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APPLICATION OF GIS (GEOGRAPHIC INFORMATION SYSTEM) FOR LANDSLIDE HAZARD ZONATION AND MAPPING DISASTER PRONE AREA: A STUDY OF KULEKHANI WATERSHED, NEPAL

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Abstract

This study provides the methods of application of GIS for landslide hazard zoning and disaster prone area mapping. The landslide hazard map is used along settlement map and landuse map to produce the disaster prone area map. The landslide distribution map is overlaid with other landslide influential spatial parameters. The qualitative judgement has been made for the ranking of these parameters considering the result obtained from GIS analysis and field experience. To perform the study both vector and raster base GIS has been used. Beside these aerial photograph was used. GIS has been found more effective in analyzing the landslide distribution spatially by overlaying with maps related with factors affecting landslide occurrence. The result of the study obtained from landslide hazard zonation and disaster prone area map illustrated three related level of severity: high; medium and low.

Key Words: Geographic Information System (GIS), Landslide, Zonation

Introduction

Landslide in mountainous terrain is a natural degradation process and one of the most important landscape building factors. Most of the terrain in mountainous areas have been generally subjected to slope failure under the influence of a variety of causal factors and triggered by events such as earthquake or rainfall. The frequency and magnitude of slope failure can be increased due to human activities such as deforestation and urban expansion. The event may disrupt normal pattern of human lives and if higher magnitude of event occurs, community needs external support to recover. This phenomenon is common in Nepal.

Nepal is young geographically, and land forming process often manifest landslides which are more dramatic and more damaging than any other land formation process (Fearnside et al, 1980). In Nepal a significant number of landslides occur each year (as many as 12000). It is found that about 13% of the total area of Siwalik and mid hilly region of the country suffer from the effects of landslide (Nicholas et al., 1991). Rapid population growth accompanied by undirected settlement growth, expansion of agricultural land, poor land and watershed management and overgrazing has compounded the landslide disaster problem in the country. Infrastructures (roads, dams) are developing in the hilly areas. So occurrence of any major disaster can cause huge loss of property as well as lives

In an area mitigation of landslide can be successful only when detailed knowledge is obtained from expected frequency, character and magnitude of landslide. The zonation of landslide hazard may be basis for any landslide disaster mitigation work and can be supplied to planners and decision-makers. The application of Geographical Information System (GIS) can be useful for this. GIS is a powerful tool for handling spatial data and landslide hazard zonation is very much related to spatial information e.g., topography, geology, land cover, etc. The objectives of the present study are:

- Identify the landslide affected area distribution pattern in the landslide influencing spatial feature (slope, aspect, land cover, geology, land form)
- Prepare a GIS database containing spatial and attribute data related to physical and biological aspects of landslide hazards
- Delineate the land slide hazard zone based on landslide occurrence pattern on the landslide influencing spatial feature
- Produce the disaster prone area map and Digital Terrain Model (DTM)

The Kulekhani watershed area lies at the northeastern part of Makhwanpur district in the central development region of Nepal, immediate south west of Katmandu valley (**Figure 1).** The study area is situated in Mahabharat range and is surrounded by mountains and hills. The terrain elevation varies from 1534m to 2621m

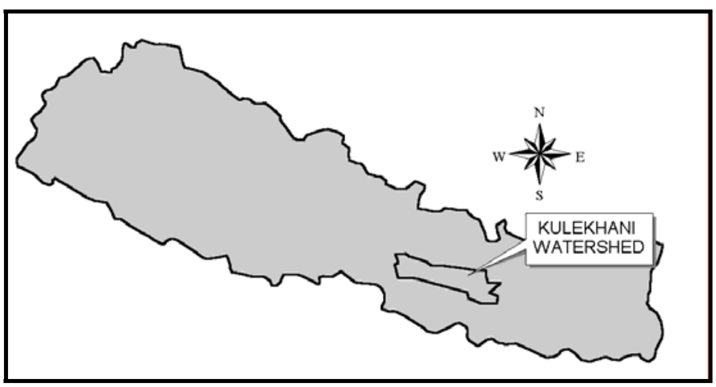

Fig 1: Kulekhani Watershed

The terrain of the watershed in general is rugged and comprised of several folds of sloped hills with a number of streams and rivers. The Kulekhani river originated in Mahabharat ranges and flows generally east and south east direction, joining the Bagmati river around 20 km south of Katmandu

The Kulekhani watershed around Mahabhart lake is structurally controlled by syncline having an East South-East trending axis and controlling the alignment of principal mountain ridges and valleys. The southern rim of the syncline is a thrust napped abutting the Siwalik range to the south. Structural surfaces are often steeply dipping and provide abundant landslide surfaces.
Materials and Methodology

The study deals with the application of relatively new tool in landslide hazard zonation i.e. computerized system for handling of geographical data, known as Geographic Information System (GIS). A GIS is designed for the collection, storage and analysis of objects and phenomena where geographic location is an important characteristic (Arnoff, 1993). The increasing availability of computers during the last few decades has created ample opportunities for a more detailed and rapid analysis of landslide hazard zonation (Westen, 1994).

The steps of methodology adopted in this study are:
a) Aerial photo interpretation
b) Field investigation
c) Application of GIS
i. Data entry
ii. Digital Terrain Model Preparation
iii. Map Overlay
iv. Analysis of data
v. Rating of hazard zonation and Disaster prone area mapping

The air photo of February 1993 has been used for the preparation of landslide distribution map and landuse map of the area. The element of photo interpretation has been considered for the landslide distribution as well as landuse identification. The interpreted information of the 1:25000 air photo has been transferred into 1:25000 contour map of the study area by the use of the sketch master on the control point basis. The prepared landslide distribution and landuse maps as well as other maps e.g. contour, land system, bedrock maps had been verified during field visit. The existing pattern of landslide and magnitude were also been observed.

The thematic map prepared from air photo and the existing maps were digitized into a vector base GIS using ARC/Info software. The following seven types of maps of the study area were digitized:

i. Contour map
ii. Landuse map

iii. Land system map
iv. Bed rock map
v. Isohytel map
vi. Seismic Zonation map
vii. Drainage map

Digital terrain model or DTM is the digital representation of terrain characteristics of an area. Since topography is an important parameter for the occurrence of landslide, DTM was used in this research for the preparation of the aspect and slope map. PC ARC/Info, ERDAS and IDRISI software used for this purpose (Figure 3).

The elevations used for DTM preparation were obtained from the topographic map (1:25000) with a vertical interval of 30m, based on 1957 Topo-maps (scale 1:63000). The elevation points were digitized in PC ARC/Info keeping the minimum horizontal and vertical distance between two any points 15m and 50m respectively. The digital map was then converted into ERDAS format, which has facilities to create elevation model. The DTM was used to generate slope and aspect map. Finally the DTM was also processed in IDRISI in order to produce a better visual effect of topographic relief. The slope and aspect maps were then again converted to PC ARC/Info to facilitate analysis with other map.

Map overlay function of the PC ARC/Info software was used to perform the fundamental spatial analysis. Drainage catchment maps have been created with the catchment distance of 50m, 150m and 350m respectively. All the three maps were overlaid to prepare a single map with three different distance zones. The same task has been performed with the same distance to prepare buffered settlement map. By overlaying all the thematic maps (eight in number) landslide hazard zonation map has been created (Figure 5). The produced landslide hazard zonation map was overlaid with ranked landuse and settlement catchment map resulted in the production of disaster prone area (Figure 6). The topographic maps of 1957 has been taken into consideration for settlement map along with photo map assuming these maps are reliable though they are prepared around forty years ago. Because of the fact that the study tries to focus more on the procedure of the disaster prone area mapping, the individual single scattered houses are not taken into account.

The data obtained from the overlaying of the landslide distribution on each map were observed and statistically analyzed. The statistical analysis was conducted to test the hypotheses related to each of the factors, which influence the landslide distribution. The Chi- square test with a confidence level of 95% was applied for this purpose, which shows the significance of landslide occurrence on different variable. The null hypothesis for these tests was the proportion of the landslide area and of no landslide area for different variable is same.

The trend of the landslide occurrence was observed from plotted data. Each thematic class has been classified as high, medium and low according to the severity of landslide-affected area. Each thematic map had been weighted based on field observation and author's subjective judgement. It has been observed from the data and field observation that the bedrock and terrain topography was major contributing factors for slope instability. The ratings and weightage were incorporated in the GIS database. The ranking of each of the class was based on the importance of the class in the livelihood for the individual and community. Weightage of the thematic map was based on the seriousness of the disaster to the influencing elements.

Results and Discussions

It has been found that working with PC ARC/Info is having many limitation. It needs more space for overlaying and conversion than other version of PC ARC/Info. These led to make the digital version of maps as small as possible leading to the loss of accuracy. Moreover PC ARC/Info could handle only up to 5000 polygons and 32000 points. This provides the limitation of work with it.

ERDAS software has been used to interpolate the individual points representing different elevation. Different search radius has been used to find out the suitable radius, which can give the best result. 770m has been found out to be the best having represented 159 points/blocks. The interpolation equation available in ERDAS was tried for DTM preparation. From the test it has been found that the following equation provide the best result (ERDAS, 1991):

Distance function = e-5*(5Q) 2
Where Q = D/S
D = Calculated distance
S = Search Radius

The slope and aspect maps created from DTM were checked with the topographical maps, aerial photograph and field experience which is generally correct. The slope of the reservoir surface had been found less than 20m, which is not true. Similarly vertical cliffs were not represented correctly. It is due to the variation of elevation within search block where elevation points within the blocks were computed separately with other blocks. The obtained DTM has been used for 3 – dimensional visualization using IDRISI software.

The obtained results after overlaying of the landslide map to each thematic map have been used to test the null hypothesis. It has been found that the proportion of the landslide area and of no landslide area of different thematic maps significantly differs.

The obtained result from the overlay of landslide distribution map to other thematic maps were the basis to consider the ranking for each class. Based on the landslide occurrences within the class of thematic maps the trend of occurrence has been classified into the relative scale as high, medium and low classes and ranked as 3,2 and 1 respectively. Each thematic map was subjectively weighted by the observation of the landslide of the landslide trend obtained from the overlay function and field observation. Different weight had been used to possible correct landslide hazard zonation map. The weight found to be satisfactory is given in table 1 along with the thematic map class rank as;

Ranking scale	1 to 3
Maximum Score	300
High Hazard Area	0 to 100
Medium Hazard Area	101 to 200
Low Hazard Area	201 to 300

The details of landslide hazard zonation area obtained from the analysis is given in Table 2 which are the product of the series of map overlay. Therefore, if there have been any small error in any of the map, the final product may have been cumulatively affected by the error. So the obtained landslide zonation map cannot be said error free.

The property, which is directly related with human livelihood, is considered as the high score e.g. houses, agricultural land etc. This concept has been applied in the GIS to overlay the three thematic maps: landslide hazard zonation map, landuse map and settlement catchment map. As the landslide hazard zonation map is the key map the weight of it is taken as 40%. According to the definition of disaster, settlement is directly affected by disaster and resulted in the loss of lives and property. So the weight is given for this is also 40%. 20% weightage is given to landuse as the property of individual and community is influenced by landslide. The further ranking of each class within the map is provided in table 3. The score obtained from the overlay is divided into three classes – high, medium and low. This result shows that 34.25% of total area lies in the high disaster prone area. Similarly 48% and 16.33% area lies in medium and low disaster prone area (Table 4). Thus we can conclude that the area needs major disaster prevention and preparedness planning. The thematic map class rank can be mentioned as follow

Ranking scale	1 to 3
Maximum Score	300
High Hazard Area	0 to 100
Medium Hazard Area	101 to 200
Low Hazard Area	201 to 300

The obtained disaster prone area shows biases towards the settlement. Therefore the higher disaster prone area is concentrated on the settlement area. The low disaster prone area found in the maps is the area on the slope with no houses. It can be said this map can be considered to identify the areas and communities, which need the disaster mitigation measures. This map cannot be considered as the guideline for settlement planning. Because if the house components are taken into consideration in the low and medium disaster prone area, then the same area may get more score to be considered as the high disaster prone area due to the weight given to buffered settlement map.

The obtained results from the study area are based on various assumptions made to show the applicability of GIS for landslide hazard zonation and mapping disaster prone area. So the result can not be generalized. The conclusion of the study has been drawn as –

- GIS is a strong tool for spatial analysis
- Vector base GIS analysis can give satisfactory result
- PC ARC/Info has limitation in handling large amount of data
- Generation of DTM is useful to produce different product map which are useful in analysis
- Aerial photograph is a useful tool in landslide mapping.

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