ANALYSIS OF REGIONAL GEOLOGIC HAZARDS(LANDSLIDE) USING GIS TECHNOLOGY

Youn-Jong Kim, Won-Young Kim, Il-Hyon Yu
Environmental Geology Research Group
Korea Institute of Geology, Mining And Materials(KIGAM)
30, Kajung-Dong, Yoosung-Ku, Taejon, Korea

Dong-jo Seo, Young-Kyu Yang
Systems Engineering Research Institute
Korea Institute of Science and Technology
1, Eoeun-Dong, Yoosung-Ku, Taejon, Korea

ABSTRACT

A regional geologic hazard map was produced in the suburbs of Seoul Metropolitan area using GIS technology, especially to indicate the potential degree of landslides. The elements of topography, geology and soil were incorporated on this map through GIS, which were enable to predict the potential hazards of landslide. The factors causing a landslide are slope geometry, geology, groundwater table, soil property, rainfall and vegetation etc. All these factors were considered in our GIS system and the cartographic simulation was conducted to produce a regional geologic hazard map. For this work, ARC/INFO and ERDAS systems were used in SUN 4/390 workstation.

KEY WORDS : Geologic hazards map, Stability rating system, Landslide occurrence, Isopleth map, Unified soil classification system, Rock quality designation.

INTRODUCTION

GIS technology was applied for assessments of landslide hazards. The final map was produced by GIS, showing the prediction of landslide occurrence and the assessment of landslide risk in the study area.

The first sign of landslide is the appearance of surface cracks in the upper part of the slope, perpendicular to the direction of the movement. These cracks gradually fill with water, which weakens the soil and increases the horizontal force which initiates the slide (Hans F. Winterkorn et al, 1975). For regional hazard analysis, we have examined some environmental factors(Walker, 1987) which affect landslide occurrences(geometry of slope, vegetation, rainfall, soil texture, geologic and hydrogeologic influences). This, primarily, permited us to recognize the spatial and temporal association of landslides with some environmental phenomena, and to develop a stability rating system for applying GIS to assess landsliding risk in the study area. Finally, GIS have produced a regional geologic hazard map through cartographic simulation in conjunction 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., and Kim,W.Y., 1991). However this study only concerns regional analysis of landslides using GIS technology. The study area encompasses about 142km^2 in the southern part, which is being developed for the construction of new town, of Seoul Metropolis in Korea. But the hazard map covers only 70 km^2 of the central part in the study area, due to lack of subsurface information.

INITIAL EVALUATION OF LANDSLIDE HAZARDS WITH ISOPLETH MAP

Isopleth mapping of landslide deposits (DeGRAFF, 1985, 1988, Wright et al, 1974) can provide economical means for assessing the degree of landslide hazards in a large area (Kim,Y.J., and Yu,I.H., 1989). 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 areal photographs(May, 1987, 1:10,000 scale) was registered as a data layer in ARC/INFO system. Preparation of
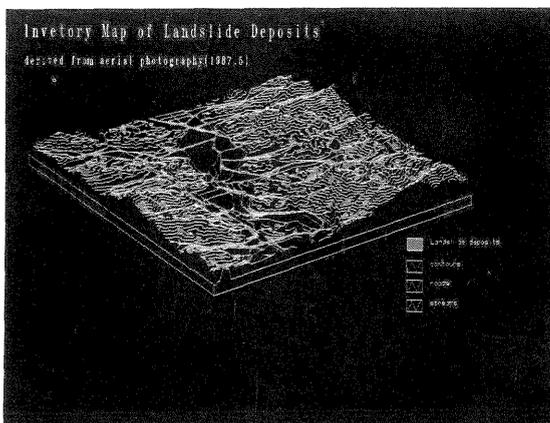

Fig. 1 Inventory map of landslide deposits (scale 1:10,000)

Fig. 2 Isopleth map of landslide deposits

(A) Slope classification for the landslide frequency

(B) Landslide frequency for the slope classification

* 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°
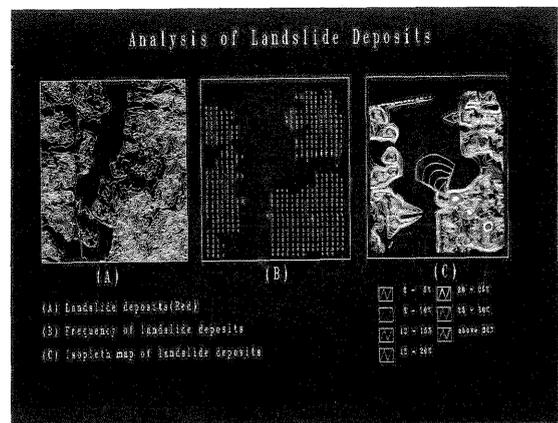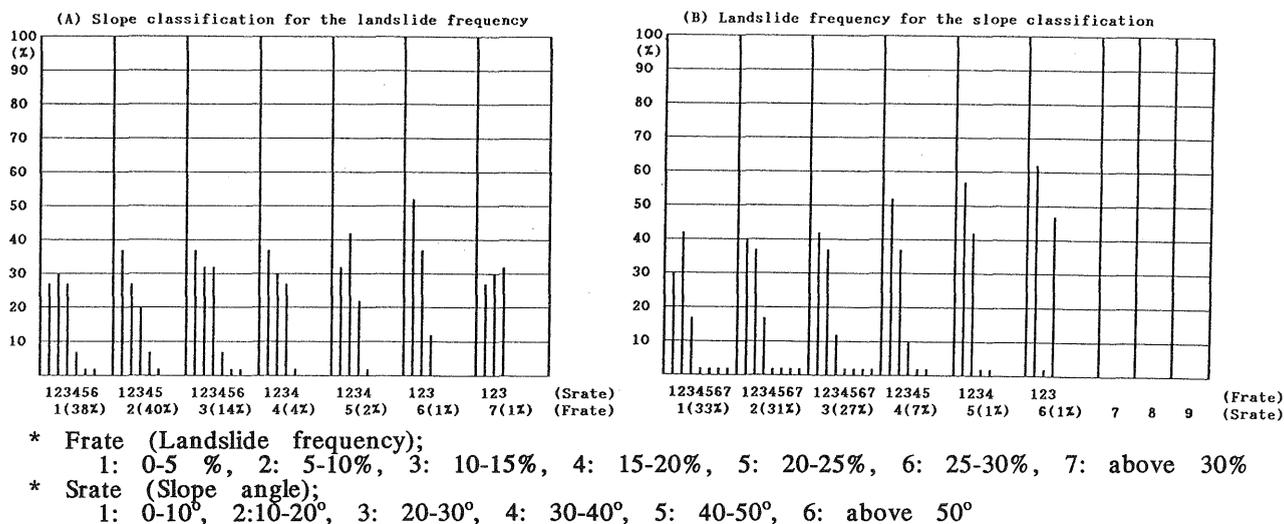
Fig.3   Relationship between slope and landslide frequency in the study area.

Table 1. Landslide susceptibility categories idenfied on isopleth map and assigned rating for landslide frequency in the study area

landslide susceptibility 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	

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

Table 3. Data layers for analysing stability rating system

1. Topographic map; topographic contours, roads, streams
2. Inventory map of landslide deposits
3. Landslide frequency map
4. Isopleth map of landslide deposits
5. Soil map (texture)
6. Soil depth
7. Land cover/use map
8. Geologic map
9. Boring data maps; Sel,Wel,Gel,Sth,Wth,Th (6 layers)
10. Point map; wells, schools..

isopleth map is described by Wright(1974), DeGRAFF(1988) and others.

The first step of the map preparation is an inventory of existing landslides by aerial photographs and field verification(Fig.1). A transparent orthogonal grid sheet with 1.3 or 1.6 cm intersection spacing is placed over the landslide inventory map(Fig.2-A). A counting circle(2.5cm diameter) enclosing an inscribed 20 x20 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(Fig.2-B). Contour lines (isopleths) are then drawn through numbers to represent in given interval or values(Fig.2-C).

The isopleth map was used in two ways. Firstly, it serves as initial means for landslide hazard assessment. Secondly, it enable to recognize some landslide-susceptible slopes by overlay technique of isopleth map and slope map in GIS system. In the study area, landslides occur mainly on slopes of less than 30 degrees(Fig.3-B). In the other regions(more than 40 degrees), they are not taking place frequently, but the risk is high.

DeGRAFF(1985) has presented landslide susceptibility categories identified on isopleth map. The overlay results of two maps(fig.3) permits us to determine new categiries in the study area(Table 1). These categories are used to develop a stability rating system as being mentioned in the next chapter. Large scale mass movement is not recognized on the isopleth map, but only small ones are seen in hilly or mountainous terrain.

ANALYSIS OF GEOLOGIC HAZARDS (LANDSLIDES) USING GIS

Slope failures depend on four kinds of following variables(Hunt,1983, 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 environmental characteristics of this study area. The ratings were developed through the evaluation of each range for each factor with respect to the other factors. They range from 1 to 7. These suggested ranges may be adjusted by other users when varying conditions are indicated by the data(Griner, 1989). Seventeen data layers (Table 3) were prepared by scanning, digitizing, vectorizing and editing processes to analyse these factors from various source data.

Slope and Landslide Frequency

Considering the relationship between slope and landslide occurrences, slope angles should be divided into several classes. The analyses by overlay technique(slope and isopleth maps) have already been illustrated in Table 1 and Fig.3. By this method, the reasonable ranges of slope and landslide frequency could be set up. The ratings of landslide frequency are presented in Table 1, and those of slope are as the
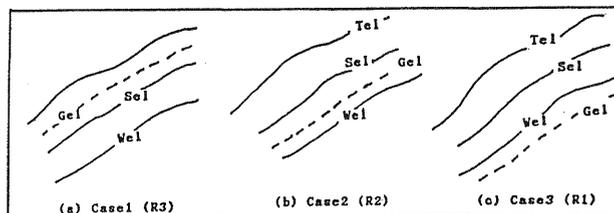
(Tel: topographic contour, Gel: groundwater table, Sel: basal surface line of soil, Wel: top surface line of bedrock)

Fig.4 Analysis of groundwater table

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 not almost present.

Groundwater Level

The rise of groundwater level severely increases seepage forces, which may reduce the resisting forces along the failure surface or increase the driving forces(Hunt, 1983). The groundwater level is affected by rainfall accumulation (infiltration), reservoir filling and other factors (influences of rainfall are examined in the next chapter). For this work, the locations of groundwater table were classified into three cases according to their levels(Fig.4). For example, when the level is located in soil zone, the rating is high(3). A data layer(Fig.5) was created by processing geologic information of subsurface such as soil depth, weathering zone, bed rock and groundwater level, using ARC/INFO, IDRISI and our programs of pascal language. 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 was analysed using a classification system of U.S.Geologocal Survey(Anderson et al, 1976).

Light or no vegetations and barren lands are hardly distinguishable from agricultual lands, which are mostly located on slopes of less than 10 degrees in the study area. Therefore, the slopes of less than 10 degrees are excluded from the overlay result of slope and land cover/use maps. Rest of the area is assumed
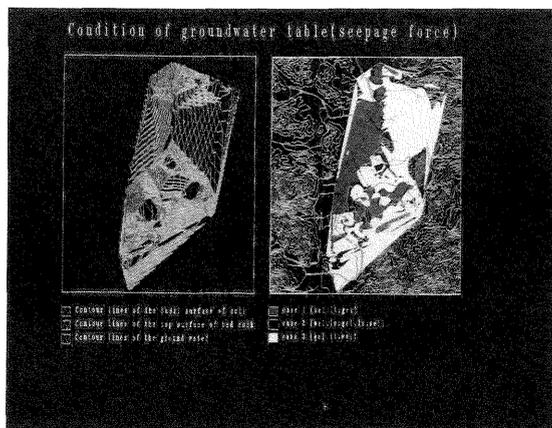
Fig.5 Condition of groundwater table

Fig.7 Overlay process
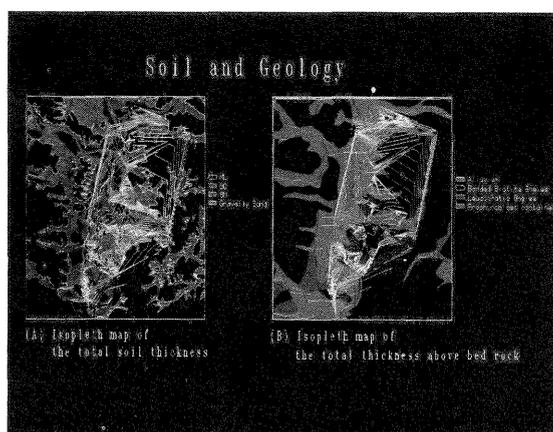
Fig.6 Soil and Geology
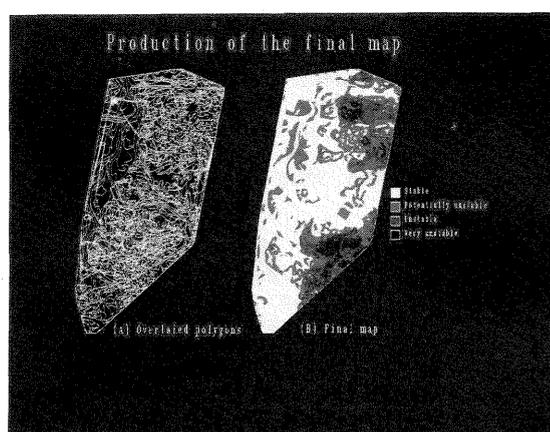
Fig.8 Production of final map

to be the vegetation area, which is rated from
1 to 4.

Rainfall

Guidicini and Iwasa(1977) presented a study on
the occurrence of landslide relation to the
cumulative precipitation record in Brazil. Based
on 46-year record of mean annual
precipitation, they also established a danger
level chart which is the relationship between
rainfall and landslides. Their methodologies are
applied for this 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. Fortunately, rainfall records
of 10-year period(1978-1987) were avaliable
from Suwon Meteorological Observatory Station
(Environmental Impact Assessment Report,
1989). The data reveals that the average
annual rainfall is about 1200 to 1300 mm. In
general, rainfall is concentrated between June
and September, recording about 820-830 mm.
One of the heaviest storm on Sept.1, 1984
marked 190.5 mm of precipitation during 24
hours. 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 1200
mm(1). According to the chart, the mean

annual precipitation of the study area belongs
to the rating(2).

Soil

A soil classification map(Fig.6-A) 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 contents of silt were about
29-43% and those of clay were about 6-15%.
Flow type of landslide is common in the fine-
grained granular soil zone. Soil formation is
considerably thick(about 5-10m). Considering the
soil characteristics of the study area, the soils
are classified in three groups: SM(1), SC(2),
ML(3:silts and very fine sands). Although
gravelly sands are highly permeable(estimated
permeability: about 10^{-3} m/s), they fall on the
lowest rating. They are mostly located on the
very gentle slopes of less than 5%, therefore
they do not affect on landslide occurrences in
the study area(especially along the side of
streams).

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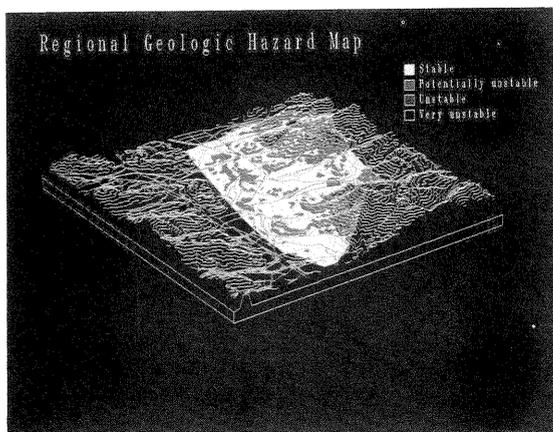
Fig.9 Regional geologic hazard map
(scale 1:25,000)

Geology

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 ground surface. No geologic event is recognized in recent years. Therefore, geologic features are divided into two: hard part(1) and soft part(2).

Some R.Q.D(Rock Quality Designation) data were taken from the test borings performed in construction sites(Soil investigation report, 1990, Geological report for electrical railway, 1989). R.Q.D allows to recognize condition of subsurface(R.Q.D(%) = 100 x length of full diameter rockcore in pieces > 0.1m / length of core run). R.Q.D of the area were classsified as followings: (3)0-20%(highly fractured), (2)20-50%(intermediate), (1)above 50% (low). They ranged from 0 to 30% at the depth of 20m from surface.

Classification of Stability Rating

After accomplishing the rating system of each factor, weights were developed from relationships between different factors(Table 2). When the rating and weights were determined, overlay process begin to create new maps(Fig. 7). A formula developed by Environmental Protection Agency(Griner, 1989) is applied to calculate the stability rating index(SR) in our study:

$$SR = T_w \times T_r + L_w \times L_r + G_w \times G_r + V_w \times V_r + R_w \times R_r + S_w \times S_r + Q_w \times Q_r + C_w \times C_r + B_w \times B_r$$

(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(Fig.8). The classification of geologic hazards(landslides) is presented as followings; (1)stable(0-15), (2) potential unstable(15-20), (3)unstable(20-25), (4) very unstable(above 25).

ASSESSMENT OF REGIONAL GEOLOGIC HAZARD MAP

A final map(Fig.9) was produced only on the area where nine envoronmental geologic data (Table 2) were available. ARC/INFO calculated the final SR values for composite polygons created by overlay process(Fig.8). Although vegetations could not be sufficiently examined due to the limit of image processing technique and source data(images), the stability rating system was very efficient to examine landslide occurrence and hazard assessment. Natural hazards could be avoided, eliminated and reduced through this risk assessment. Most of the study areas are comprised in stable class (57%), but some places, particularly pediment areas which slope angles are less than 10 degrees, are included in the second class(24%) due to soil texture(ML:3) and high groundwater level(rating:3). Unstable areas(third or forth class; 19%) are mostly located on slopes of higher than 30 degrees(or 20-30% of landslide frequency).

CONCLUSIONS

The regional geologic hazard map produced by GIS can be effectively applied to predict the landslide hazards. Unstable slopes(third or fourth class) in Fig.9 should be carefully treated during construction according to geologic conditions, although most of the areas is assessed as stable(first or second class). Consequently, the analysis of landslide activity by the 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, but slope, landslide frequency and groundwater level remain constant factors.

The results illustrate that this approach is useful in providing information for preliminary planning and assessment of landslide hazards. Moreover, this technique can contribute to natural hazard reduction by recognition of landslide occurrences in the hazard map. 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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