THE EFFECTS OF UNCERTAIN TOPOGRAPHIC DATA ON SPATIAL PREDICTION OF LANDSLIDE HAZARD

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ABSTRACT GIS-based spatial data integration tasks have used exhaustive thematic maps generated from sparsely sampled data or satellite-based exhaustive data. Due to a simplification of reality and error in mapping procedures, such spatial data are usually imperfect and of different accuracy. The objective of this study is to carry out a sensitivity analysis in connection with input topographic data for landslide hazard mapping. Two different types of elevation estimates, elevation spot heights and a DEM from ASTER stereo images are considered. The geostatistical framework of kriging is applied for generating more reliable elevation estimates from both sparse elevation spot heights and exhaustive ASTER-based elevation values. The effects of different accuracy arising from different terrain-related maps on the prediction performance of landslide hazard are illustrated from a case study of Boeun, Korea.

KEY WORDS: Data Integration, Accuracy, Landslide, Kriging

1. INTRODUCTION

GIS-based spatial data integration tasks usually deal with multiple spatial data sets as input data. Since several multi-source spatial data are considered simultaneously, different degrees of reliability and accuracy would affect the final integration result. Thus, a sensitivity analysis for their effects should be properly considered in data integration tasks.

Topographic data including elevation and slope have been regarded as one of important input data layers for landslide hazard mapping. These elevation and slope maps can be generated from various data types and sources such as spot heights and contours. The elevation map can be generated by interpolating these elevation data types. Alternatively, aerial photographs or satellite-based stereo images can be used to generate the elevation map by applying digital photogrammetric techniques. No matter the way in which such elevation estimates are constructed, they are inherently uncertain and may affect the associated slope values and further analyses.

In this paper, the effects of elevation estimates derived from different sources on landslide hazard mapping are investigated. Three different elevation estimates are considered: 1) ground-based sparsely sampled spot height data, 2) exhaustive elevation data derived from ASTER stereo images, and 3) an integrated elevation data sets which account for above two different sources of elevation and was generated via geostatistical kriging. Slope values are computed from elevation maps constructed using different input data combinations and the associated performances of landslide hazard mapping is illustrated through a case study of Boeun, Korea.

2. STUDY AREA AND DATA SET

The present study was conducted at Boeun area, Korea, which suffered heavy landslide damage following intense rainfall event in 1998 (Lee *et al.*, 2008). Among several GIS layers constructed by Lee *et al.* (2008), a landslide location map including 459 past landslides and an elevation map generated from ASTER stereo images were only considered to investigate the effects of terrain-related variables on landslide hazard mapping. The average elevation error reported in Lee *et al.* (2008) was about 6.88m by comparison of a digital topographic map at 1:25,000 scale. In addition, 1292 elevation spot height points were extracted from the digital topographic map and were regarded as hard elevation data.

3. CASE STUDY

3.1 Processing of Elevation Data

We first examined how strong elevation values from ASTER were correlated with those at hard spot height locations. A strong linear relationship was obtained ($r \sim 0.96$). From this linear relationship between hard and soft data, it might be expected that the integration of ASTER-based elevation would result in the improvement of accuracy of elevation values estimated at unsampled locations.

As for the integration of sparsely sampled hard spot height data with exhaustively sampled ASTER-based data, kriging with an external drift (KED) was chosen among various multivariate kriging algorithms. KED is an extension of kriging to accommodate a trend model and a smoothly varying secondary variable is used to derive the trend of the primary variable (Goovaerts, 1997). Unlike simple kriging with varying local means (SKlm), the unknown regression coefficients for modeling the linear relationship between primary and secondary variables are locally estimated through the kriging system with each search neighbourhood (Goovaerts, 1997). Interested reader should refer to Goovaerts (1997) for a detailed description on KED.

For comparison purposes, elevation values at unsampled locations were estimated through ordinary kriging (OK) using only the 1292 spot height elevation data (Figure 1). The OK-based elevation map shows much smoother patterns of elevation values than those from ASTER and KED, which is a typical characteristic of kriging. Leave-one-out cross validation was carried out to compare the prediction performances of OK and KED. The integration of soft data which have a strong linear relationship with the hard data lead to the improvement of prediction performance in terms of root mean square error (OK: 18.77 vs. KED: 13.99). This result means that accounting for ASTER-based elevation data can complement the sparsely sampled spot height observation and thus improve the accuracy of elevation values estimated at unsampled locations. For subsequent for landslide hazard mapping purposes, three slope maps were generated from three different elevation maps and are shown in Figure 1.

3.2 Data Integration for Landslide Hazard Mapping

Land slide hazard maps were constructed by integrating different elevation and slope maps shown in Figure 2 to investigate the effects of different accuracy arising from different terrain-related maps on the prediction performance of future landslide hazard.

The integration method applied in this study is a likelihood ratio model with empirical kernel density estimation. The joint likelihood ratio values were transformed into rank values to visualize relative hazard levels in the study area (Figure 2). The overall patterns of hazard levels in the three hazard maps are very similar to those of slope values shown in Figure 1. Since the slope patterns were computed from different sources of elevation, it is anticipated that the prediction performance associated with the resulting three hazard maps would be different.

3.3 Validation Results

To quantitatively evaluate the prediction performance of the three different landslide hazard maps shown in Figure 3, a cross-validation approach based on random spatial partitioning of past landslides was carried out. The prediction rate curve (Chung and Fabbri, 1999) was computed from relative hazard values at all landslide locations as a quantitative prediction of landslides.

The cross-validation results based on different sources of elevation are shown in Figure 3. The best prediction performance was obtained from KED-based elevation and slope. The map of elevation constructed using OK of spot heights only showed the worst prediction rate values. If the most hazardous 10% of the area is considered, then about 24% of the landslides are located in the KED-based landslide hazard map. In the case of ASTER- and OK-based hazard maps, about 21% and 16% of landslides are located in that area, respectively. By using elevation estimates which can account for both sparsely sampled hard spot heights and satellite-based soft elevation data, more realistic topographic data with less uncertainty could be generated and thus the best prediction performance could be obtained. When considering that ground-based field surveys are limited by the cost of sampling and accessibility, soft information from remote sensing data, which provides exhaustive information over the area of interest, would be a useful information source for thematic mapping

4. CONCLUSIONS

This paper has demonstrated that the integration of elevation and slope maps derived from different sources of data yielded different prediction performances for landslide hazard mapping. The landslide hazard map constructed by using the elevation and the associated slope maps based on geostatistical integration of spot heights and ASTER-based elevation resulted in the best prediction performance. Landslide hazard mapping using elevation and slope maps derived from the interpolation of only sparse spot heights showed the worst prediction performance.

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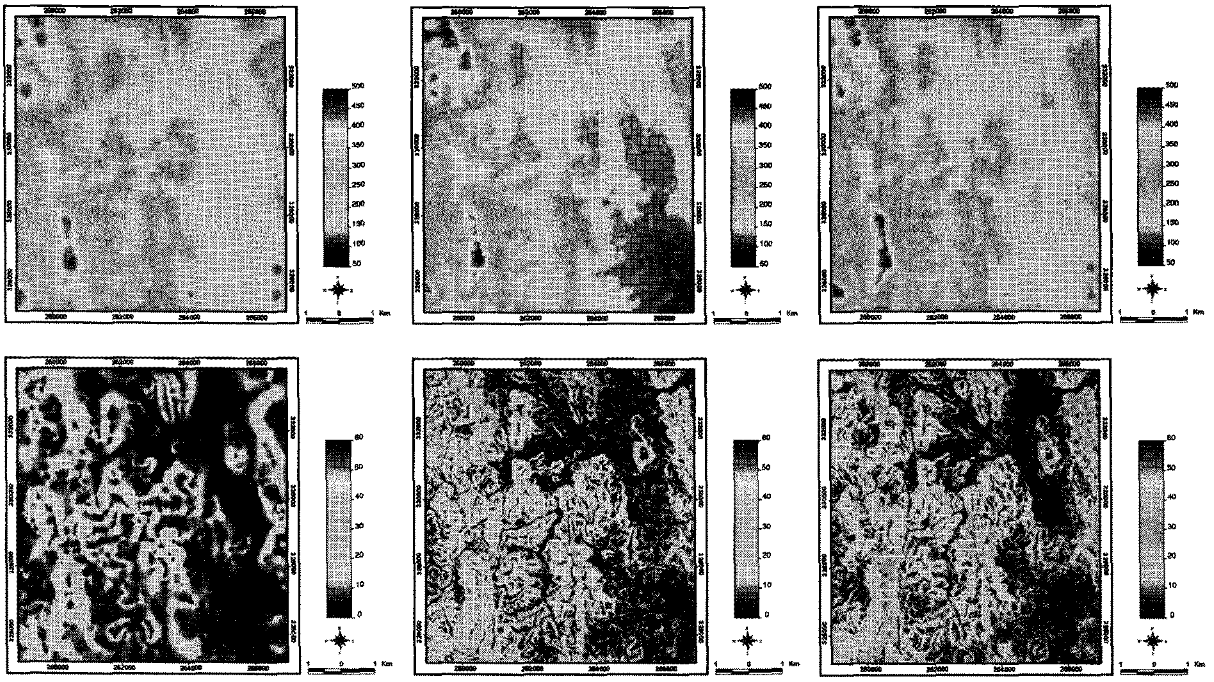

Figure 1. Elevation and slope maps derived from three different sources of elevation (left: OK of spot heights, middle: ASTER, right: KED of spot heights and ASTER elevation, upper: elevation, lower: slope)

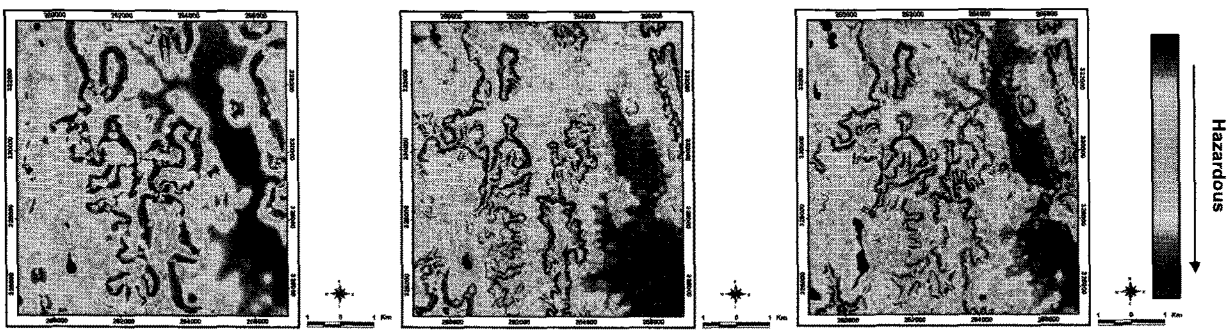

Figure 2. Landslide hazard map based on elevation and slope, from: (left) OK of spot heights, (middle) ASTER, (right) KED of spot heights and ASTER elevation.

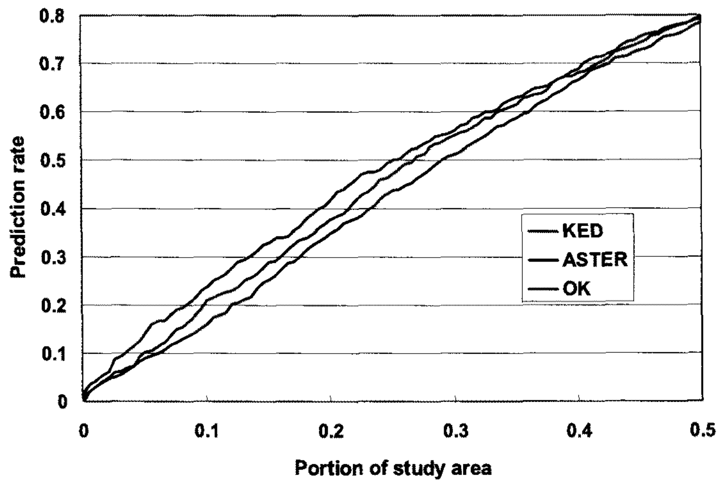

Figure 3. Prediction rate curve based on random partitioning of past landslides.