Landslide risk assessment using frequency ratio model and flow analysis in Gumdeok mine, North Korea

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ABSTRACT

The purpose of this study is to identify landslide hazard around Gumdeok zinc mine in North Korea. Since it is impossible to conduct site survey in North Korea, the analysis was carried out using satellite images and GIS data. A landslide inventory map was produced from high resolution satellite image. Then, elevation, slope, aspect, curvature, distance from water were used as landslide factors for frequency ratio model in producing landslide hazard map. Lastly, landslide risky areas affected by the flow of soil were identified by applying multiple flow analysis. Overall accuracy of predicting landslide risk from frequency ratio model was about 75%. Because North Korea is not systematically equipped with roads and railway networks compared to South Korea, damage caused by landslides can lead to massive disruption in the transportation of mining products. Therefore, it is essential to prevent any damages caused by landslides through reinforced construction. This study is expected to be used for as a basic data for constructing infrastructure for mineral resource development cooperation.

1 INTRODUCTION

In Korea, due to the industrial structure centered on heavy industry, mineral resources are very important. However, most of them are imported from abroad because of lack of mineral resources and low self-sufficiency rate. In particular, metals such as iron ore, copper, and zinc, which depend on imports for most of the demand, are sensitive to price fluctuations in the international resource market. One of the ways to reduce the economic instability can be resource development cooperation with North Korea. North Korea is known to have relatively rich mineral resources compared to South Korea. In addition, North Korea is very close to South Korea in comparison with other countries, so it has advantages in terms of transportation of mineral resources. Mining development cooperation can also contribute to revitalizing North Korea's economy.

Of the various kinds of minerals, zinc (Zn) is expected to have a great effect on the cooperation of mineral resource development. Zn is one of the most important metals in Korea, and is known to be buried in North Korea in a large scale. In particular, the Gumdeok mine, which is one the largest Zn mine in North Korea, has great potential. However, the Gumdeok mine has been flooded by heavy rainfalls and typhoons in 2007 and 2012, and nearby facilities have been damaged by landslides. Therefore, measures should be taken against floods and landslides.

The purpose of this study is to evaluate the risk of landslides around the Gumdeok mine for mine development cooperation in the future and to find the place where landslide can occur. The risk of landslides was assessed through spatial analysis using satellite images and geographic information system (GIS) data. First, through the high-resolution satellite images, we found an area where a landslide occurred near the Gumdeok mine in North Korea and produced an inventory map of landslides. The frequency ratio analysis was performed to assess the relationship between the inventory map and the landslide inducing factors and evaluate the landslide risk. In addition, we found the landslide risky area by using multiple flow analysis.
2 MATERIALS

2.1 Study area

The Gumdeok mine is an underground mine located at an altitude of 630 ~ 1700 m above sea level, with a total area of over 100 km². The ore deposits are composed of sedimentary metamorphic rocks and intrusive rocks penetrate them. The strata generally have a north-south strike with a slope of 60 to 80 degrees to the east. Of the more than 50 kinds of minerals found in the Gumdeok mine, industrially valuable minerals are zeolite, galena, and brassite. The reserves are estimated to be about 300 million tons based on the ore amount, and the grade of 5.09%.

In the Gumdeok mine, inundation occurred due to rainfall in 2007 and 2012, resulting in production disruption. The floods destroyed the sedimentation basin, causing the production to stop in the concentrator. In addition, the water has risen up to the end of the mine pit and caused severe damage to the hauling line. Landslides caused by floods destroyed railway stations and railways.

2.2 Data

We used the World Imagery data from ESRI ArcGIS software as a base map to build an inventory map for occurred landslides near the Gumdeok mine. After finding the landslide area through the satellite image data, the correlation between these landslides and the landslide inducing factors was analyzed. The altitude data were obtained from the ASTER Global DEM (Digital Elevation Model) data and the factors such as slope angle, elevation, curvature and aspect were extracted from the corresponding DEM data. The distance from the water system is calculated from the water information provided through the Open Street Map. All five of these raster data were converted to have a spatial resolution of 30 m. The data for the five factors used in the analysis are shown in Figure 1.

![Landslide factors](image)

Figure 1: Landslide factors (a) Elevation, (b) Aspect, (c) Distance from water, (d) Slope, (e) Curvature

3 METHODS

3.1 Landslide inventory map construction
In the process of assessing the risk of landslides, it is necessary first to find areas where landslides have occurred in the past and to construct a landslide inventory map. Previous studies have used aerial imagery and satellite imagery to investigate areas where landslides have occurred and to investigate them in person. There have been some studies on constructing inventory map using satellite imagery such as ASTER stereo images and multispectral images (Alkevli et al., 2011), SPOT-5 images (Moine et al., 2010) and Landsat TM and ETM + multispectral images (Sato et al., 2009). In North Korea, it is difficult to conduct aerial imagery and directly investigate through field visits. Therefore, the satellite image of resolution 0.5m provided by DigitalGlobe was analyzed in this study. Then, regions where landslides have appeared in the past were extracted.

3.2 Frequency ratio model for landslide susceptibility

Frequency ratio model was used to identify the relationship between landslide location and factors (Lee and Pradhan, 2007). Using the frequency ratio model, frequency ratios for the class or type of each factor were calculated by dividing the landslide occurrence ratio by the area ratio. If the frequency ratio is 1, it means that the ratio of the category to the total area and landslide area is the same. If the value is greater than 1, it means that the relationship between the category and landslide occurrence is large. When the frequency ratio of each factor is calculated, the landslide index (LSI) can be calculated by adding the value of each frequency ratio.

3.3 GIS-based flow analysis for landslide risky area

When a landslide occurs, the landslide flows down from the point where landslides occur and damages various facilities around. Therefore, it is important to understand in which direction the soils move down. Therefore, in this study, we conducted a flow analysis to find out which of the major infrastructure facilities such as residential area, industrial area, roads and railways around the mine would be affected by landslides. In this study, a multiple flow algorithm (Freeman, 1991) was applied to model the diffusion of soil in various directions. The single-flow algorithm computes that the fluid flows in one direction with the greatest slope, while the multi-flow algorithm computes that the flows into all grids that are lower than the center grid.

4 RESULTS

The risk map of the landslide obtained from frequency ratio model is shown in Figure 2a. This area is within the top 20% when the landslide risk is expressed as a percentage. The slope of the west side of the mine seems to have a great risk of landslide. It also can be seen that the surrounding area of the Ryongyang mine, which is North Korea's representative magnesite mine has a high risk of landslide. In addition, the risk of landslides increases with the proximity of water areas.

Assuming that the landslide occurred in the top 5% of the landslide risk, the flow of sediment from this area was analyzed in Figure 2b. Based on this result, the hazardous areas affected by landslide were analyzed for residential areas, industrial areas, roads, and railways around the mines. In residential areas around mine, landslides are more likely to occur on the northwestern slope, and the soil is likely to affect the central and western regions of the residential area. In industrial areas, the risk of landslides is high because the area is surrounded by steep slopes, and the soil is likely to flow down from the north and west slopes. Because North Korea is not systematically equipped with roads and railway networks compared to South Korea, damage caused by landslides can lead to massive disruption in the transportation of mining products. In particular, railways in this region are the only means of transporting Zn from the Gumdeok mine to the smelter. Therefore, it is essential to prevent any disruption to railway transportation caused by landslides through reinforcement work in areas where the possibility of landslide damage is high.
CONCLUSIONS

In this study, we analyzed the risk of landslides near the Gumdeok mine using high resolution satellite imagery and frequency ratio model. In addition, when landslides occur in areas with high landslide risk, we predicted areas where damage could be caused by the flow of soil. Although the industrial and residential area near Gumdeok mine are relatively safe, there is a possibility that some areas will be damaged by the landslide. Therefore, it is necessary to carry out the reinforcement work for the landslide risky area. This study has a limitation of low accuracy due to the inaccessibility to North Korea. Although high-resolution satellite images have been used for this study, it is necessary to improve and validate the accuracy of landslide risk assessment through a field investigation in the future. In addition, five factors were used in this study because of the limit of data acquisition. If more data such as soil map and geological map can be obtained, it is expected that the accuracy of results can be improved. Although the accuracy of the analysis is limited because of scarce data, this study is of great value as a useful basic resource for landslide analysis in North Korea. In the future, it will be possible to improve the accuracy of the research results by acquiring detailed and precise data of the region through active cooperation with North Korea.

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