$O\{D|B\} = O\{D\}\frac{P\{B|D\}}{P\{B\,|\,\overline{D}\}}, \text{ and} \tag{5}$$

$$O\{D\,|\,\overline{B}\} = O\{D\}\frac{P\{\overline{B}|D\}}{P\{\overline{B}|\overline{D}\}} \tag{6}$$

where $O\{D|B\}$ and $O\{D|\overline{B}\}$ are the posterior odds of a landslide given presence and absence of evidence B.

Logits are natural logarithms of odds and they are used in weights of evidence modeling. The natural logarithms are applied to both sides of equations (5) and (6) obtaining the next equations:

$$Logit\{D|B\} = Logit\{D\} + W^+, \text{ and} \tag{7}$$

$$Logit\{D|\overline{B}\} = Logit\{D\} + W^- \tag{8}$$

where W^+ is the positive weights-of-evidence when evidence B is present, and W^- is the negative weights-of-evidence when evidence B is absent.

Positive and negative weights (W^+ and W^-), which combine these conditional probabilities (Bonham-Carter, 1994):

$$W^+ = log_e\frac{P\{B|D\}}{P\{B\,|\,\overline{D}\}}, \text{ and} \tag{7}$$

$$W^+ = log_e\frac{P\{\overline{B}|D\}}{P\{\overline{B}|\overline{D}\}} \tag{8}$$

The weights of evidences for all predictor variables are combined in order to estimate the conditional probability of landslide occurrence given the presence and absence of all the binary predictor variables. Combining the weights of evidences of the different binary predictor maps requires an assumption that the input maps are conditionally independent.

3 APPLICATION

To investigate the influence of physical parameters to landslides, in this paper, the correlations of landside occurrences and parameters such as lithology and structure, slope gradient, slope aspect, elevation, vegetation, drainage and land-use were analyzed by Bayesian statistical model.

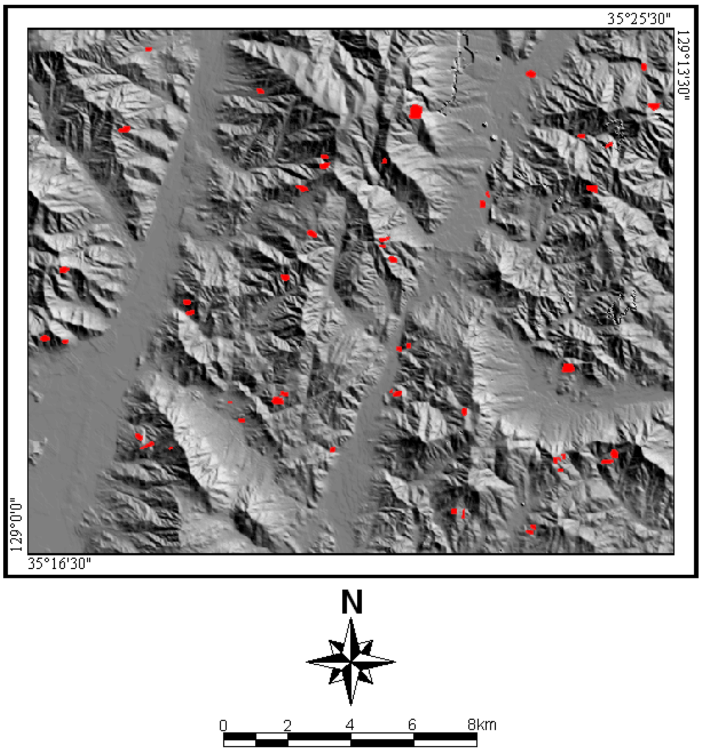
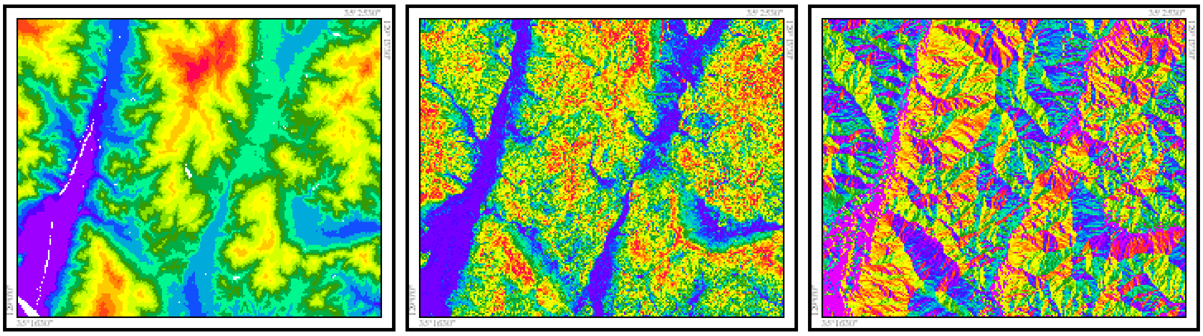


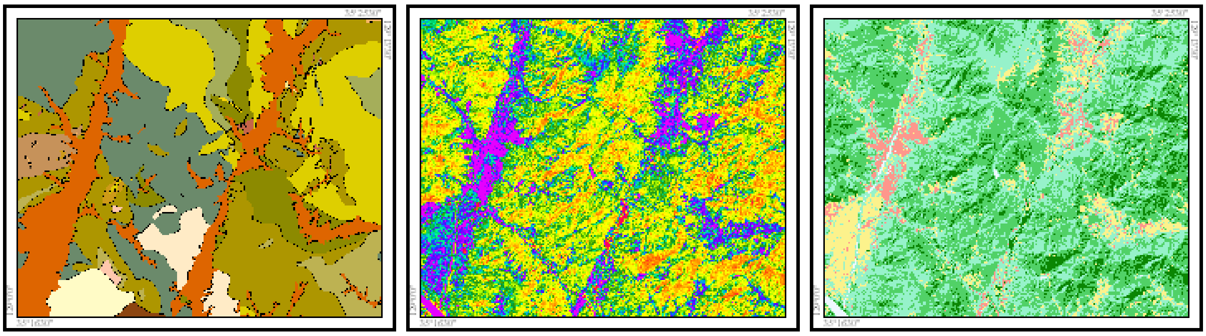
Figure 2. Landslide location

The landslide locations are defined by a detailed field survey at a 1:5,000 scale and aerial photo interpretation. The morphological and structural setting of the area control the form of mountain ranges which approximately parallel to the north-south faults. Drainage of the area is closely related to the structural lines and it has a general trend of north-northeast to south-southwest.

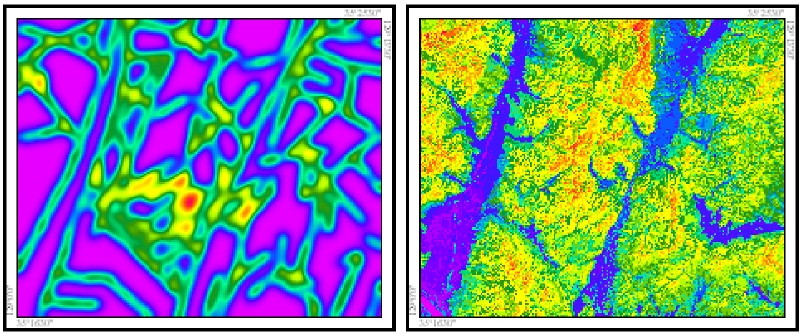
In order to analyze landslide susceptibility efficiently, the landslide distribution map and the other maps are digitized and processed in GIS. The factors were converted to a $30x30m^2$ grid and the total cell number was 377,400, and the number of landslide occurrence cells is 2,432. Using GIS software, a grid of 680x555 with a point spacing of 30m was overlaid with each parameter layer in the study area (figure 3).



DEM Slope Aspect



Geology Vegetation Landuse



Lineament Drainage

Figure 3. Landslide controlling factors

The hazard map (figure 4) was produced by multiplying the weights of the classes with the weights of the parameter maps, and then summing up all weights of each pixel. The susceptibility map was eventually divided into four hazard classes: very low, low, moderate and high. The ranges of the individual categories were derived from the histogram of the estimated susceptibility to landslides.

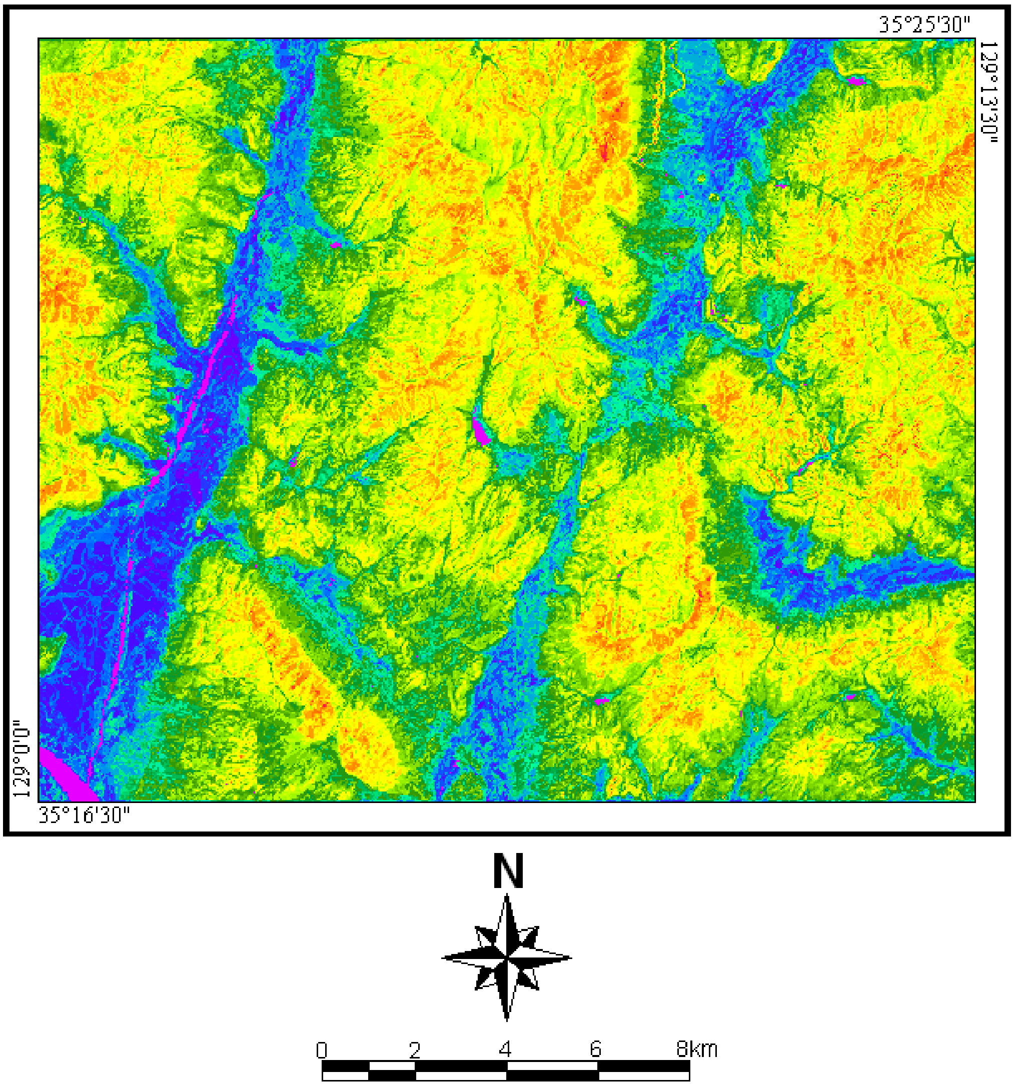


Figure 4. Landslide susceptibility map

Most of the locations of the identified landslides actually fall into moderate and high classes of the produced susceptibility map. This validates the applicability of proposed methods, approaches and classification scheme.

4 CONCLUSION

The paper has demonstrated that, the considered factors have had a strong influence on the occurrence of landslides in study area. Method of weights of evidence with the application of GIS-assisted indirect multi-criteria evaluation techniques has been shown a relatively simple and cost-effective approach for assessing landslide hazard when costly geotechnical and groundwater data are not available at adopted scale. The susceptibility map is useful for hazard prediction, planning land use and construction

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