Chapter 12
GIS Application in Landslide Susceptibility Mapping of Indian Himalayas

Shantanu Sarkar and Debi Prasanna Kanungo

Abstract The landslide susceptibility zonation maps provide an assessment of the safety of existing habitations and infrastructural elements. This in turn helps to plan further developmental activities in mountainous regions. GIS has been proved to be an integral part of landslide studies in recent times. Besides mapping landslides based on field investigation and remote sensing image interpretation to create a landslide database, GIS has been established as an indispensable tool for preparing various thematic data layers pertaining to landslide causative factors by using field-based data, digitally interpreted remote sensing data and through spatial and 3D analysis of terrain data. These thematic data layers are spatially integrated using arithmetic and weighted overlay statistical techniques on GIS platform to prepare landslide susceptibility maps. CSIR-CBRI has carried out landslide susceptibility mapping of different parts of the Himalayas by employing different techniques such as expert opinion-based approach, field-based rating criteria, statistical approach, and ANN and fuzzy concept-based approaches, in which GIS and remote sensing has extensively been used. The present paper illustrates a broad methodology employed for mapping of landslide susceptibility in GIS environment.

Keywords Landslide susceptibility · GIS · Remote sensing · Himalayas

12.1 Introduction

Landslide occurrences have been a regular feature in the Himalayan region. Loss of lives, properties and functional activities due to landslides are immense and apparently are growing as urbanisation expands into hill areas under the pressure of expanding populations. A greater awareness of landslide problems has led to significant research in the subject. The Himalayan mountain-building process is still

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continuing and as a result, it is frequently subjected to several natural disasters such as earthquakes, landslides, avalanches, glacial lake outburst floods, and flooding. Further, intensified regional precipitation caused by changing climatic pattern is also responsible for increase in frequency of landslide events. Landslides, rock fall, and avalanches are posing serious problems in the regions of mountainous areas, where the means of mitigation and corrective measures are scarce. Hence, it is imperative to assess the hazard and risk of hilly regions.

There has been a drastic increase in magnitude and frequency of natural disasters but at the similar time there is a dramatic increase in the technical capabilities to mitigate them. A considerable amount of work has been carried out worldwide to assess the landslide susceptible zones in the form of landslide hazard zonation mapping. Application of GIS for landslide hazard zonation has been well documented by van Westen (1994). Now, we have remote sensing technology coupled with geographical information system (GIS) which has proven their usefulness in disaster mitigation and management. In this direction, an integrated approach using remote sensing and GIS has been increasingly used in India for landslide hazard mapping (Nagarajan et al. 1998; Gupta et al. 1999; NRSA 2001; Sarkar and Kanungo 2004). The paper illustrates the GIS-based methodology used for landslide susceptibility mapping in Indian Himalayas by the authors.

12.2   Landslide Mapping on Satellite Image

Mapping of existing landslides is essential to understand the relationships between the landslide distribution and the causative factors. As it is just not possible to map each and every landslide via field surveys in a rugged hilly terrain, a comprehensive mapping of landslide in GIS through remote sensing image interpretation, aided by field verifications at sampled locations is an wise alternative. Landslide information extracted from satellite images with high spatial resolution is successful in mapping the existing landslides. Landslide detection on satellite imagery largely depends on the spectral characteristics, size, shape, contrast and morphological expression. In general, there is a distinct spectral contrast between landslides and the background area. With the recent advancement in remote sensing, landslides can be well identified, mapped and transferred to the real world to produce a landslide inventory map, which serves as a crucial information for preparing landslide susceptibility maps. A landslide inventory map shows the landslide distribution in the area. Such maps are very useful for determining the weights of the factors in most of the statistical and soft computing techniques. Further a landslide inventory map can be used for the validation of the landslide susceptibility map. To prepare such maps, landslides are usually detected on satellite image (Fig. 12.1) and through field investigation and finally transferred in GIS. A landslide map prepared in GIS platform provides the area coverage of the individual landslides which is one of the valuable parameters while carrying out the susceptibility analysis.
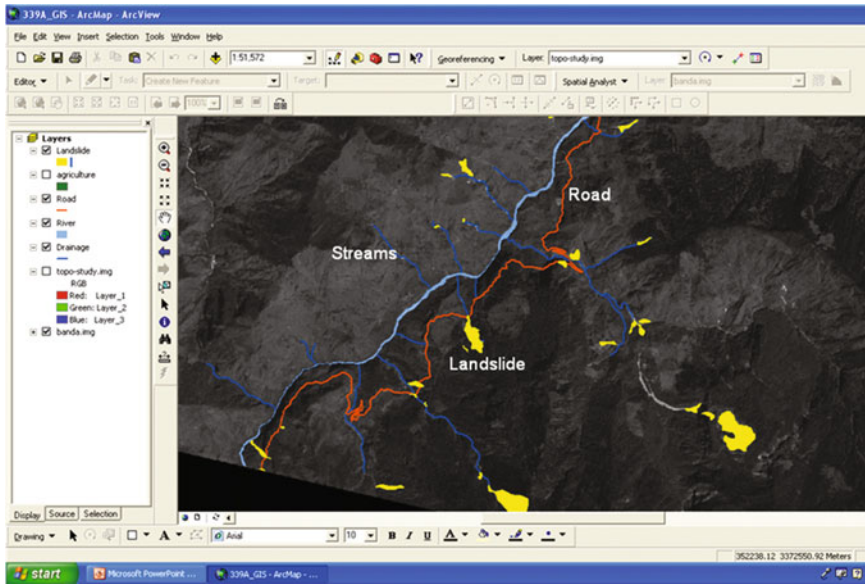
Fig. 12.1 Landslide identified in CARTOSAT 1 satellite image

12.3   Thematic Data Layers in GIS

Landslide occurrences are governed by several factors and broadly these come under geology, geotechnical engineering, hydrology, land use and climate. However, it is not always possible to obtain all the data. In most of the landslide susceptibility studies, the triggering factors such as rainfall and earthquakes are not considered. The factors considered are essentially the preparatory factors which can be collected from the field and available information. Various thematic data layers corresponding to the causative parameters are necessary to be prepared which are the input parameters for any landslide susceptibility mapping. These data layers should be prepared by collecting data from satellite image, published maps, field investigation and also through spatial and 3D analysis of terrain data in GIS. In our study, we have mostly considered slope, aspect, lithology, soil type, drainage density, lineament density, presence of faults and land use parameters for landslide susceptibility mapping. The selection of these factors and their classes depends on the nature of terrain and existing landslides based on the field investigation. To establish relationship between the factors and the landslide, a landslide distribution map also needs to be prepared. A few of the data layers where GIS has been extensively used by the authors are described below.

12.3.1   Digital Elevation Model and Its Derivatives

A digital elevation model (DEM) can be used to obtain data related to two important parameters i.e. slope and aspect. To prepare DEM, Survey of India topographic map sheets of the area at 1:25,000 and 1:50,000 scales are generally employed. The contour data are digitised for generating the DEM using the TIN module of Arc View 3D Analyst. Slope angle which is one of the key factors in inducing slope instability is then derived from the DEM and the slope map with required cell size is generated. Slope can be designated as the first derivative of DEM. A slope map is a raster map in which the attribute of each pixel denotes the maximum slope at a particular location. The map represents the spatial distribution of slope values in the range from 0° to 90° in the area. These are then suitably classified into various classes as desired for the analysis (Fig. 12.2a). Aspect is defined as the direction of maximum slope of any location on surface of the earth. Aspect can be designated as the second derivative of DEM. The aspect map generated from the DEM shows slope directions from 0° to 360° with respect to the north. A slope aspect map is also generated from the DEM with a desired cell size (Fig. 12.2b).

12.3.2   Lithology

Rock types play an important role in slope stability. The lithological constituents, their texture and degree of weathering are the basic elements which differentiate various rock types in influencing slope instability in a region. For example, it has been found that phyllites, schists are more prone to landslides than quartzites. Hence, a geological map which contains different lithologies of the area is an
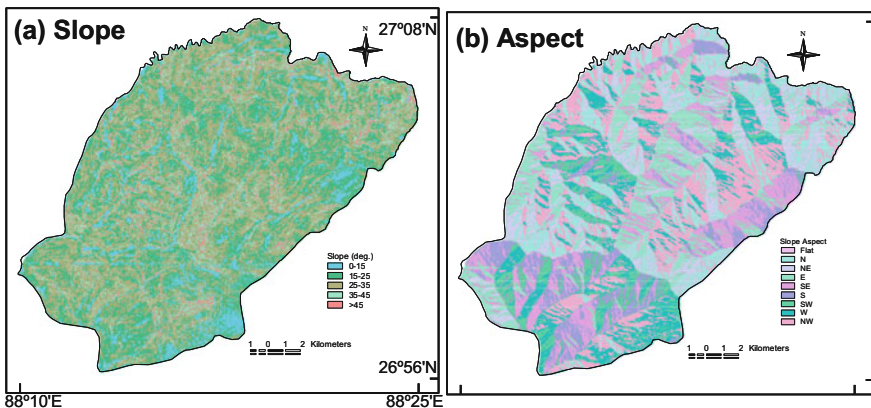

Fig. 12.2 Slope and aspect maps of Darjeeling Himalaya, India (Kanungo et al. 2009a, b)

essential component. The lithological map is mostly prepared from the available geological maps and field investigation and finally transferred into GIS.

12.3.3 *Lineament*

The lineaments represent the fractures, discontinuities and shear zones which can be interpreted from the satellite image. Faults also could be considered as mega lineaments. After preparing the lineament map, the lineament density for the desired cell size is obtained and a lineament density map is prepared by classifying the density into desired classes. It has been observed that thrust/faults have an effect on landslide occurrence. Some times to incorporate the effect of thrust/major faults/lineaments, a fault/lineament buffer map is also generated in GIS with a desired buffer width which could vary from a few metres to a few kilometres.

12.3.4 *Drainage*

The drainage map can be prepared from the topographic map with additional inputs from the satellite images. From the drainage map, the drainage density for the desired cell size is obtained. From this data, a drainage density map is prepared which classify the area into various drainage density classes. From the drainage map, sometimes the drainage order map is also prepared as it has been observed that the first order drainages are mostly associated with landslides as compared to the higher drainage orders. A drainage buffer map (Fig. 12.3a) is sometimes also generated in GIS with a desired buffer width for some particular orders of drainages.
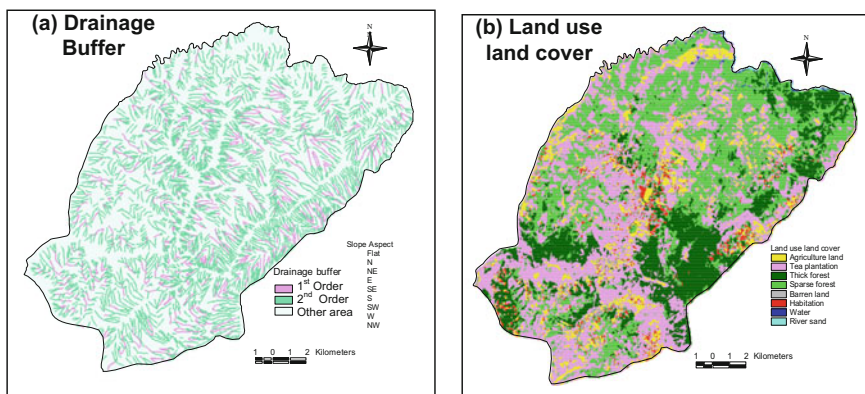

Fig. 12.3 Drainage buffer and land use and land cover maps of Darjeeling Himalaya (Kanungo et al. 2009a, b)

12.3.5 Land Use

Land use is one of the very important factors in landslide susceptibility studies. Land use map in hilly areas generally shows the distribution of forest cover, water bodies and habitats. This map can be prepared by satellite data interpretation using unsupervised and supervised classification techniques using remote sensing software such as ERDAS Imagine. An unsupervised classification is the natural grouping of pixels in the input image data. The classes obtained in the unsupervised classification are checked in the field. These classes are considered as training samples for the supervised classification process. Finally, the land use map is prepared using the supervised classification technique with the maximum-likelihood parametric rule. The land use map is finally prepared in the GIS (Fig. 12.3b).

12.4 Landslide Susceptibility Mapping in GIS Environment

In recent years, assessment of landslide susceptibility in the form of hazard zonation maps has been widely attempted in almost all the countries where landslides are considered to be one of the recurrent disasters. The methodology for preparing such maps has diverse approaches. In India, an integrated approach combining remote sensing and spatial data analysis using GIS has been greatly used for landslide susceptibility mapping. GIS is a powerful tool in modelling the landslide hazards by evaluating the combined effect of the factors which are responsible for landslide occurrence.

12.4.1 Methodology

Landslide susceptibility mapping of different parts of Himalaya has been attempted by many research workers by applying different techniques. The most commonly used techniques are qualitative map combination, statistical approach, analytic hierarchy process, and fuzzy- and ANN-based methods. The selection of suitable techniques depends on nature and availability of data, expertise and mapping scale. In India, mostly the landslide susceptibility maps are on 1:50,000 and 1:25,000 scale. Now, it is being felt that we need such maps on larger scale preferably on 1:10,000 scales. Different LSZ approaches are given in details from time to time in the review articles by Hansen (1984), Varnes (1984), van Westen (1994), Carrara and Guzzetti (1995), Hutchinson (1996), Mantovani, et al. (1996), Aleotti and Chowdhury (1999), Guzzetti et al. (1999) and Kanungo et al. (2009a, b). The different methods with different input data and thematic data layers used by the authors is summarised in the flow diagram (Fig. 12.4).
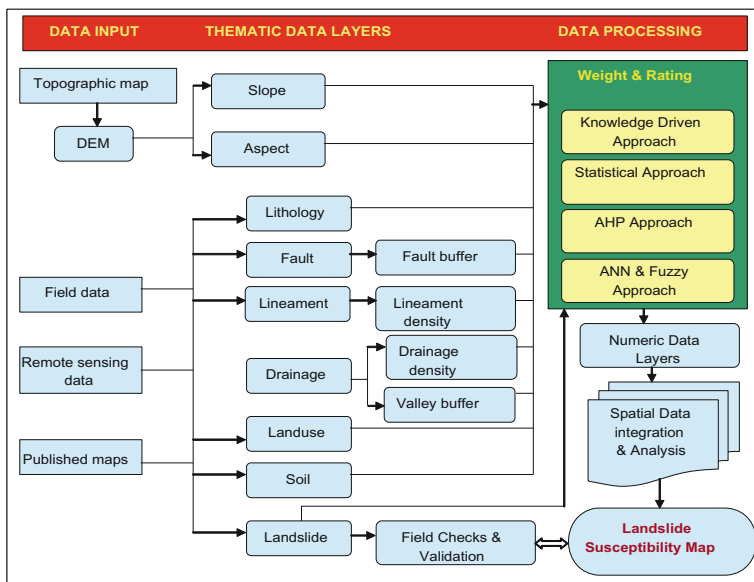
Fig. 12.4 Flow diagram showing the methodology for landslide susceptibility mapping
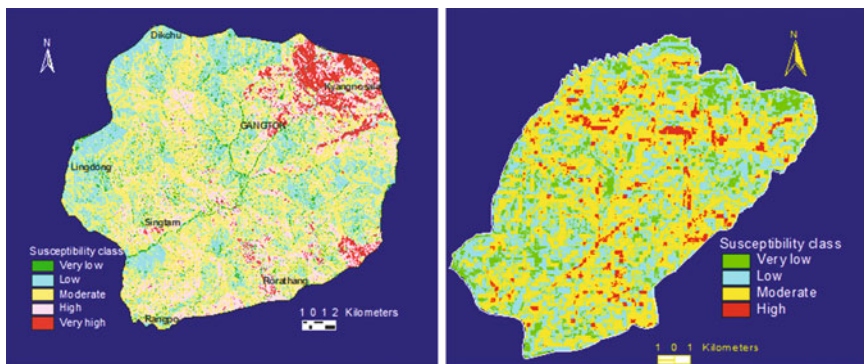

Fig. 12.5 Examples of landslide susceptibility maps from Sikkim and Darjeeling Himalayas (Sarkar et al. 2008; Sarkar and Kanungo 2004)

The input data used are mostly collected from the field, remote sensing data, topographic maps and published literature. These data are converted into digital form to generate the thematic layers in GIS. The desired parameters are taken for the spatial analysis in GIS depending on the techniques employed. After assigning or deriving the weights to different factors and their categories using different techniques, the thematic layers are integrated and classified into various classes of susceptibility in GIS to produce the landslide susceptibility maps (Fig. 12.5).

Further a comparative analysis of landslide susceptibility maps of an area obtained through different techniques can be done using GIS. A comparative study of landslide susceptibility maps of parts of Darjeeling Himalaya using ANN and fuzzy approaches has been carried out by Kanungo et al. (2006).

12.5   Conclusion

The collection of information through remote sensing and spatial data analysis using GIS has proved the capabilities of geoinformatics in the field of landslide disaster mitigation and management. Landslide susceptibility mapping is one of the crucial aspects for any regional landslide hazard study. Analysis of landslide hazard is a complex task, as many factors play a crucial role and with the help of GIS these different kinds of spatial data can be easily integrated. It is observed that analysis of all the factors leading to instability in the region may be accomplished more systematically and scientifically using GIS.

In general, the landslide susceptibility map shows four to five relative classes of landslide susceptible zones as documented. Such maps can be validated by determining the landslide density using the landslide inventory map and also using success rate curve method for different susceptible classes. These landslide susceptibility maps are very useful for planners for selecting suitable locations for any infrastructural developmental projects. However, the area under very high and high landslide susceptible zones should be investigated in detail to pinpoint the potentially unstable slopes so that suitable protection measures can be designed and implemented for a safe built space.

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