LANDSLIDE HAZARD ZONATION USING THE GRASS GIS: A CASE STUDY IN THE OJIYA DISTRICT, NIIGATA PREFECTURE, JAPAN

Venkatesh Raghavan[1] , **Shinji Masumoto**[2], **Atsushi Kajiyama**[2], **Tatsuya Nemoto**[2] **and Takashi Fujita**[3]

[1]Graduate School of Creative Cities and Media Center, Osaka City University,
3-3-138 Sugimoto, Sumiyoshi-ku, Osaka 558-8585, Japan

[2]Department of Geosciences, Graduate School of Science, Osaka City University
3-3-138 Sugimoto, Sumiyoshi-ku, Osaka 558-8585, Japan

[3]Fault Research Data Center, 4-3-2 Itachibori, Nishi-ku, Osaka 550-0012, Japan

*Corresponding author's e-mail: raghavan@media.osaka-cu.ac.jp

ABSTRACT

A methodology for landslide hazard zonation has been implemented in the GRASS GIS framework and applied to the Ojiya District in Niigata Prefecture, Japan. The basic data that was used for the landslide hazard zonation was the 50 meter resolution DEM, digitized geological maps and landslide distribution map. Raster layers depicting parameters contributing to the occurrence of landslides were generated using the program functions of the GRASS GIS. Based on the distribution of landslide elements in various geo-environmental categories, two probability models were considered to represent the degree of instability of slopes. In the first model the Landslide Hazard Index (LHI) was calculated based on the conditional probability of landslide elements occurring in a particular geo-environmental sub-category. The second model involves the calculation of Information Value (IV) based on the landslide distribution statistics. The LHI and IV were related to four classes representing the relative slope instability in the area. Comparison of the expected and actual landslide sites in different instability zones suggest that the estimated precision of predicted results show fairly good accuracy.

1 INTRODUCTION

Landslide hazard zonation has been actively pursued for the last two decades and is still being refined. Landslides and related disasters frequently occur in the Japan and extensive studies have been carried out by several institution and individuals focusing on the extent, type, and causes of such disasters. Many of these are fairly detailed site-specific investigations. In comparison, several works related to hazard mapping have been carried out in many countries abroad (e.g., Carrara and others, 1991; Rengers *et al*, 1992; Chung and Leclerc, 1994; Djamaluddin, 1994). However, except for a few studies (e.g. attempts being made by many agencies and individuals often rely on proprietary software. Some of these studies dealing in methodology only suggest the need to implement them in a GIS environment, but actual implementation have not been carried out (e.g., Gupta and Joshi, 1990; Anbalagan, 1992; Pachauri and Pant, 1992; Thigale and Khandge, 1995).

The main objective of the present research was to implement a methodology for landslide hazard mapping on the Free and Open Source Software (FOSS) Geographic Information System (GIS) environment and evaluate the results. It may be noted that hazard evaluation can pertain to relative hazard (used to rate susceptibility to sliding), absolute hazard (e.g. factors of safety which are based on calculations), empirical hazard (based on subjective knowledge) and monitored hazard that are connected to internal processes of the slope. In this paper, we assess the relative landslide hazard by assigning ratings to different factors contributing to the landslide susceptibility.

2 STUDY AREA AND METHODOLOGY

The Ojiya district is located in the eastern part of the Niigata Prefecture and lies between 37° 10'N to 39° 20'N and 138° 45'E to 139° 00'E (Figure 1). The area shows a hilly topography with altitude ranging from 30-681 meters above MSL. The general stratigraphic sequence in the area consist of a Mesozoic basement which is overlain by a thick sequence of Miocene to lower Pleistocene sediments with well developed terrace which are followed by Holocene deposits. The study area is characterized by the prevalence of NNE-SSW trending folds and faults. Several landslides occur in the region (Yanagisawa *et al.*, 1986). Landslides in the Niigata Prefecture have been reported to frequently occur in the Neogene formations and are controlled by structural features such as anticlinal axis (Fujita, 1987).

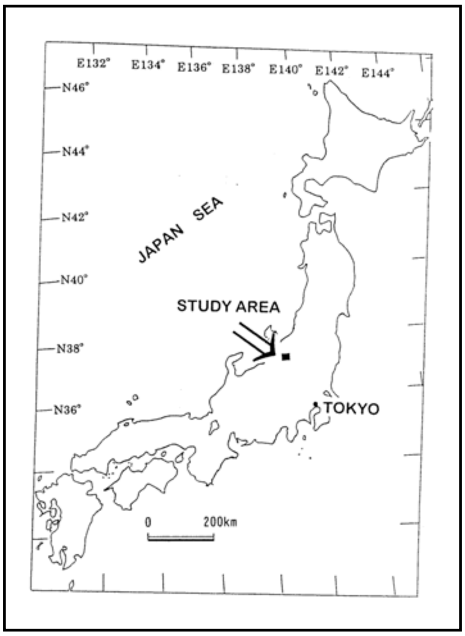


Figure 1: Study Area

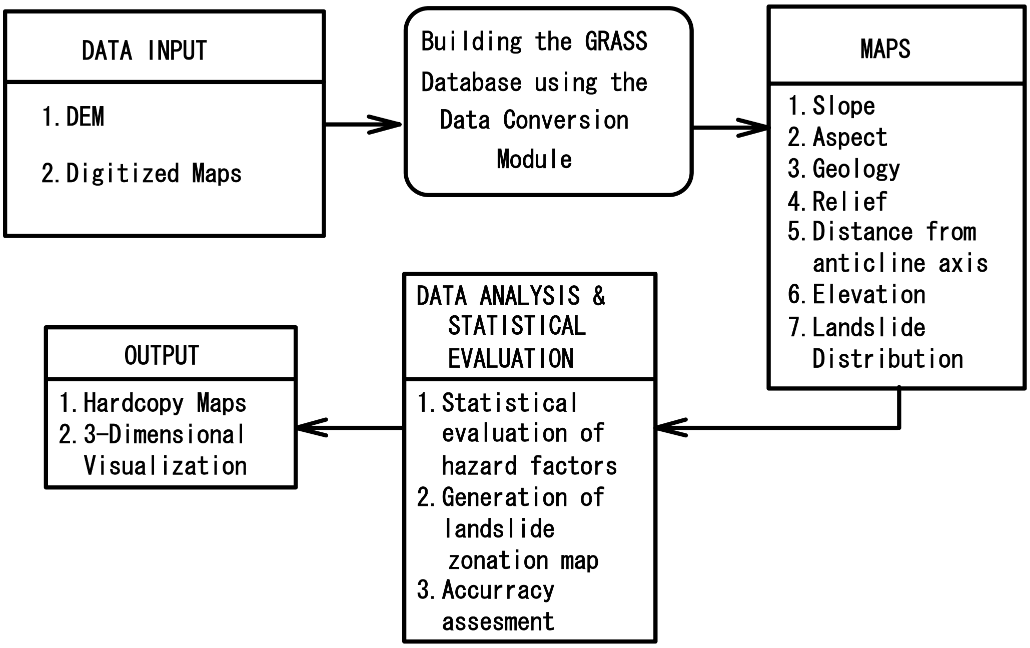


Figure 2: Flowchart showing the GIS approach for landslide hazard zonation mapping.

The approach used in this study is outlines in Figure 2. The basic data that was used for the hazard zonation mapping was the 50 meter resolution Digital Elevation Model (DEM), digitized geological map and landslide distribution map. Raster layers depicting geo-environmental parameters (e.g., slope, aspect, relief, geology etc.) relevant to the occurrence of landslide were generated using the program functions of the GRASS GIS. Based on the distribution of landslide elements in various geo-environmental sub-categories, two probability models were considered to represent the degree of instability of slopes in the Ojiya district. In the first model the Landslide Hazard Index (LHI) were calculated based on the conditional probability of landslide elements occurring in a particular geo-environmental sub-category. The procedure used for calculating the LHI is show below;

$$\text{Conditional probability } P\{L \mid B\} \text{ is defined as}$$

$$P\{L \mid B\} = \frac{N\{L \cap B\}}{N\{B\}}$$

$$Where\ N\{B\} = \text{Total number of elements in the sub - category}$$

$$N\{D \cap B\} = \text{Number of landslide elements } (L) \text{ on this sub - category } (B)$$

$$\text{LHI is defined as}$$

$$\text{LHI} = \frac{\text{Conditional probability of landside incidence in a geo - environmental subcategory}}{\text{Average conditional probability of the various sub - categories of that category}}$$

The second model uses the information theory and involves the calculation of Information Value (IV) based on the distribution landslide elements in different geo-environmental sub-categories. The IV_i for each variable is calculated as shown below;

IV_i is the Information value supplied to the landslide by the variable i and is defined as

$$IV_i = \log \frac{S_i / N_i}{S/N}$$

$$\text{Where:}$$

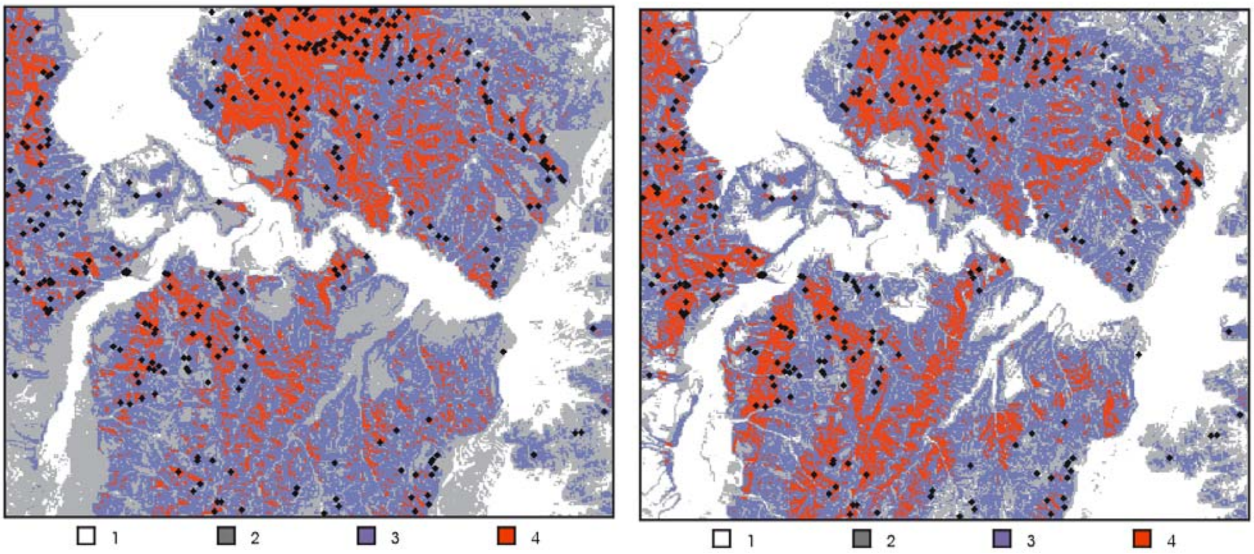
$$N = \text{total number of elements}$$

$$S = \text{number of elements with history of landslide occurrence;}$$

$$S_i = \text{number of elements with the history of landslide occurrence involving variable } i;$$

$$N_i = \text{Number of elements involving variable } i$$

The LHI and the IV were related to four classes (1-very low 1, 2-low, 3-moderate and 4-high) representing the relative slope instability in the area (Figure 1(a) and (b)).



(a) (b)

Figure 1: Zonation map based on LHI (a) IV (b) method (Black dots show landslide sites).

Comparison of information obtained using the two statistical models reveals high convergence. Although there are some differences between the zonations achieved by both these methods, none of areas classified as “high” in LHI method fall on the “very low” or “low” categories of the IV map. Finally, raster layers shown in Figure 1(a) and (b) were combined into a unique category raster layer that was reclassified to generate the map shown in Figure 2.

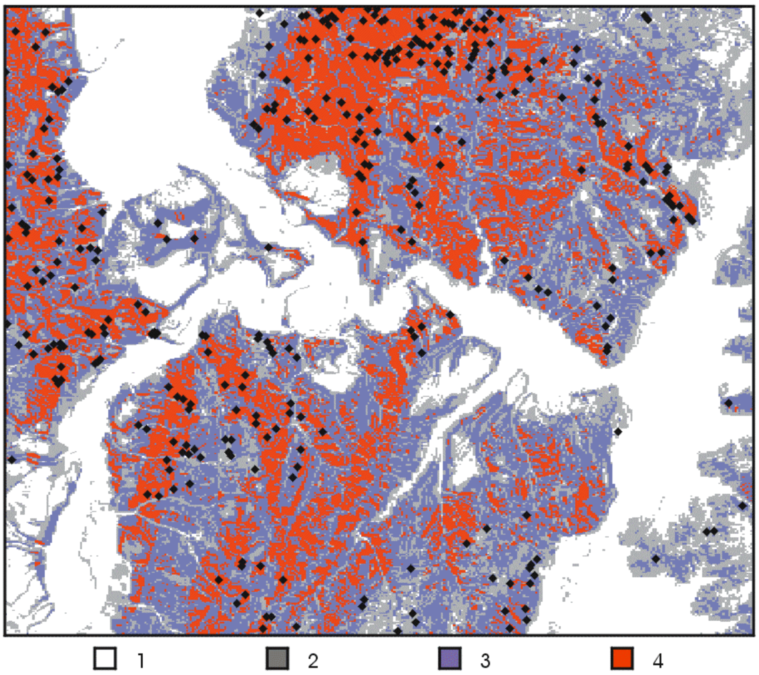


Figure 2: Combined zonation map using LHI and IV method (Black dots depict landslide sites)

The accuracy of these methods in the prediction of slope instability has been compared using two techniques. In the first technique, the precision of the predicted results has been expressed in the form of experimental probability (Jade an Sarkar, 1993). The experimental probability is calculated as shown below.

$$P_E = \frac{K_s}{S}\left(1 - \frac{K - K_s}{N - S}\right)^{1/3}$$

$$\textit{where } N = \text{total number of elements}$$

$$S = \text{number of elements containing landslides}$$

$$K = \text{number of elements falling into the high and moderate grade of slope instability}$$

$$K_s = \text{number of elements falling into high \& moderate grade of slope instability}$$

containing landslides

In the second technique the precision has been expressed as a simple ratio as shown below.

$$P = \frac{K_s}{S}$$

$$S = \text{number of elements containing landslides}$$

$$K_s = \text{number of elements falling into high and moderate grade of slope instability}$$

containing landslides

The predicted results determined by the two methods are shown in Table 13. The estimated accuracy of predicted results by the two methods show fairly good accuracy (72-93%) when compared with existing landslides in the area.

Table 13: Accuracy assessment for moderate and high landslide susceptibility zone.

Method	N	S	K	Ks	P (%)	P_E (%)
LHI	9726.08	317	5048	294	93	73
IV	9726.08	317	4937	288	91	72
LHI & IV Combination	9726.08	317	5347	297	94	72

3 CONCLUSIONS

A methodology for landslide hazard zonation has be implemented in the GRASS GIS framework and applied to the the Ojiya District in Niigata Prefecture, Japan. The basic data that was used for the hazard zonation mapping was the 50 meter mesh DEM and digitized geological map. Different raster layers depicting geo-environmental parameters (e.g., slope, aspect, relief, geology etc.) contributing to the occurrence of landslide were generated in the GIS database. Based on the distribution of landslide elements in various geo-environmental sub-categories, two statistical models that are based on the probability theory were considered to represent the degree of instability of slopes. In the first model the Landslide Hazard Index were calculated based on the conditional probability of landslide elements occurring in a particular geo-environmental sub-category. The second model is based on the information theory and involves the calculation of Information Value based on the distribution landslide elements in different geo-environmental sub-categories.

The Landslide Hazard Index and the Information Values were related to four susceptibility classes (e.g. very low, low, moderate and high) representing the relative slope instability in the area. Comparison of information obtained using the two statistical models reveals high convergence. The estimated precision of the predicted results by the two method show fairly good accuracy when compared to existing landslides in the area.

Two important factors namely the hydrogeological conditions and climatic conditions have not been directly considered. In the present study we have only considered geologic and geomorphologic factors, assuming that effects of precipitation would be uniform through out and also that local geomorphology characteristics (e.g. slope, relief etc.) reflect hydrogeological effects in some ways. The landslide hazard zonation map prepared in the present study depicts relative susceptibility under existing natural. The change in natural environment may change the grade of instability. Such changes obviously carry a temporal dimension and need to be considered using a time-series data on landslide occurrence where ever such information. Although the hazard zonation maps do not replace site specific studies, they can serve as a database for planning site specific studies within problem areas that require detailed study. The susceptibility map can also be used for assessing the landslide “risk” in areas of existing and/or proposed development.

Lastly, the methodology evolved in the present study has been implemented on a FOSS/GRASS GIS. We consider that FOSS/GRASS offers an open GIS framework not only for research but also for operational use. Wide use of FOSS/GRASS could promote refinement of existing methodology and development of customized solutions to support landslide hazard mitigation.

4 REFERENCES

Anbalagan R., 1992. *Landslide hazard evaluation and zonation mapping in mountainous terrain*, Engineering Geology, 32, 269-277.

Carrara, A., Cardinali, M., Detti, R., Guzzetti, F., Pasquiv., and Reichnbach, R., 1991. *GIS techniques and statistical models in evaluating landslide hazard, Earth Surface Processes and Landforms*, 16, 427-445.

Clerici A., 2002. *A Grass GIS Based Shell Script For Landslide Susceptibility Zonation*, Proceedings of the "Open Source Free Software GIS - GRASS users conference 2002", Ciolli M., Zatelli P. Editors, Trento, Italy (http://www.ing.unitn.it/~grass/conferences/GRASS2002/proceedings/).

Chung C.F., and Leclerc, Y., 1994. *A quantitative technique for zoning landslide hazard*: IAMG'94, Mont Tremblant, Canada, 87-93.

Djamaluddin, 1994. *Application of remote sensing and GIS to mass movement hazard zonation in West Java, Indonesia*, 10th Thematic Conference on Geologic Remote Sensing, 1, 375-384.

Fujita, T., 1987. *Geological features of Landslides in Japan*, Proceedings of The China-Japan Field Workshop on Landslides, Xian-Lanzhou, China, p. 61-68.

Gupta R.P, and Joshi B.C., 1990. *Landslide hazard zonning using the GIS approach - A case study from the Ramganga catchment*, Himalayas, Engineering Geology, 28, 119-131.

Jade S., and Sarkar, S, 1993. *Statistical models for slope instability classification*, Engineering Geology, 36, 91-98.

Pachauri A.K., and Pant, M., 1992. *Landslide hazard mapping based on geological attributes*, Engineering Geology, 32, 81-100.

Paudits P., and Bednarik M., 2002. *Using GRASS in Evaluation of landslide susceptinility in Handlovska Kotlina basin*, Proceedings of the "Open Source Free Software GIS - GRASS users conference 2002", Ciolli M., Zatelli P. Editors, Trento, Italy (http://www.ing.unitn.it/~grass/conferences/GRASS2002/proceedings/).

Rengers N., Soeters R., and van Westen C.J., 1992. *Remote sensing and GIS applied to mountain hazard mapping*: Episodes, 5, 1, 36-45.

Thigale S., and Khandge, A.S., 1995. *Generation of database for preparation of landslide zonation map of the Western Ghats of Maharashtra, India*, International Association of Mathematical Geology (IAMG'95), Osaka, Japan, 51-53.

Yanagisawa, Y., Kobayashi, I., Takeuchi, K., Tateishi, M., Chhara, K., and Kato, H., 1986. *Geology of the Ojiya district, Geological Survey of Japan, Quadrangle Series*, *Niigata*, 7, 50, 177 (with geology map).