Development of a GIS-based Spatial Database for the Debris Flow Hazard Assessment of Expressways in South Korea

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***Abstract*—In this study, a database based on the geo-information system (GIS) was developed for the debris flow hazard assessment of expressways in South Korea. The debris flow assessment method developed by the Korea Expressway Corporation (KEC) was used for estimating the debris flow hazard grade and for building the database schema. PostgreSQL was selected as a database management system, and PostGIS was used to process the spatial data. The primary information (e.g., expressway, rainfall, digital numerical map, processed information) assess using the KEC method can be standardized and stored in the constructed database. So far, the database was established based on the expressway and debris flow hazard information of 4,478 points along the 22 expressways in South Korea.**

Keywords- Database; debris flow; GIS-based; hazard assessment; expressway.

I. INTRODUCTION

Understanding the mechanism of debris flow is essential for forecasting occurrence and estimating its hazard. There are various factors, however, that affect debris flow occurrence and movement. Many research institutes and national agencies dedicated to mitigating the debris flow hazard have developed their own assessment method [1]-[3]. For instance, Korea Forest Research Institute developed a prediction model for debris flow occurrence and damage, and published a landslide/debris flow hazard map [3]. They highlighted not only the geological, geomorphological, geotechnical, and hydrological factors but also the dendrology factors like the vegetation condition.

Owing to the diversity of the factors affecting debris flow occurrence and movement, developing a debris flow database based on the geo-information system (GIS) has become essential for evaluating the hazard grade in wide regions such as the stations along the expressways. The mapping of the debris flow hazard and the development of a GIS-based database system can be made possible by the use of the constructed debris flow database.

In this study, a debris flow database was developed for the hazard assessment of the mountainous areas near the expressways in South Korea [4]. The database schema was built using the framework for the GIS-based assessment of the debris flow hazard of Korea Express Corporation (KEC). The method developed by KEC focuses on the possibilities of road hazards. The method can be quantitatively and objectively implemented in a simple way by using documents such as numerical maps and expressway design files, minimizing the need for tiresome field investigations on countless potential debris flow occurrence regions in vast areas.

In Section 2, the KEC debris flow hazard analysis method is described. Section 3 describes the database framework for hazard assessment and Section 4 describes the constructed GIS-based database for expressways. Finally the conclusion is provided in Section 5.

II. RESEARCH METHODOLOGY

The KEC debris flow hazard analysis method uses a limited amount of data. Therefore, it is applicable in a national scale. Only digital elevation models (DEMs) and expressway design files of the mountainous area to be assessed are used. The DEMs can be obtained from Korea National Geographic

 ISBN: 978-1-61208-539-5

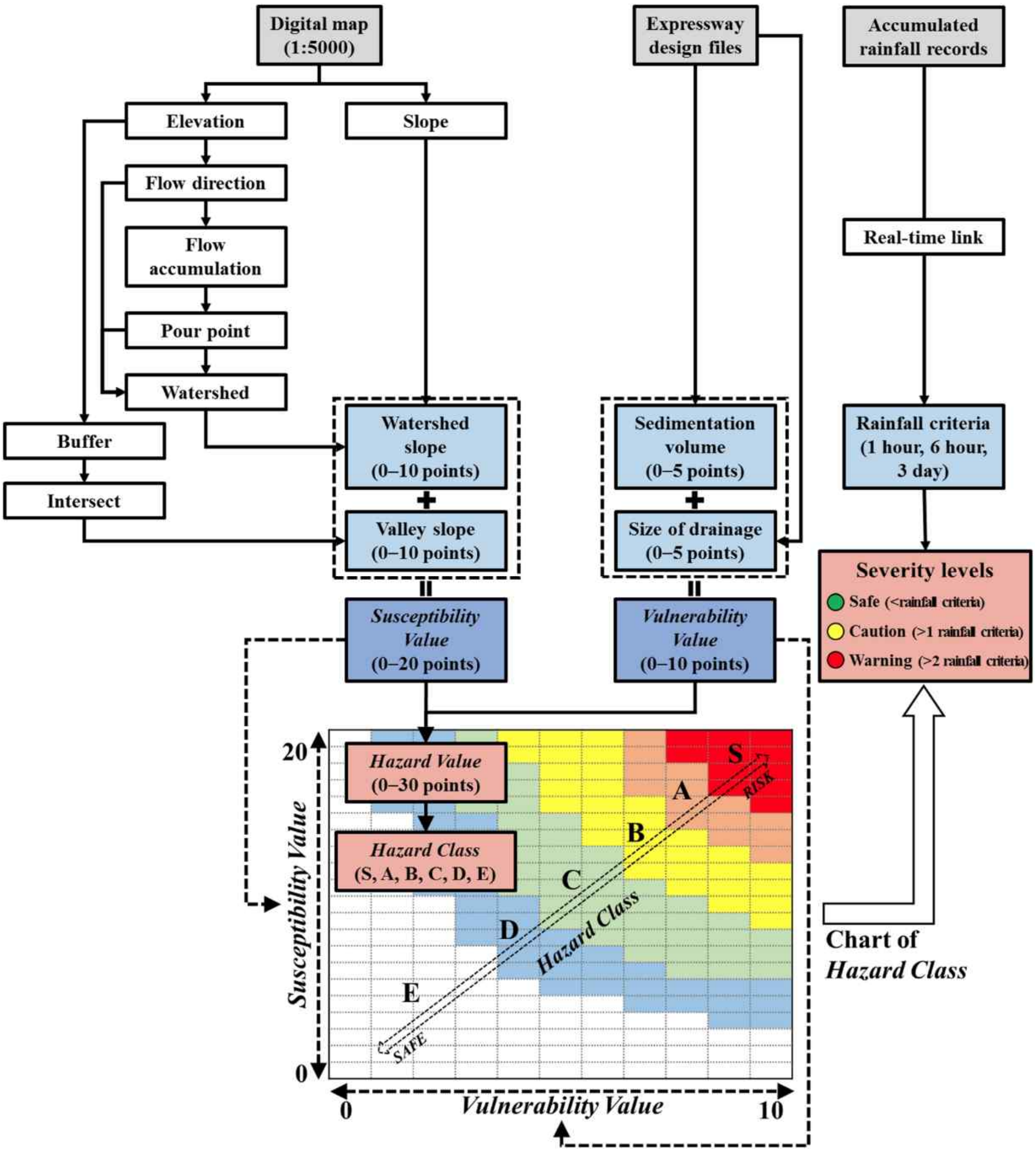

Figure 1. Debris-flow hazard assessment framework for expressways. [5]

Information Institute (KNGII), and the expressway design files can be obtained from KEC.

The debris flow hazard is evaluated using with two indices (Fig. 1): the susceptibility value and vulnerability value. The susceptibility value is the degree of likelihood that a debris flow will occur in the target area whereas the vulnerability value pertains to the degree of likelihood that the occurred debris flow will actually damage or have an impact on the expressway sections.

The susceptibility value is the combination of the debris flow initiation point and the debris flow movement point. For the calculation of the debris flow initiation points, the mean watershed slope degrees and the percentage of watershed over 35° are used. The values of the mean watershed slope degree point and the percentage of watershed over the 35° point are between 0 and 5, respectively. Therefore, the value of the debris flow initiation point is between 0 and 10. For the calculation of the debris flow movement points, the mean valley slope and the length percentage of the valley with slopes over 15° are used. The value of mean valley slope point and the length percentage of valley are between 0 and 5, respectively, and that of the debris flow movement point is between 0 and 10.

In the KEC debris flow hazard assessment method, only the DEMs data are considered for the debris flow possibilities, which are expressed as susceptibility values. The other factors that affect the debris flow possibilities, such as the size and shape of the valley, along with the variations in the slope direction, the properties of the subsoil, and the vegetation, are not used for calculating the susceptibility value for the simplification of the method.

The vulnerability value can be assessed based on the volume of the margin area for depositing debris flow materials before reaching the expressway structures, and the sizes of the drainage facilities running through the expressway. The sedimentation volume attribute, which refers to the volume of the margin area, has a value between 0 and 5, and the size of the drainage attribute is also between 0 and 5. The total vulnerability value can be up to 10 points according to the grading standard.

With the calculated susceptibility and vulnerability values, a hazard class is given for a target expressway section (Fig. 1). The x- and y-axis indicate the vulnerability and susceptibility values, respectively. Based on the results of the investigations of the past debris flow occurrences, the hazard classes were separated by rainfall reoccurrence period for expressway design purposes. Hazard class S indicates the likelihood of debris flow occurrence in areas with 2- to 5-year rainfall reoccurrence periods. Hazard classes A, B, C, and D have 5- to 20-year, 20- to 50-year, 50- to 100-year, and over-100-year rainfall reoccurrence periods, respectively. Hazard class E indicates an area with a very low likelihood of debris flow damage [4]-[6].

III. DEBRIS FLOW HAZARD ASSESSMENT DATABASE FRAMEWORK

For data storage and debris flow hazard management, a database was developed. The developed database can be called "geodatabase (GDB)" because it is a container for spatial and attribute data. PostgreSQL (Ver. 9.5) was chosen for the database management system (DBMS), and PostGIS was used to assign the spatial attributes of the expressways. PostGIS is a specified extension function of PostgreSQL for storing GIS objects. It provides spatial objects for the PostgreSQL database, allowing the storage of and query on information about location and mapping [7][8].

Fig. 2 shows the structure of the geodatabase for debris flow hazard assessment. The database basically contains information on two information classes: primary information and processed information. Primary information stores not only general expressway, and rainfall information but also digital numerical-map data. The basic topographical information, which is used for calculating the susceptibility value of the hazard assessment system, is derived from the digital numerical-map data. The expressway information is composed of organization information used to manage the

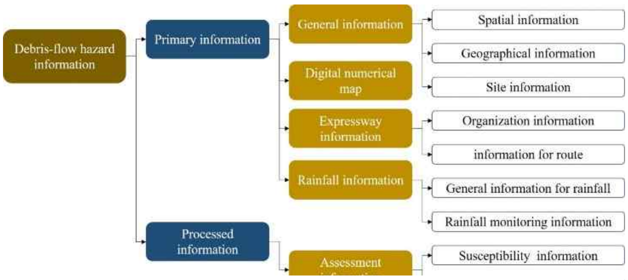

Figure 2. Structure of the database for debris flow hazard assessment.

South Korean expressway route data and spatial information. The rainfall information data format has also been standardized. The rainfall data from automatic weather station (AWS) is essential to the real-time debris flow warning system combined with the hazard assessment system.

Using the standardized primary information data, hazard assessment of the target area can be performed. After that, the results of the hazard assessment, such as the hazard class, susceptibility value, and vulnerability value, should again be stored in the database.

IV. GIS-BASED DATABASE CONSTRUCTION FOR THE EXPRESSWAYS IN SOUTH KOREA

The database construction procedure consists of four parts.

Figure 3. Data collection from the field survey.

First, a field survey is conducted (Fig. 3). The susceptibility value of the hazard assessment system can be computed with only the topographic data from the digital numerical map. A field survey should be conducted, however, to calculate the vulnerability value.

Moreover, it is possible to confirm the factors that need to be considered when calculating the susceptibility value with the naked eyes in the field survey. This helps confirm the accuracy of the susceptibility assessment result.

After the field survey, the result should be reported in a fixed form. The report includes not only the field survey result but also the debris flow hazard class, which was determined

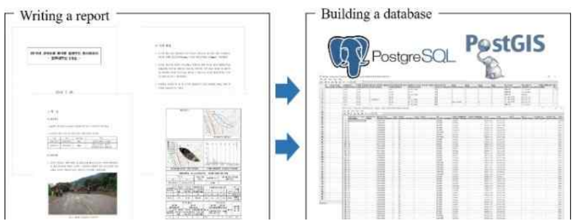

Figure 4. Reporting of results and building of the database.

using the KEC debris flow hazard assessment method. The spatial data, field survey data, and hazard assessment results of the target point were standardized to construct a database using PostgreSQL and PostGIS (Fig. 4).

 ISBN: 978-1-61208-539-5

The data stored in the debris flow hazard database can be inquired about and visualized with the GIS system. In this study, the representative open-source GIS system Quantum GIS (QGIS, version 2.14.3-Essen) desktop was utilized for visualization (Fig. 5) [9]. The green dots indicate the target points for the debris flow hazard assessment along the expressways in South Korea. The information on the debris flow hazard assessment results and field survey results of 4,478 debris flow risk sites along the 22 expressways is being stored in the developed debris flow hazard database up to now. The blue dots mark the 676 AWS points for collecting rainfall data.

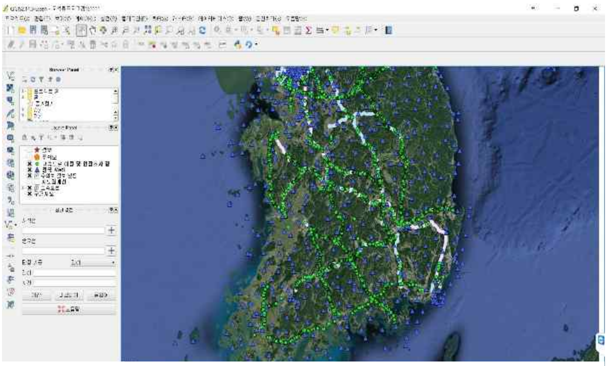

Figure 5. Visualization of the constructed database using Quantum-GIS.

Then, the QGIS plugin was developed to display the picture of the target site and the countermeasurement plan of the debris flow hazard areas (see Fig. 6 and Fig. 7). The

Figure 6. The QGIS plugin for displaying local pictures.

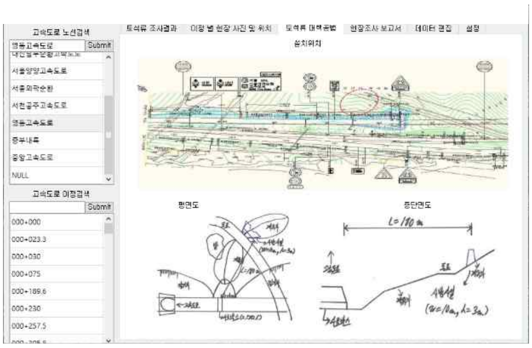

Figure 7. the QGIS plugin for displaying countermeasurement plan.

programming language Python was used to develop the plugins [9][10].

V. CONCLUSIONS

For the effective debris flow hazard management of the expressways in South Korea, a database based on the geo-information system was constructed. To assess the debris flow hazard of the target points along the expressways, the Korea Express Corporation (KEC) method was adapted. The database schema and structure were based on the factors that need to be considered when estimating the hazard grade with the KEC method.

The general information, digital numerical map, expressway information, and rainfall information were standardized. Then the processed information, such as the susceptibility information, vulnerability, and the hazard class information, of a target point were again stored in the database.

Various open-source GIS tools were utilized to construct the database. PostgreSQL and PostGIS provided a database frame for handling the spatial attributes. Moreover, QGIS provided a visualization platform for mapping and inquiring about the information.

The constructed database was used for debris flow assessment on 4,478 points along the 22 expressways in South Korea. Various countermeasurements were applied to the sites estimated to be hazardous among them.

ACKNOWLEDGMENT

This research was supported by a National Research Foundation of Korea grant funded by the South Korean government's MSIP (No.2015R1A5A7037372)

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