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GIS technolgy for analysing regional geologic hazards (Landslides)
광역 지질재해분석(산사태)을 위한 GIS 활용

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Abstract/요 약

GIS(Geographic Information System) technology was applied for analysis of the potential degree of regional geologic hazard, especially landslide hazards in the suburb of Seoul City, whereby a regional geologic hazard map was produced. The factors causing a landslide such as slope geometry, geology, groundwater, soil property, rainfall and vegetation were incorporated through GIS in order to predict the potential hazards in this area. Cartographic simulation was finally made with these factors to produce a regional geologic hazard map. For this study, ARC/INFO and ERDAS systems were used in SUN 4-390 workstation.

GIS를 이용, 서울 근교 지역을 대상으로 광역지질재해도를 작성하여 대상 지역에 대한 광역 지질재해, 특히 사면 붕괴에 관한 분석 연구를 시도 하였다. 사면붕괴를 야기 시키는 요소인 사면형태, 지질, 지하수, 토양의 성질, 강우, 식생 등을 GIS 기법을 이용하여 정량적으로 분석 하였으며, 최종적으로 이들 요소들을 지도모형으로 변환 시켜 광역재해도를 작성하게 되었다. 본 연구를 위하여 SUN 4-390 Workstation 과 ARC/INFO & ERDAS가 이용 되었다

INTRODUCTION

A regional geologic hazard map was produced by GIS in the southern part of Seoul , encompassing about 70 km^2. The study are aimed firstly to predict the landslide potentials and risks, and secondly to utilize the data for land development project of this area. For the hazard analysis in the area, some geoenvironmental factors affecting landsliding have been examined. These include geometry of slope, geology, groundwater, soil property, rainfall and vegetation etc. For application these factors to GIS, a stability rating system was introduced, which allowed the quantitative interpretation of landslide risk. Finally GIS produced a regional geologic hazard map through a cartographic simulation in conjuntion with this rating system.

Comprehensive analyses of the landslide hazards require laboratory test of materials, test borings, geophysical prospecting and numerical modelling analyses of potential failure surfaces(Kim, Y.J.,et al., 1991, 1992). However, this study only limited to the regional analysis of landslides using GIS technology.

EVALUATION OF LANDSLIDE FREQUENCY BY ISOPLETH MAP

Isopleth mapping (Kim,Y.J., and Yu,I.H., 1989) can provide information for assessing the regional landslide hazards through the evaluation of landslide frequency. But isopleth maps only serve as a simple way to predict landslide hazard zonation, although they can be used to reduce landslide hazards. A isopleth map prepared from aerial photographs(May, 1987, 1:10,000 scale) was used to recognize landslide frequency in GIS(Fig.1).

The first step of isopleth map preparation is an inventory of existing landslides by aerial photographs and field verification(Wright,1974, DeGRAFF,1985). A transparent orthogonal grid sheet with 1.3 or 1.6 cm intersection spacing is placed over the landslide inventory map. A counting circle(2.5cm diameter) enclosing an inscribed 20x20 per 2.5cm grid is centered at each intersection. The number of points within the circle over landslide is divided by total number of grid points within the circle and multiplied by 100 to yield a percentage value. This process is repeated until that all intersections have percentage values. Contour lines (isopleths) are then drawn through numbers to represent in given interval or values(landslide frequency, Fig.1-B).

The isopleth map was used in two ways. Firstly, landslide hazard assessment and secondly, recognition of some landslide-susceptible slopes by the overlay technique of slope map and landslide frequcncy map in GIS(Fig.1, Fig.2). DeGRAFF(1985) has presented landslide susceptibility categories identified on isopleth map. The results of two maps overlaid permit to determine new categories in the study area(Table 1), where landslides occur mainly on slopes of less than 30 degrees(Fig.2-A). In the other regions(more than 40 degrees), they are not taking place frequently, but the risk is high(Fig.2-B). Large scale mass movement is not recognized on the isopleth map, but only small ones are seen in some hilly or mountainous terrains.

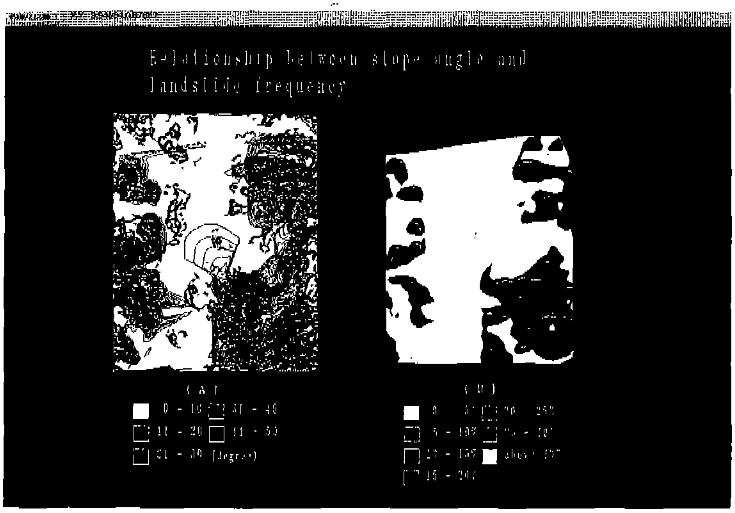

Fig. 1 Overlay of slope map and landslide frequency map
(A) Slope map and isopleth map(black lines) of landslide deposits
(B) Landslide frequency map.

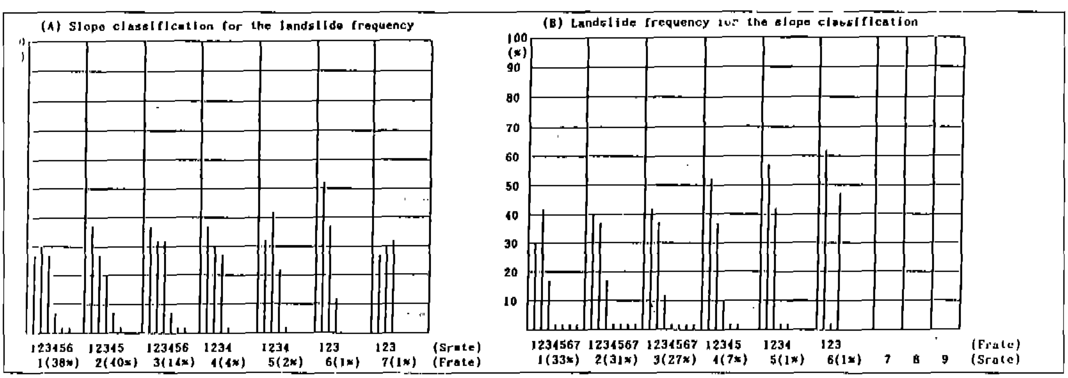

Fig. 2 Relationship between slope and landslide frequency in the study area

* Frate(Landslide frequency): 1: 0-5 %, 2: 5-10%, 3: 10-15%, 4: 15-20%, 5:20-25%, 6: 25-30%, 7: above 30%
* Srate(Slope angle) : 1: 0-10°, 2: 10-20°, 3: 20-30°, 4: 30-40°, 5: 40-50°, 6: above 50°

Table 1 Landslide susceptibility categories identified on Isopleth map and assigned rating for landslide frequency in the study area (Kim,Y.J. et al., 1992).

landslids suscep-tibility categories	area covered by landslide deposits in percent (landslide frequency)	rating	evaluation guidelines
negligible	0 - 5(%)	1	(DeGRAFF, 1985)
very low	5 - 10	2	
low	10 - 15	3	
moderate	15 - 20	4	
high	20 - 25	5	
very high	25 - 30	6	
extreme	above 30	7	

ANALYSIS OF LANDSLIDE HAZARD POTENTIAL USING GIS TECHNOLOGY

Slope failures generally depend on the following variables(Hunt,1986, Walker et al.,1987): topography(slope inclination and height), geology(material structure and strength), seepage forces and runoff quantity, seismic activity. On the basis of these elements, nine factors(Table 2) were examined to establish a stability rating system in accordance with geological characteristics of this study area. The ratings were given through the evaluation of each factor. They range from 1 to 7. The data layers were prepared by scanning, digitizing, vectorizing and editing processes to analyse these factors from various source data, especially test boring data(Soil investigation report, 1990): soil map, groundwater level, land cover/use map, topographic map, geological map etc.

Landslide frequency and slope

Considering the relationship between

Table 2 Summary of stability rating system in the study area.

Factors	Weight	Rating
1. Topographic slope (Tw. Tr)	5	1 - 6
2. Landslide frequency (Lw, Lr)	4	1 - 7
3. Groundwater level (Gw, Gr)	3	1 - 3
4. Vegetation (Vw, Vr)	2	1 - 4
5. Rainfall (Rw, Rr)	2	1 - 4
6. Soil texture (Sw, Sr)	1	1 - 3
7. Geology (Qw, Qr : weathering or faults)	1	1 - 2
8. Condition of bedrock (Cw, Cr : fractures or hardness)	2	1 - 3
9. Bedding dips in the direction of potential failure (Bw, Br)	3	1 - 2

slope and landslide occurrences, slope angles should be divided into several classes. In the preceding chapter, the resonable ranges of slope and landslide frequency have been already evaluated by the overlaid results of slope map and landslide frequency map(Fig.2). The ratings of landslide frequency are presented in Table 1, and the slope angles relevant to the rating are as the followings; 1(0°-10°), 2(10°-20°), 3(20°-30°), 4(30°-40°), 5(40°-50°), 6(above 50°). The slopes of higher than 60 degrees and landslide frequencies of more than 35% are almost absent.

Groundwater level

The rise of groundwater level increases

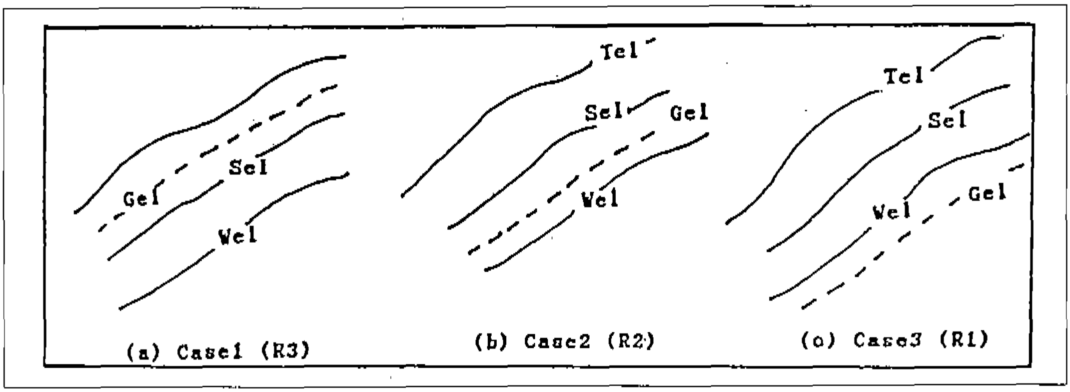

Fig. 3 Analysis of groundwater table
Tel: topographic contour, Gel: groundwater table,
Sel: basal surface line of soil, Wel: top surface line of bedrock.

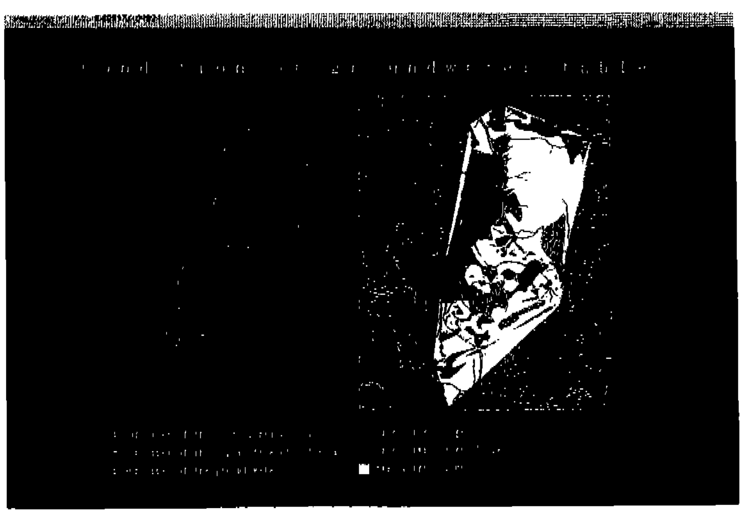

Fig. 4 Condition of groundwater table.

seepage force, which may reduce either the resisting force along the failure surface or increase the driving force(Hunt, 1986). For this work, the locations of groundwater table were classified into three cases according to their locations (Fig.3). When the level is located in soil zone, the rating is high(3), medium(2) in weathering zone and low(1) in bed rock. A data layer(Fig.4) was created by processing geologic information of subsurface, using ARC/INFO, IDRISI and pascal language programs. This information was prepared from 271 test boring data(Soil investigation report, 1990, Geological report for electrical railway, 1989).

Vegetation

Roots reinforce the soil, increasing soil shear strength. They also bind soil particles at the ground surface, reducing their susceptibility to erosion. Foliage intercepts rainfall, causing absorptive and evaporative losses that reduces rainfall available for infiltration(Walker et al, 1987). From these viewpoints, vegetations in the study area were divided into four groups according to their density; heavy vegetation(1), light vegetation(2), grass or very light vegetation(3), no vegetation(4).

In order to analyse vegetations, land cover/use maps were prepared by PCA (Principal Component Analysis) technique and by clustering methods with Thematic Mapper images(Oct.1987, Sep.1988). Interpretation of aerial photographs supported the shadow parts of TM images, streams and roads. The TM images were analysed using a classification system of U.S.Geologocal Survey(Anderson et al., 1976).

Rainfall

Guidicini and Iwasa(1977) studied on the occurrence of landslide relation to the cumulative precipitation record in Brazil. They also established a danger level chart, based on 46-year record of mean annual precipitation, which is the relationship between rainfall and landslides. This methodology is applied to our study.

Rainfall has to be analysed in three important aspects; climate cycles over a period of year, rainfall accumulation in a given year, intensities of given storms. On the basis of the chart of Guidicini and Iwasa, mean annual precipitation were divided into four categories; above 2500mm(4), 2000-2500mm(3), 1200-2000mm(2), below 1200mm(1).

Fortunately, rainfall records of 10-year period(1978-1987) in the study area were avaliable from Suwon Meteorological Observatory Station(Environmental Impact Assessment Report, 1989). The data reveal that the annual average rainfall is about 1200 to 1300 mm. In general, three quater of annual precipitation is concentrated between June and September, recording about 820-830 mm.

Soil

A soil classification map was produced on the basis of agricultural soil maps (Institute of Agricultural Sciences, 1977) and laboratory tests. The classification was made according to the Unified Soil Classification System. Important factors for rating system of a given soil are: soil texture, permeability, shear strength and weight ratio of sand and clay. Silty sands (SM) and clayey sands(SC) occupy in most of the study area. Laboratory tests showed that the silt contents in weight were about 29-43% and those of clay were about 6-15%. Flow type of landslide occurs commonly in the fine-grained granular soil zone and considerably thick soil formation(about 5-10m). Considering the soil characteristics of the study area, the soils are classified in three representative groups: SM(1), SC(2), ML(3:silts and very fine sands).

Geology and condition of bedrock

The study area is mostly composed of banded biotite gneiss and granitic gneiss (Geological map of Dunjeon, 1982). The bedrock outcrops are severely weathered on the surface. Therefore, geologic sections are divided into hard part(1) and soft part(2) on the basis of the weathering grade.

Some R.Q.D(Rock Quality Designation) data were taken from the test borings previously performed in this area(Soil investigation report, 1990, Geological report for electrical railway, 1989). RQD values allow to recognize condition of subsurface. R.Q.D at the depth of 15m from the surface were classsified as followings: 0-20%(highly fractured: rating 3), 20-50%(intermediate: 2), above 50% (low: 3).

Classification of potential landslide hazards

After accomplishing the rating system of each factor, the weight of each factor was given based on the relationships between the other factors(Table 2). When the ratings and weights were determined, overlay method of the data layers begin to create new maps in GIS. A formula developed by Environmental Protection Agency(Griner, 1989) is applied to this study to calculate the stability rating index (SR), which conducts the classification of potential landslide hazards:

$$SR = Tw \times Tr + Lw \times Lr + Gw \times Gr + Vw \times Vr + Rw \times Rr + Sw \times Sr + Qw \times Qr + Cw \times Cr + Bw \times Br$$

SR ; Stability rating index, w and r ; weight and rating of the factors in Table 2.

SR values in the study area ranged from 4 to 46. A percentage cumulative curve (areas vs. SR values) was drawn. On this curve, three important break points(15,20, 25) were selected for classification of SR values. The high value of SR indicates more dangerous slope. The classification is presented as followings;① stable(0-15),② potential unstable(15-20), ③ unstable(20-25), ④ very unstable(above 25).

INITIAL ASSESSMENT OF REGIONAL GEOLOGIC HAZARD MAP

GIS calculated the final SR values for composite polygons created by overlay process. A final map(Fig.5) was produced on the area where data availiable as in the Table 2. The stability rating system(Table 2) was very efficient to examine landslide occurrence and hazard assessment in the large area. Natural hazards could be avoided, eliminated and reduced through the risk assessment. Most of the study area are comprised in stable class(57%), but some places, particularly pediment areas where slope angles are less than 10 degrees, are included in the second class (24%) due to soil texture(ML) and high groundwater level. Unstable areas(third or fourth class; 19%) are mostly located on slopes of higher than 30 degrees.

DISCUSSIONS AND CONCLUSIONS

This study illustrates that GIS technology is useful for analysing potential landslide hazards. A regional hazard map produced by GIS can be effectively applied to predict the geologic hazards(landslides). Moreover, this GIS map can contribute to natural hazard reduction by recognition of landslide occurrences. Unstable slopes in the hazard map should be carefully treated during construction according to geologic conditions, although most of the area is assessed as stable. Consequently, the analysis of landslide activity by this map

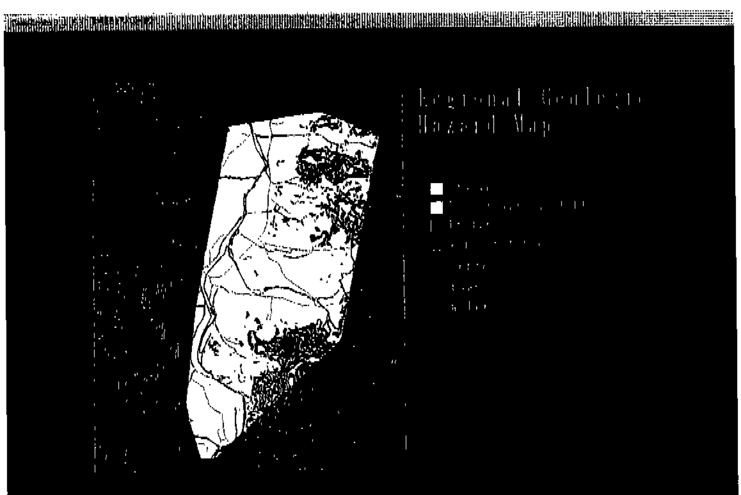

Fig. 5 Regional Geologic Hazard Map.

can play an important role in optimal land use planning in the study area. The stability rating system adopted in the area may be changed in other regions due to different environmental characteristics. The accuracy of the hazard map can be improved by application of more data layers through overlay process. This methodology can provide the better guide for environmental geologic study, and become a basis for construction of geological hazard information system.

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