Mapping of Landslide Susceptibility Using Geospatial Technique - A Case Study in Kothagiri Region, Western Ghats, Tamil Nadu, India

M. Kartic Kumar[*], R. Annadurai[**]

[*] *Assistant Professor ,Department of Civil Engineering, Karpagam University, Coimbatore*
[**] *Professor and Head, Department of Civil Engineering, S.R.M University, Chennai*

Abstract

Landslides present a significant constraint to development in many parts of the study area which experience frequent landslides. Landslides are among the costliest and more damaging natural hazards in mountainous regions, triggered mainly under the influence of earthquakes and/or rainfall. Landslides cause adverse effects on human lives and economy worldwide. Through scientific analysis of landslides, we can assess and predict landslide-susceptible areas, and thus decrease landslide damage though proper preparation. This paper presents modeling of landslide susceptibility mapping using remote sensing data, GIS tools In this study, the landslide susceptibility maps are prepared based on the causative factors of slope, aspect, geology, geomorphology, soil, drainage density, lineament density and land use and land cover. All these factors are extracted from the spatial database constructed using remotely sensed data and topographic maps. The different classes of thematic layers were assigned the corresponding rating value, as non spatial information in the GIS was used to generate for each data layer. The weighted parametric approach was applied to determine degree of susceptibility to landslides. The landslide susceptibility map was prepared using this technique and is reclassified into four classes showing low to very high susceptibility classes. The analysis of the susceptibility modeling results shows the high significance of slope, drainage density, geological and land cover parameters. The landslide susceptibility map can be used to reduce damage associated with landslides and to land cover planning

Keywords: GIS, Landslides, Susceptibility, Slope, Kothagiri - Remote Sensing

1. Introduction

Landslides cause adverse effects on human lives and economy worldwide. Mountainous terrains are characterized by steep slopes, fractured, folded and high relative relief weathered rocks. Expansion of urban and man-made structures into potentially hazardous areas leads to extensive damage to infrastructure and occasionally results in loss of life every year (Vahidnia et al 2009). Landslide presents a significant constraint to development in many parts of the study area which experience frequent repetitive landslides. Steep slope, steep dips of the litho types, presence of clay layer in weathered rock types, events of continuous heavy rains, flooding on the slopes and improper land use practices play a major role in the genesis of landslides in the Nilgiri District of Tamil Nadu (Manimaran et al 2012). The landslide hazard is used as an umbrella term for wide range of complex slides. Different threats are posed by different type of slope movements (Hafezi Monghaddas et al 2007). Landslide hazard and risk analysis for a town or city normally involved sequence of mountain ranges surrounding the area, and thus the use of hazard map is found necessary. Landslide hazard map is very useful in estimating, managing and mitigating landslide hazard for a region (Chau et al 2004). As the urbanization is rapidly growing, the evaluation of landslide susceptibility is perceived now a days as the initial stage in mitigating landslide hazards. Traditionally, landslide susceptibility was determined using the physical laws that cause slope instability. Damages and losses are regularly incurred because; historically there has been too little consideration of the potential problems in land use planning and slope stability analysis. Recently, greater awareness of landslide problems has led to significant changes in the control of development on unstable land. Landslides, debris slides, debris flows and rock falls cause extensive damage to forests, roads and highways, residential areas, water supplies, irrigation channels and occasionally result in loss of life. Damage to property and people are particularly great during earthquakes and after intense rainfall. (Hafezi Monghaddas et al 2007). Terrain information, such as, land cover, geology, geomorphology and drainage could also be derived from it and the existing thematic information can be updated to enable the quantification of human interference on the Earth's surface. Due to geological location, geomorphology, topography, climate, active tectonics, vegetation and dense population, the area suffers a number of natural hazards of different types, including all kind of mass movement. Generally, the most important factors are bedrock geology (litho logy, structure, degree of weathering), geomorphology (slope gradient, aspect, and relative relief), soil (depth, structure, permeability, and porosity), and land use and land cover, and hydrologic conditions. Many factors influence the development of landslides, and a particular slide can seldom be attributed to a single factor; however, it may be possible to identify the main factors controlling landside. Theoretically, the landslide process can occurred as the result of the disturbance of slope equilibrium. The disturbance of equilibrium of the slope is caused by the increasing of the shear stress and the decreasing of the shear strength. Physiographic characteristics such as slope, aspect, relative relief, geological character, drainage and landuse/land cover play a major role in deciding the potential sites for slope failure. Such analysis is a complex task involving numerous factors affecting slope failure and requires inclusion of several parameters and analytical techniques.

2. Remote sensing and GIS

Geographic Information System (GIS), as a computer- based system for data capture, input, manipulation, transformation, visualization, combination, query, analysis, modeling and output, with its excellent spatial data processing capacity, has attracted great attention in natural disaster assessment (Guzzetti et al. 1999). The spatial and temporal thematic information derived from remote sensing, thematic maps and ground-based information needs to be integrated. Specifically GIS has the potential of performing landslide susceptibility using various thematic layers. The spatial data management and manipulation can be performed through GIS (Sarkar et al 2004, Clerici A 2006, Pradhan et al 2009). GIS provides strong functions both in geo-statistical analysis and data base processing. In addition, the extension of the analysis to include environmental impact assessment of a slope failure can be easily and effectively performed using GIS (Thesis Thugralus). GIS analysis helps in determining macroscopic variables such as elevation, slope gradient, slope aspect, drainage density, etc. from Digital Elevation Model (DEM).

The integration of remotely sensed data into GIS can help to develop a decision support system for further monitoring and prediction of similar activity in the area (Nagarajan et al. 1998; Saha et al.2002).Advances in GIS and the mathematical/statistical tools for modeling and simulation, have led to the growing application of quantitative techniques in many areas of the earth sciences (Carrara et al 2008). The study of landslide hazard also applied these basic tools frequently with intensively use of digital elevation models (DEMs).Landslide susceptibility mapping is a valuable tool for assessing current and potential risks that can be used for developing early warning systems, mitigation plans and land use restrictions. Various researchers have listed a range of factors that are responsible for landslides; these factors are site-specific (Padma et.al. 2011; Kanungo et al 2009).

Recently a few attempts have been made to predict these landslides or preventing the damage caused by them. Several scholars have proposed different schemes for landslide hazard zonation using qualitative approaches or quantitative approaches, Remote sensing and GIS technologies for LHZ studies (Aleotti and Chowdhury 1999; van Westen, 2000; Lin and Tung, 2003; Sharma and Kumar, 2008; Chauhan et al., 2010, Das et al., 2010).. The various methods of data integration for LHZ have been reviewed by Van Westen (1994). The main type of methods are: (1) landslide spatial distribution analysis providing information on the occurrences of landslides, (2) the ordinal scale (quantitative) approach using weighting-rating system of terrain parameters (ground-based knowledge) and (3) the statistical method, which finds suitability for small areas with detailed information. Due to limited availability of field data, the quantitative approach has been adopted for Landslide Susceptibility Zone (LSZ) for the study area. However, very limited information is available on the use of remote sensing and GIS for identification of LSZ in Indian conditions. Therefore, the present study was planned to demarcate the LSZ of the Kothagiri region of Tamil Nadu using Remote Sensing and GIS

3. Study area Description

The Kothagiri Taluk is situated in the eastern part of the Nilgiri District, Tamil Nadu as shown in Fig. 1. The area has a mountainous character. The study area covers 425.49 Kms and lies between latitudes 11° 10' 00"N to 11° 42' 00" N and longitudes 76° 14' 00" E to 76° 02' 00" E and located at 50 km Northwest of Coimbatore city in Tamil Nadu. The topographical elevation values vary between 431m to 2629m. The general physiographic trend is NW to SE following the main drainage system. The study area receives rainfall both in southwest and northeast monsoons. The climate of the study area is temperate and salubrious throughout the year. It is influenced by altitude, and in general, is of temperate type. The pronounced wet seasons are during the north-east monsoon in October and November. The northeast monsoon is moderate, contributing nearly 40 percent. The average annual rainfall of the study area is 1920 mm. The study area lies at an average height of 2600 m above mean sea level.

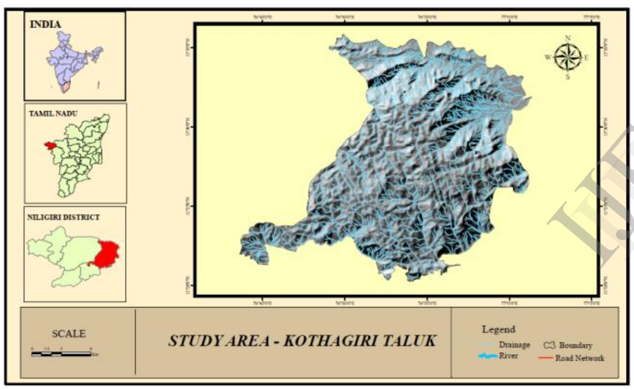

Fig.1 Location Map of the Study area

4. Data Base and Techniques

This study required multiple approaches for collecting and verifying information and for capturing the various perceptions that exits. Our aim was to collect enough information to analyze Landslide Susceptibly zones in the study area. The analysis is based on maps from Survey of India and Geological Survey of India and satellite imageries (Table 1).

Table.1 Details of Various Data Sets used in Present Study

Types of Data	Data of Details	Use/Purpose
Survey of India	1:50,000 scale)	Thematic maps: drainage, drainage density
SRTM (DEM)	30 m Resolution	Slope , Aspect, Relief
IRS-1D LISS III 2012	Spatial resolution 23.5m	Land use/land cover, Geomorphology, Lineament and Lineament density
Geological map	Scale 1:2,50,000	Soil, Geology,

5. Methodology

The present landslide susceptibility analysis was carried out using different layers of information derived from various sources. The construction of cartographic database, comprising several maps used for landslide susceptibility assessment, was based on three different tasks: digitizing and editing of previous cartographic information, remote sensing data interpretation, and detailed field surveying. The basic data sources that have been used to generate these layers are Survey of India (SOI) topographic maps (1:50,000 scale) and geological and structural maps prepared by Geological Survey of India (1:250,000). Various thematic maps pertaining to slope, aspect, lineament, drainage, geological structure soil and landuse/land cover were generated with the help of ArcGIS 9.3 and ERDAS 9.1 software for the study area.GIS database thus constructed includes slope angle, slope aspect, drainage density, lineament density, lithology, land use and geomorphic features. A landslide occurrence database was generated from newspaper archives for 1980-2012 and GPS measurements were taken during field survey. The slope, aspect and relative relief layers were derived from ASTER DEM using 'Modeler' tools in ERDAS IMAGINE, while drainage density analysis was performed using 'Hydrology' tools and 'Fishnet' analysis in ArcGIS. The landslide-related factors are extracted from the spatial database. These factors are assigned with a weight to analyze landslide susceptibility. These weighted factor maps were overlaid using multivariate criteria analysis to prepare a landslide susceptibility zonation (LSZ) map for study area. Method adopted for landslide susceptibility analysis is given in Fig. 2.

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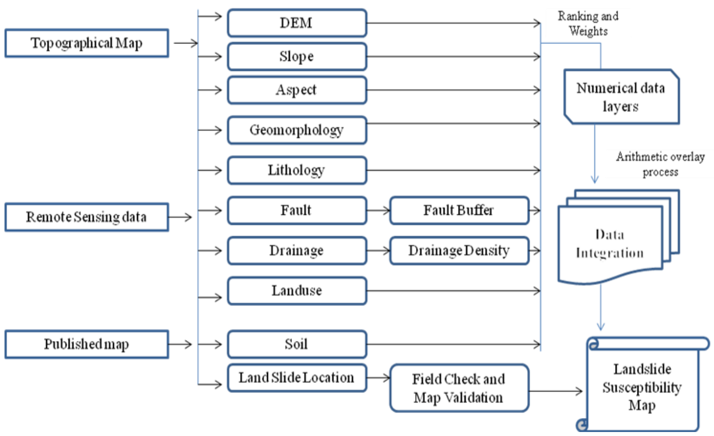
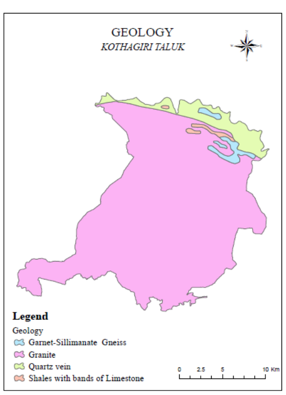


Fig 2 Methodology

6. Result And Discussion

A) Geology

Geology of the study area is underlain entirely by Archaean Crystalline formations with recent alluvial deposits. Weathered, fissured and fractured crystalline rocks and the recent alluvial formations constitute the important aquifer systems in the areaThe dominant geological units identified in this area are 1) Garnet-Sillimanate Gneiss, 2) Granite, 3) Quartz vein, 4) Shales with bands of Limestone. The spatial distribution of geological features is shown in figure no 3. The Garnet-Sillimanate Gneiss are strongly foliated and sheared, showing very high weathering at most locations. The Granite and quazite are stronger than the other rocks in the area



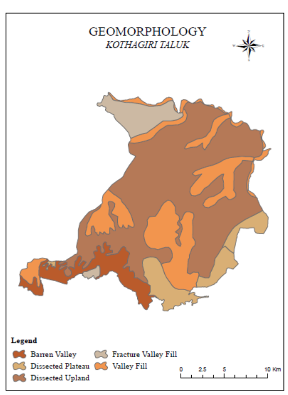


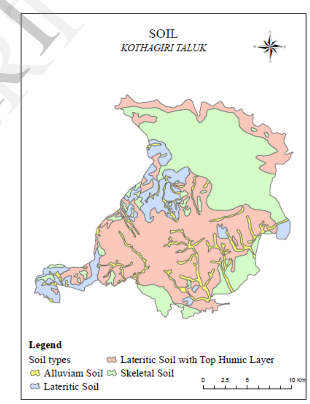
Fig : 3 Geology **Fig:4 Geomorphology**

B) Geomorphology

This study area is a mountainous region of Nilgiri district with many hill ranges and broad valleys with slopping towards plain. The prominent geomorphic units identified in the area through interpretation of Satellite imagery are 1) Barren valley, 2) Dissected plateau, 3) Dissected Uplands, 4) Fracture Valley fills, 5) Valley fills. The Kothagiri Hills rise abruptly from the plains 400 m above Mean Sea Level (MSL) to an average elevation of 2500 m above MSL. The spatial distribution of geological features are shown in figure no 4

C) Soils

The topsoil cover on a slope has an influence on landslide occurrence as observed in the field. For our study, the soil map was derived from a regional soil map at a 1:250,000 scale . The soils of the study area can be broadly classified into 4 major soils types viz., Lateritic soil, skeletal soil, alluvial soil and Lateritic soil with top humic layer. Major part of the region is covered by Lateritic soil. The Skeletal soil and alluvial soil occur as small patches. Alluvial soil is developed in the valleys; where the water logging is also common during the monsoon period. The alluvial are seen along the Valleys and major river courses respectively.



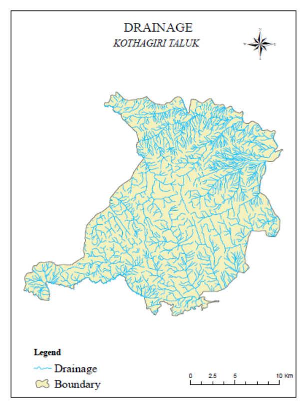


Fig : 5 Soil Fig:6 Drainage

D) Drainage

The drainage map was prepared from the topographic maps with additional inputs from the satellite images. The drainage was digitized using Survey of India toposheets on 1:50,000 scale using ARC GIS 9.3 software. The study area is drained by a number of streams originating from the number of peaks available in the district. Among the major rivers Moyar River flows in an easterly direction and is bordering the northern boundary of the district. Sigur and Pykara tributaries are the major streams of Moyar River; number of minor streams joins this river from north – northwest and south directions. The Bhavani River originates in Bhavaniar Betta and flows southwest ward and swings southwards. The Khuda River drains southern part of the study area which joins Bhavani River in the south. The Katteri is another minor river, which flows eastwards and joins the Bhavani River. The river Kethar halla flows in the northern direction. Dominant drainage pattern is dentritic pattern.

E) Lineament density

Lineaments are structurally controlled linear or curvilinear features, which are identified from the satellite imagery by their relatively linear alignments. These features express the surface topography of the underlying structural features. The lineaments showing fractures, discontinuities, and shear zones were interpreted from the LISS III images. The lineament density map of the study area is shown in Fig 7, and it reveals that high lineament density is observed in the center of the study area with a value ranging from 0 to 1.2 km2. The lineament density for each 200-m by 200-m cell was computed using the line density analyst extension (Saraf, 1999) of ArcGIS 9.3 and were classified into low (0), moderate (0.4 to 0.6 Km2), and high (0.8 to 0.12 Km2) density.

F) Drainage density

The drainage map was prepared from the topographic maps with additional inputs from the satellite images. Drainage density is defined as the closeness of spacing of stream channels. It is a measure of the total length of the stream segment of all orders per unit area. Drainage density of the study area is calculated using line density analysis tool in ArcGIS software. The study area has been grouped into four classes. These classes have been assigned to 'very good' (0.8 – 1.6 km/km2), 'good' (1.6 -2.4 km/km2), 'Moderate' (2.4 – 3.2 km/km2), 'poor' (>3.2 km/km2) respectively. High drainage density (3.2 km/km2) is recorded in the northeastern parts of the study area (Fig. 8).

G) Slope

Slope is an important factor for the identification of groundwater potential zones. Higher degree of slope results in rapid runoff and increased erosion rate with feeble recharge. The slope map of the study area was prepared based on SRTM data using the spatial analysis tool in ArcInfo 9.3. Slope grid is identified as "the maximum rate of change in value from each cell to its neighbors" (Burrough, 1986). Based on the slope, the study area can be divided into six slope classes. The areas having 0–3° slope fall into the 'very good' category because of the nearly flat terrain. The areas with 3°–7° slope are considered as 'good' for flat to gentle sloping. The areas having a steep slope of 30°–45 ° cause damages due to higher slope and landslide. Fig 9 illustrates the slope map of the study area.

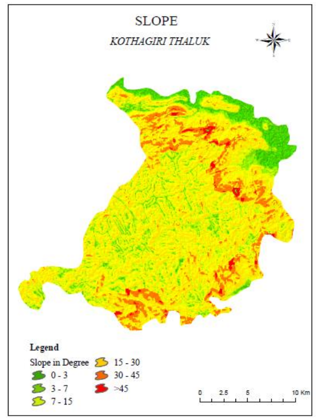


Fig : 7 Slope

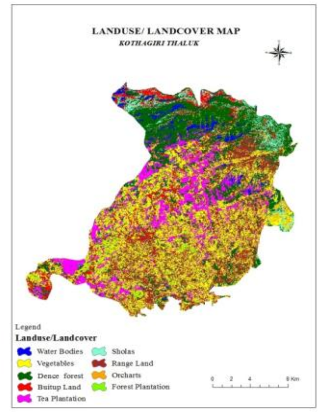


Fig : 8 Land use/Land cover

H) Land Use/Land Cover

A land-use map in hilly areas in general shows the distribution of forest plantation, water bodies, Agriculture land, Fallow land are the types of land-use practices. The satellite image was classified using supervised classification (after several ground truth verifications) with maximum likelihood classification algorithm in ERDAS imagine Software. The classified land use / land cover map of the study area is presented in Fig. 11. It was observed that the areas covered by dense forest, range land, barren land, and water bodies were correctly classified. These classes were considered as training samples for the supervised classification process. The ground truth for other land-use classes present in the area (agricultural land, tea plantations, and habitation) was collected from the field and identified on the image by defining polygons. Finally, the land-use map was prepared using the supervised classification technique with the maximum-likelihood parametric rule. After preparing the map, it was again checked in the field. Some errors were observed, particularly in the areas of tea plantations and agricultural land. The land-use map was finally transferred to the GIS.

7. Rating Scheme and Assigning Weights

The identification of potential landslide areas requires that the factors considered be combined in accordance with their relative importance to landslide occurrence. The scheme of giving weightages by National Remote Sensing Agency (NRSA, 2001) and stability rating was devised by Joyce and Evans (Joyce and Evans, 1976) they are combined and used in the present study as depicted in Table 2. This can be achieved by developing a rating scheme in which the factors and their classes are assigned numerical values (Sarkar et al 2004). The weighting-rating system based on the relative importance of various causative factors as derived from remotely sensed data and other thematic maps was carried out (Saha et al. 2002). A rating scheme was developed based on the associated causative factors for landslides surveyed in the field and various literatures. In this scheme, the factors were assigned a numerical ranking on a 1 to 10 scale in order of importance. Weights were also assigned to the classes of the factors on 0 to 10 ordinal scales where higher weight indicates more influence towards landslide occurrence. The scheme was suitably modified by undertaking several iterations using different combinations of weights.

8. Results

Combining all the controlling parameters by giving different weight age value for all the themes, the final LSZ map is prepared and categorized into 'Very High', 'High', 'Moderate', and 'Low' hazard zones. The output map is generated on a scale of 1: 50,000. Various hazard classes are described below

A) Very High Susceptibility Zone

The very high susceptibility is mainly found near Adderley Tea Estate, Madpabetta, and Vuruvur malai, Kengarai. This zone constitutes an area of about 62.39 sq. km and forms 14.66 % of the total study area. Geologically, this zone is highly unstable and is at a constant threat from landslides, especially during and after an intense spell of rain. This is so, because, the area forms steep slopes with loose and unconsolidated materials, and includes areas where evidence of active or past landslips were observed. Besides, it also includes those areas which are located near faults and tectonically weak zones. The susceptibility analysis shows that slopes with a radiant of 40°- 45° with concave to straight slopes are more vulnerable to landslides. This shows that water retention along with slope gradient control slope instability. Altitudes between 2600 m–2000 m show more probability to failure. Such areas have to be entirely avoided for settlement or other developmental purposes and preferably left out for regeneration of natural vegetation for attainment of natural stability in due course of time.

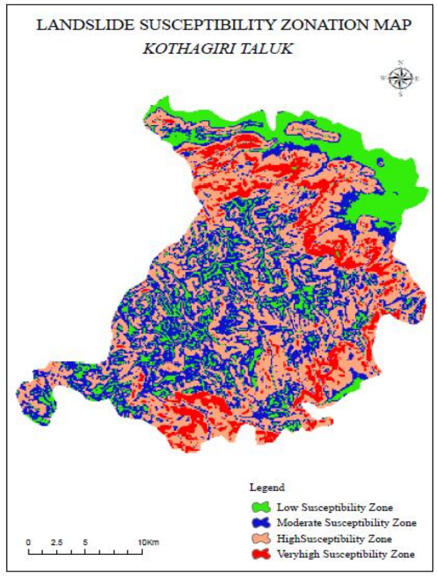


Fig: 9 Landslide Susceptibility Map

B) High Susceptibility Zone

This zone is generally considered stable, as long as its present status is maintained. It comprises areas that have moderately dense vegetation, moderate slope angle and relatively compact and hard rocks. Although this zone may include areas that have steep slopes (more than 35 degree), the orientation of the rock bed and absence of overlying loose debris and human activity make them less hazardous. . It is also noted that mid latitudes between 1500 m– 2200 m are vulnerable to landslides. Since the High Hazard Zone is considered highly susceptible to landslides, it is recommended that no human induced activity be undertaken in this zone. The High Susceptibility Zone is well distributed within the study area. Several parts of the human settlement also come under this zone. Although this zone is generally considered moderately stable, it may contain some pockets of unstable zones in some areas. Seismic activity and continuous heavy rainfall may also reduce its stability. As such, it is important not to disturb the natural drainage, and at the same time, slope modification should also be avoided as far as possible. This zone is mainly found in Kirimonad, Madanad, Pommanu, and Rangasamy Betta regions. This zone covers relatively large area of about 160.21 sq. km. which is 37.65 % of the total study area.

c) Moderate Susceptibility Zone

This zone includes areas where the combination of various controlling parameters is generally unlikely to adversely influence the slope stability. Altitudes between 1000 m–1300 m shows the moderately vulnerable to landslides .Vegetation is relatively dense, the slope angles are generally low, about 25-30 degrees or below. As far as the risk factor is concerned, no evidence of instability is observed within this zone, and mass movement is not expected unless major site changes occur. Therefore, this zone is suitable for carrying out developmental schemes. It spreads over an area of about 127.35 sq. km. and occupies 29.93 % of the total study area. It is recommended that human activity that can destabilize the slope and trigger landslides should be undertaken within this zone. Although this zone comprises areas which are stable in the present condition, future land use activity has to be properly planned so as to maintain its present status.

d) Low Susceptibility Zone

This zone generally includes valley fill water bodies and other Agriculture land. These are prominent features within this zone. As such, it is assumed to be free from present and future landslide hazard. The aspect and slope angles of the rocks are fairly low. Flatlands and areas having gentle slope degrees fall under this zone. This zone is mainly confined to areas where anthropogenic activities are less or absent, and is found predominantly in the western part of the main town. Flat areas are not susceptible to landslides and slopes facing south and north-eastern direction although the geology may comprise of soft rocks and overlying soil debris in some areas, the chance of slope failure is minimized by low slope angle. This zone extends over an area of about 75.54 sq. km. and forms 17.75 % of the total area

9. Conclusions

Landslides in hill terrains cause substantial life and economic losses every year. Susceptibility mapping is an indispensable tool in these areas to define areas prone to landslide. In this present study, various triggered factors like Slope, Aspect, Geology, Geomorphology, Soil, Landuse, Drainage density and Lineament density are analyzed are takes into account seven factors that cause landslides. The methodology for landslide susceptibility mapping presented here involves the generation of thematic data layers, development of a suitable numerical rating scheme, spatial data integration, and validation of results. The data from the susceptibility map can be successfully integrated in the decision process through a cost benefit analysis. In the present study, remote sensing and GIS were extensively used. The numerical rating scheme of the methodology was improved iteratively by evaluating and optimizing the results. The landslide susceptibility map divides the area into different zones corresponding to four relative susceptibility classes (Low, moderate, high and Vey high).The results delineates very high and moderate susceptibility where limited slope stability analysis can be carried out to find the factor of safety of the unstable slopes where infrastructure projects like road construction and widening is to be carried out. Further, any change in the natural environment by human interference, such as implementation of development projects, deforestation, etc., may change the existing landslide susceptibility of the area. The Landslide Susceptibility map can be used on a regional scale as a base for carrying out risk analysis to assist slope management and land use planning and designers in selecting the suitable route paths. Therefore, the Landslide Susceptibility Map prepared through this study will be useful for planning future developmental activities, and also for undertaking mitigation measures

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