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Assessment of ground subsidence using GIS and the weights-of-evidence model

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ABSTRACT

The weights-of-evidence model, one of the Bayesian probability models was applied in evaluating a ground subsidence spatial hazard near abandoned underground coal mines (AUCMs) at Magyori area, Samcheok City in Korea using GIS. Using ground subsidence location and a spatial database containing information such as mining tunnel, borehole, topography, geology, and land use, the weights-of-evidence model was applied to calculate each relevant factor's rating for the Magyori area in Korea. Seven major factors controlling or related to ground subsidence were determined from the probability analysis of the existing ground subsidence area; depth of drift and distance from drift from the mining tunnel map, slope gradient obtained from the topographical map, ground water level and permeability from borehole data, geology and land use. Tests of conditional independence were performed for the selection of factors, allowing 6 combinations of factors to be analyzed. For the analysis of mapping ground subsidence spatial hazard, the contrast values, W^+ and W^-, of each factor's rating were overlaid spatially. The results of the analysis were validated using receiver operating characteristic (ROC) with the previous ground subsidence locations. In the case of all factor used, the area under the ROC curve (AUC) showed 0.9667, which corresponds to an accuracy of 96.67%. In the case of the combinations, the case of distance from drift, depth of ground water and land use used, showed the 90.71% (AUC: 0.9071) accuracy which is the best result produced in this analysis. The results can be used for hazard prevention and land-use planning near AUCM areas.

1. Introduction

The presence of ground subsidence near abandoned coal mine areas can be hazardous to people and property because of its tendency to happen without warning. The prognostication has recently become a serious social problem in Korea, since almost all underground coal mines have been abandoned, and few remain since 1989. However, the effort of scientifically assessment of susceptible ground subsidence areas is very few, especially in coal mining areas where the structures of the geology and mining area complex. Thus, this study aims to quantitative assess ground subsidence for spatial hazard mapping around an abandoned underground coal mines (AUCMs) area by applying the weights-of-evidence method with validation of results. As a basic analysis tool, a Geographic Information System (GIS) was used for spatial data management and manipulation.

A method that assesses the probability of ground subsidence empirically, within surprisingly narrow limits considering the form of the input data, has been suggested (Goel and Page, 1982) using (1) the intact strength of the rock, (2) the stress field, (3) the geological structure, (4) the depth of the mining horizon, (5) the extent of the mined area, and (6) the volume extracted per unit area of mining. The National Coal Board has published a basic technique to determine the estimated area influenced by ground subsidence based on the height of the cavity, the width of the mined panel, and the angle of inclination of the coal seam (National Coal Board, 1975). The method used to assess the subsidence area is dependent on the structure of the local geology and the coal-mining method used, and the empirical methods discussed above were developed for conditions involving horizontal coal seams and longwall working, which are predominant in Europe. However, in Korea, there are coal seams of various widths, and irregularly inclined coal seams and strata because of the heterogeneous structure of the geology, so the slant-chute block caving method has been used. As a result, a sinkhole type of subsidence is usual, and therefore a different estimation of ground subsidence is necessary. Table 1 shows the factors that commonly affect sink-hole-type ground subsidence over time (Coal Industry Promotion

Table 1
Factors affect sink-hole type ground subsidence (Coal Industry Promotion Board, 1997).

Occurrence of ground subsidence	Progress	Ground collapse
———————————	During time after abandoned mine	——————→
·Mechanical character of Rock mass ·Flow of ground water ·Structural geology (joint, fault, dyke) ·Excavation method ·Rate of excavation ·Back filling	·Flow of ground water ·Structural geology ·Rate of cubical expansion ·Rate of mining	·Depth of mining ·Height of cavity

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Board, 1997). Furthermore, quantitative analysis of presumptive ground subsidence near AUCMs in Korea has not been well studied heretofore. However, some researchers have recently attempted to evaluate subsidence hazard using probabilistic (Galve, 2009a, b; Lee et al., 2010; Kim, 2006), statistic (Lee et al., 2010; Kim et al., 2006), multicriteria decision (Mancini et al., 2009), artificial neural network (Kim et al., 2009), fuzzy operator (Choi et al., 2010) analysis, etc., in GIS environment. In this study, ground subsidence spatial hazard was evaluated using GIS based on the weights-of-evidence model. The approach generally uses dichotomous maps, and the generalization and reclassification of geodata into dichotomous maps may result in distortion and possible loss of valuable information. Moreover, reclassification rules are based on available information and these rules may change as more information becomes available (Porwal, 2006). The model was originally developed for mineral potential assessment (Agterberg et al., 1990, 1993; Bonham-Carter et al., 1989; Bonham-Carter, 1994; Alok and Hale, 2000; Emmanuel et al., 2000; Harris et al., 2000; Venkataraman et al., 2000; Asadi and Hale, 2001). Also the model was applied to landslide hazard mapping (Lee and Choi, 2004; Neuhäuser and Terhorst, 2007; Dahal et al., 2008a,b). The difference of this study from the other studies is the application of the GIS-based weights-of-evidence method to ground subsidence spatial hazard mapping.

The Magyori carefully assessed field investigations and reinforcement reports related to ground subsidence was selected as a suitable study area where 21 signs of ground subsidence have been indentified near an AUCM at Samcheok City (Coal Industry Promotion Board,

Fig. 1. Photographs of ground subsidences in the study area (above: near railroad, the gabions have bended due to ground subsidence. below: in the field, the ground has sunk by ground subsidence).