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ISSN: 2319-6505

International Journal of Current Advanced Research
Vol1.3, Issue, 8, pp.27-33, August, 2014

International Journal of Current Advanced Research

ISSN: 2319 - 6475

RESEARCH ARTICLE

LANDSLIDE SUSCEPTIBILITY ZONATION MAPPING USING GIS IN KOLLI HILL, TAMIL NADU, SOUTH INDIA

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A R T I C L E I N F O

Article History:

Received 11th, July, 2014
Received in revised form 20th, July, 2014
Accepted 11th, August, 2014
Published online 14th, August, 2014

Key words:

Kolli hills; Landslide; susceptibility; GIS (Geographic Information System); Slope; Land use/land cover

A B S T R A C T

Landslide susceptibility map delineates the potential zones for landslides occurrence. The paper presents anintegration approach through spatial data analysis in GIS for landslide susceptibility mapping in Kolli hill, Namakkal District, Tamil Nadu. Six important causative factors for landslide occurrences were selected and corresponding thematic data layers were prepared in GIS. Topographic maps, satellite image, field data and preparation of the following maps like Drainage, lineament, soil, geology, slope, land use/land cover. Numerical weights for different categories of these factors were determined based on the weighted thematic layers were integrated in GIS environment to generate the landslide susceptibility map of the area.The landslide susceptibility map classifies the area into five different landslide susceptible zones i.e., very high, high, moderate, low and very low. This map was validated using the existing landslide distribution in the area.

INTRODUCTION

In recent years, researchers in geotechnical engineering and other fields have become increasingly interested in using geographical information systems (GIS) in order to provide landslide hazard maps. GIS has the facility to manage and assess landslide hazard on a large scale, where numerous calculations, data collection, and management are required. Thus the use of GIS has become an important aspect in assessing landslide hazard maps where the probability,

Location and frequency of future landslides can be predicted. A hazard map that aims at predicting where slope failures (or mass movements) are most likely to occur, is more accurately defined as a landslide susceptibility map (Brabb, 1984). Landslide susceptibility is in fact the relative spatial probability of a new landslide occurring in the future (Remondo *et al*., 2003) and its assessment in a given area should normally be based on the analysis of slope behaviour and landslide occurrence in the recent past.

Debris flows are a type of landslide events common to mountainous areas (Innes, 1983), usually described as the rapid movement of blocky, mixed debris of rock and soil by flow of wet, lobate mass (Rapp & Nyberg, 1981), and as a rapid mass movement similar to viscous fluids (Varnes, 1978). These events are usually the result of a complex interaction between environmental (e.g., lithology, slope of the hill, land cover,) and human factors (e.g., land use), being triggered by intensive, relatively infrequent rainstorms falling onto a previously saturated landscape, the bursting of a natural dam formed by landslide debris, glacial moraines or glacier ice, earthquake shaking or ice melting (Blijenberg, 1998; Dai *et al*., 2002; Lorente *et al*., 2002). Furthermore, it is generally assumed that areas sensitive to debris flow initiation require the occurrence of steep and bare terrain units where large amounts of unconsolidated material are present (de Joode & van Steijn, 2003; Lin *et al*., 2002).

The GIS-based data analysis procedures provide ways and means to integrate diverse spatial data (e.g. Bonham-Carter, 1994; Carrara and Guzzetti, 1995; DeMers, 2000; Gupta, 2003). The advanced GIS computational tools offer numerous advantages in multi-geodata handling, as is evident from various geoenvironmental studies. However, these studies lack spatial level comparison of GIS derived maps. The focus of this paper is on comparative evaluation of spatial maps through different approaches.

Study Area

The proposed study is taken up in Kolli hills, the area chosen for the present lies almost wholly in the Namakkal District of Tamil Nadu State (Fig.1), except a small pocket on the eastern part of the hills, which lies in Tiruchirappalli District. The study area is geographically situated between the north latitudes 11°11’ N to 11°30’N and east longitudes 78°16’E to 78°29’E covering an area of 485 km2. On the northern side, it is bounded by Salem District and in the eastern and the south eastern sides it is bounded by Tituchirappalli District.

The study area forms pari of two taluks viz. Rasipuram Taluk and Namakkal Taluk. While the northern portion of the hills forms part of the Rasipuram Taluk, the southern portion forms part of the Namakkal Taluk. The part of the Kolli hills, which falls in Namakkal Taluk has seven revenue villages viz. Selur Nadu, Devanur Nadu, Thinnanur Nadu, Valappur Nadu, Vazhavandhi Nadu, Ariyur Nadu and Gundur Nadu. The northern part of the hills, which comes under the Rasipuram Taluk also, has seven revenue villages viz. Perakarai Nadu,

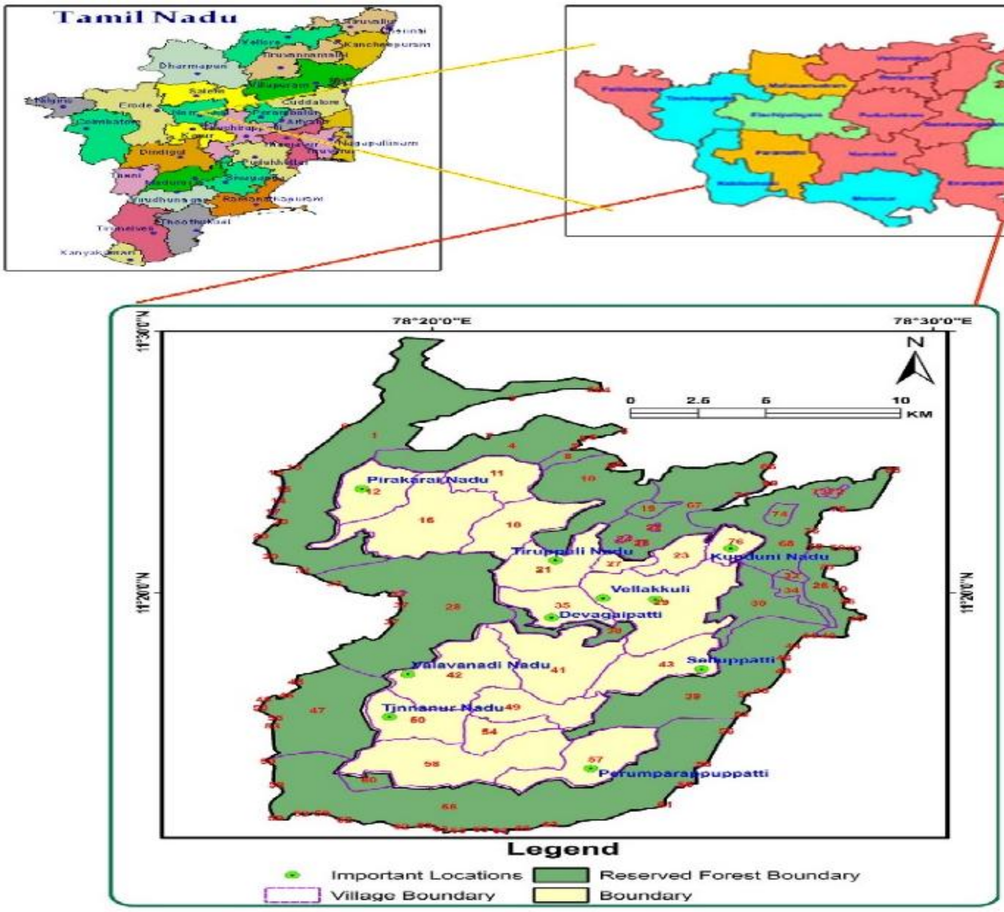

Fig. 1 Study area Map with Village boundary

Bail Nadu, Sittur Nadu, Edapuli Nadu, Thirupuli Nadu, Alathur Nadu and Kunduni Nadu. .All these villages are confined to the upper plateau portion of the hills, which are surrounded by reserved forests.

METHODOLOGY

The base map was prepared using toposheet nos. 58I/7, 8 of 1:50,000 scale. In the present study base map showing drainage details have been prepared from toposheets (SOI). Drainage map was prepared from the said toposheets. Their attributes are added and drainage density zone map was prepared using ArcGIS software. Geology map published by the Geological Survey of India (1997) was made use of for preparing the geological map of the study area. The soil map published by the National Bureau for Soil Survey and Land Use board in 1997 has been used to study the soil types of the area and the spatial distribution of the various soil types in the study area of its attributes are added and analyzed in ArcGIS version 10.2 software. Spatial analysis tools were used for the preparation of interpolation raster map. The maps were interpolated raster by using inverse distance methods. These raster maps are converted into vector maps. These maps were clipped with the boundary to derive within the boundary of the study area to arrive the spatial distribution map. Spot height map has been used for the preparation of slope map. Using this data, Arc GIS software Surface Analysis tool was used to prepare the slope map. In the present study register remote sensing data of the Kolli hills in Namakkal district hilly terrain area Resources at remote sensing data for the year 2013. Land use/land cover features like agricultural land, built-up-land, ever green forest, decidious forest, waste land, plantation and water bodies studies were made from the Resources at image acquired on 02Nov. 2013.

RESULTS AND DISCUSSION

The results of thematically spatial distribution maps are discuss bellow, the present study mainly focused on landslide vulnerable and hazard zonation in Kolli hills, Namakkal district, Tamil Nadu, India.

Rock Types and Structure

Geology spatial distribution map (Fig.2and Table 1) reveals that the Kolli hills is almost entirely composed of Chamockites except a small patch in the south eastern part of hills (in the Selur reserved forest) which is composed of hornblende biotite gneiss.

Table 1 Spatial Distribution Result of Geology

Sl. No.	Class	Area in Km^2
1	Charnockite	438.86 sq.km
2	Basic Dykes	17.40 sq.km
3	Alluvium	6.80 sq.km
4	Hornblende Biotite Gneiss	11.36 sq.km
5	Lateritic Bauxite Cappings	5.14 sq.km
6	Magnetite Quartzite	1.66 sq.km

A few linear bands of dolerite dykes and magnetite quartzites are found traversing the various parts of the hills. The dolerite dykes present in the study area are oriented in the northeast, southwest direction. Of these dolerite bands the most prominent one passes right across the Kolli hills, extending the whole length of the hills for about 30 kms, from one end to another.

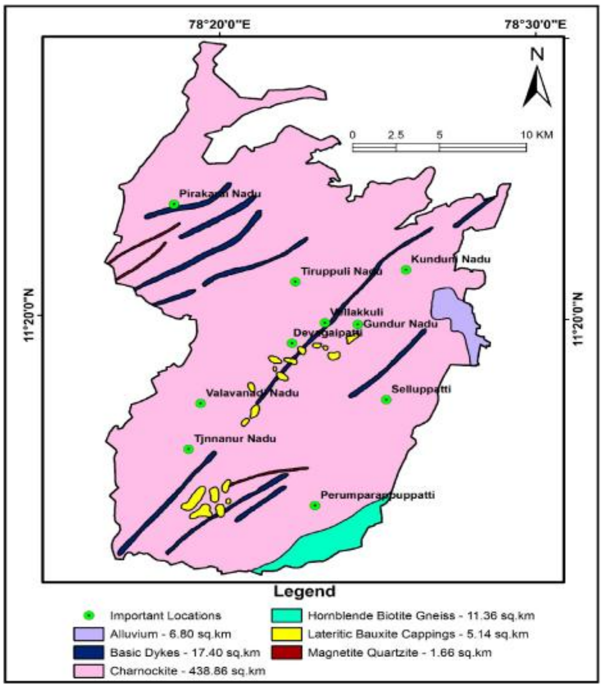

Fig. 2 Geology of the Study area

Narrow, linear bands of magnetite quartzites are found to occur in the north western (in the Bail Nadu reserved forest) arid the southern (Thinnanur and Selur Nadu) parts of the study area. The laterite capping demarcated, which are 19 in number, are irregular in shape and vary in thicknesses. The cappings are restricted to the plateau landforms in the southern and central parts of the Kolli hills.

The laterite occurrences characterized by rounded topography and most of the patches occupy heights over l230 meters. A large patch of alluvium is found in the eastern foothills and plains, near, Vairichettipalaiyam reserved forests, which are found due to the deposition of materials brought by the streams from the hills. The strike direction of the rocks of the study area is roughly NE-SW with dip amounts varying between 65°-75°. Geology is one of most important parameter for landslide vulnerable and hazards zone.

Soil Types

Soils spatial distribution map of the study area are found to vary in respect of texture, depth, drainage and profile development depending upon their position on the landscape and nature of parent material. From the figure 3 and Table 2, it is clear that the study area is mainly composed of four soil types. The map symbols used in the soil map of the study area (Fig.3) is given as found in the soil map published by the National Bureau for Soil Survey and Land Use Board (NBSSLB) and a brief description of the map symbols shown in the figure.

Table 2 Spatial Distribution Result of Soil

Sl. No.	Class	Area in Km^2
1	Gravelly Loamy	277 sq.km
2	Clay	182 sq.km
3	Gravelly Clay	8.6 sq.km
4	Loamy	13 sq.km

The major soils of this map symbol include fine, mixed, typic Rhodustalfs and fine mixed typic Haplustalfs. These are characteristically deep to very deep, well drained and clayey in nature and are associated with moderately sloping areas. These soils are prone to severe - moderate erosion. Soils of this category are found to occur in the upper portion of the hills especially in the plateau portion.

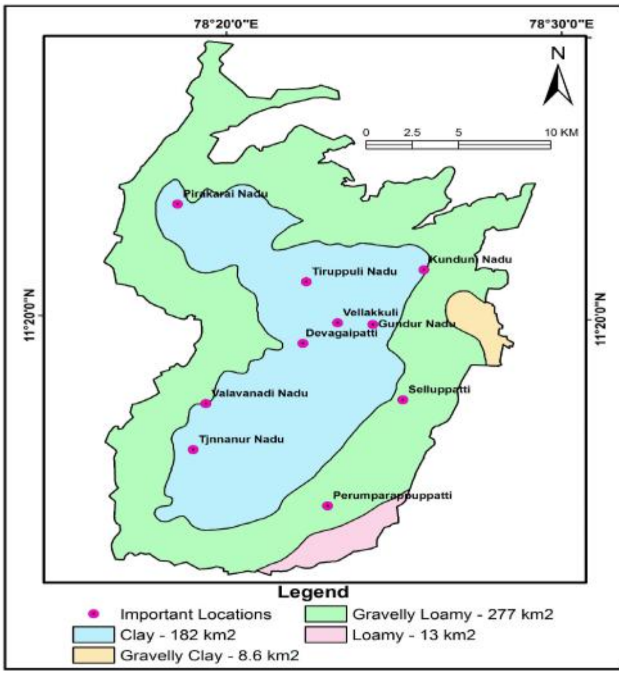

Fig. 3 Soil of the Study Area

The major soils of this unit include loamy - skeletal mixed lithic Ustropepts and loamy, mixed lithic Ustorthents. These are characteristically shallow to very shallow, well drained and loamy in nature and represent areas of severe soil erosion. Soils of this category are found to occur in the steep, slope areas of the hills.

Soil Erosion Hazard

For identifying soil erosion in an area, a number of methods have been adopted among which most commonly used method in the one, which is known as the universal soil loss equation (USLE). It is expressed as

A: R.K.L.S.C.P where

- A - is the computed soil loss expressed in tons per hectares
- R - is the rainfall and runoff factors
- K - is the soil erodobility factors
- L - is the factor of slope inclination
- S - is slope - gradient factor (percentage steepness)
- C - is the cover and management factor and
- F – is the support practice factor

The above relationship clearly shows that for using this relationship, data of a number of parameters are required. But, inspite of this limitations, it is still the commonly used expression for identifying soil erosion.

Land use/land cover

The land use map of the area was prepared from the remote sensing data.

Table 3 Spatial Distribution Result of Land use/land cover

Land cover class	2013	
	Km^2	%
Deciduous forests	291	60.49
Evergreen forests	65	13.5
Agriculture land	60	12.47
Waste land	65	13.5

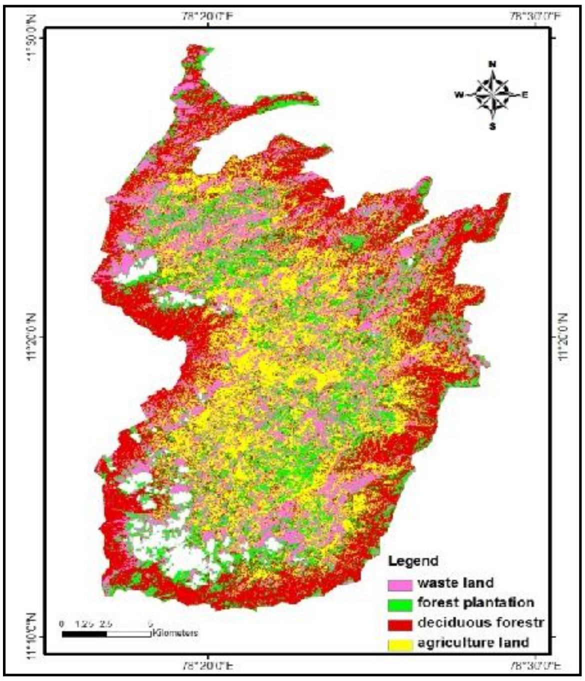

Fig. 4 Land use/land cover map – 2013

Ground truth data were collected from the field and also perceived from the topographical maps. Resources at satellite image was interpreted for various land use in terms of vegetation cover. The land use map, thus prepared, classifies the area into thick forest, moderate forest, sparse forest, agriculture land and barren land (Figure 4 and Table 3). It can be observed from the map that the maximum area is covered by moderate and sparse forest categories followed by agriculture land and thick forest respectively. The barren land which occupies the least area is predominant at higher elevation in the northeastern part.

Drainage Pattern

The Kolli hills form a major catchment area for the important rivers of the region viz. the Aiyar river, the Thirumanimuthar river and the Sweta Nadhi.

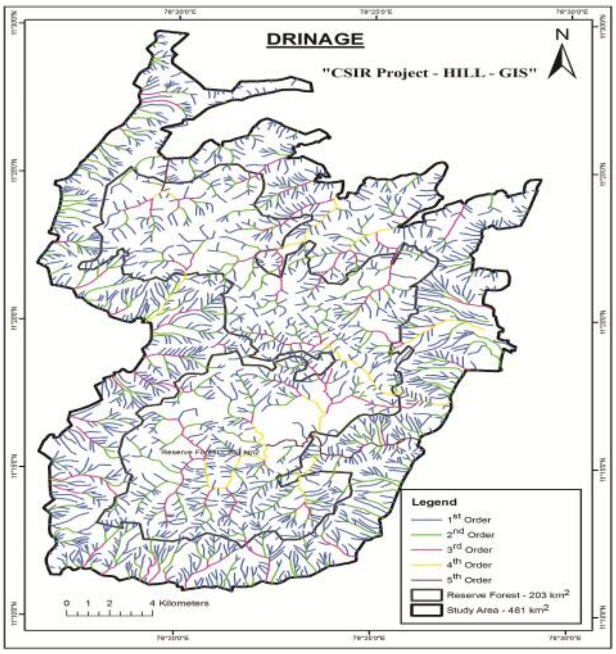

Fig. 5 Drainage of the Study Area

The tributaries of Aiyar river drains the southern plateau region and the eastern slopes of the kolli hills. In general these tributaries of the Aiyar river in the Kolli hills flow in a west to east direction before joining the main river, the Aiyer, which flows in a north to south direction in the adjacent plains on the eastern side of the Kolli hills. Similarly, the streams, which drain the western slopes of the Kolli hills, flow in an east west direction before joining the Thirumanimuthar river, which flows in a north to south direction in the adjacent plains, on the western side of the hills. The streams that drain the northern part of the hills flow predominantly in a south west – northeast direction before joining the Sweta Nadhi, which flows in an east-west direction in the adjacent plains on the northern side of the hills.

As far as the drainage (Fig.5) pattern is concerned, the plateau portion of the hills has a dendrtitc pattern, which is characteristic of an area with massive homogenous crystalline rock with a more or less a flat terrain (Morisawa, 1985). Because of the existence of such condition in the study area, the pattern of the drainages is found to be dendritic. However, in the outer slopes of the hills, parallel to sub parallel drainages are found which is due to the fact that the northern part of the study area, the streams flow in preferably southwest – northeast direction occupying the structural valleys and in a few areas of this part of the study area, trellis pattern in noticeable. These apart, radial drainage partterns are found locally in the areas of small rounded to oval shaped hills.

Drainage Density

Drainage density map (Fig.6 and Table 4) is considered to be one of the important parameters for assessing the groundwater potential and landslide hazards zone in an area.

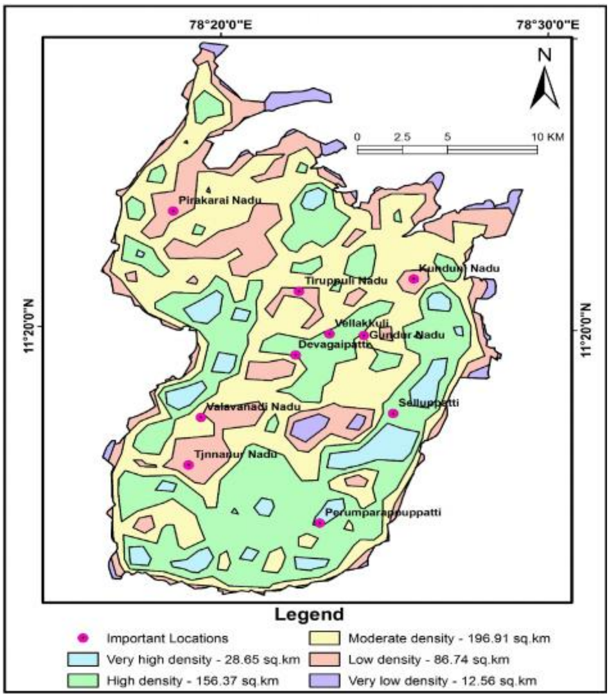

Fig. 6 Drainage Density Map of Study Area

Since drainage density is a useful index for understanding the nature of the surface material and their permeability and infiltration characteristics, drainage density has been used in conjunction with other parameters such as slope, geomorphology and rock types.

Table 4 Spatial Distribution Result of Drainage Density

Sl.No.	Class	Area in Km^2
1	Very low density	12.56 sq.km
2	Low density	86.74 sq.km
3	Moderate density	196.91 sq.km
4	High density	156.37 sq.km
5	Very high density	28.65 sq.km

Lineaments

The term lineament map (Fig.7) refers to the linear or curvilinear feature that is structurally controlled.

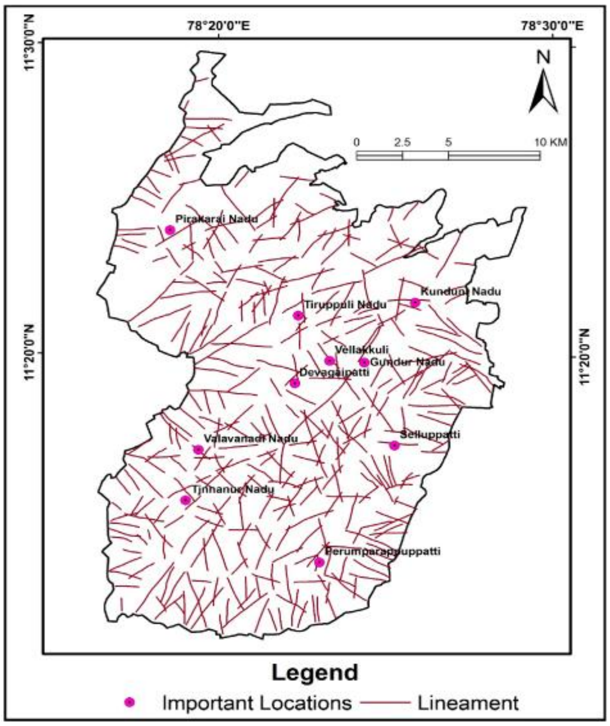

Fig. 7 Lineament of Study Area

Such lineaments are the surface expressions of faults, ridges, joints, valleys, dykesrocks etc. and may be related to regional tectonic activity. For the present study, the lineaments that represent the joints, faults, etc. of the area have been identified as these may provide some useful information for locating the fracture zones of the area. Since, these fracture zones are less resistant to erosion than the rock, these-represent the weak zones, which possess favourable conditions for groundwater with landslide occurrences.

Lineament Density

The study of lineament density map (Fig.8 and Table 5) help to identify the weathered zones in an area, which is very essential in the studies relating to groundwater exploration, soil erosion, landslides etc. The lineament density map for the present study area was prepared using lineament map prepared by interpretation of satellite data.

Table 5 Spatial Distribution Result of Lineament Density

Sl. No.	Class	Area in Km2
1	Very low density	46.89 sq.km
2	Low density	78.20 sq.km
3	Moderate density	196.26 sq.km
4	High density	124.31 sq.km
5	Very high density	35.56 sq.km

From the above description, it is clear, that higher lineament density classes are found mostly in the southern slopes and the central parts of the plateau portion. The areal extent of low lineament density class is found mostly in the outer slopes whereas moderate lineament density class is found well distributed in the plateau portions as well as outer slopes.

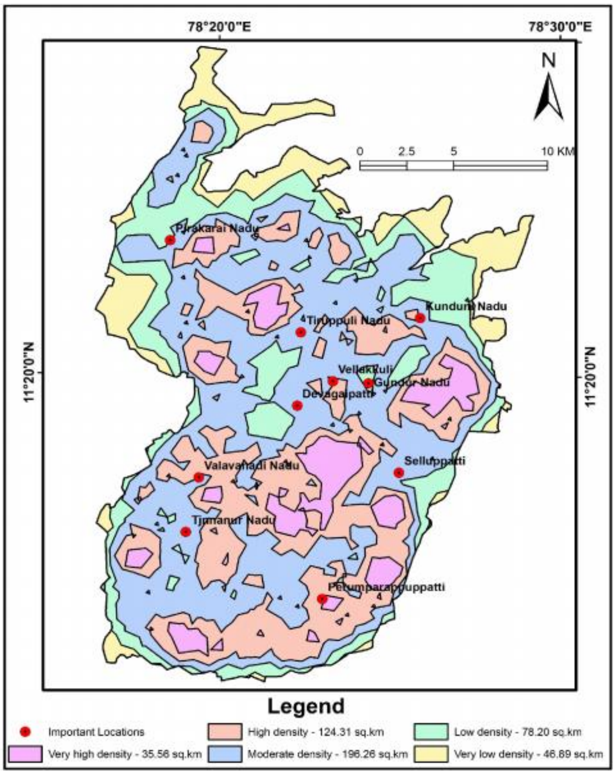

Fig. 8 Lineament Density Map of Study Area

Slope

The slope map of the study area was prepared by adopting the widely used Wentworth's (1930) average slope method. The various slope classes and their spatial distribution are shown in figure 9 and Table 6.

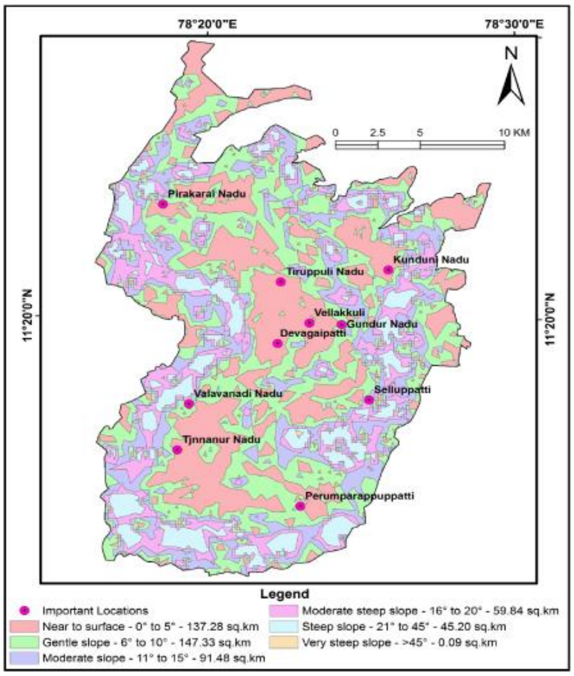

Fig. 9 Slope Map of Study Area

Patches of near to surface class (<5°), gentle slope class (6 to 10°) are found in the plateau portion (south western and central parts of Vazhavandhi Nadu, north eastern part of Thinnanur Nadu, eastern part of Ariyur Nadu and western parts of Valappur Nadu), and the eastern (southern and central parts of Vairichettipalayam reserved forest) and western outer slopes (lower portions of Bail Nadu reserved forests, Karavallikombai reserved forest). Small isolated patches of this slope class are found in the northern (Bail Nadu reserved forest) and thesouthern (Selur reserved forest) western (Karavallikombai reserved forest) slopes of the study area.

Table 6 Spatial Distribution Result of Slope

Sl. No.	Class	Area in Km^2
1	Near to surface - 0° to 5°	137.28 sq.km
2	Gentle slope - 6° to 10°	147.33 sq.km
3	Moderate slope - 11° to 15°	91.48 sq.km
4	Moderate steep slope - 16° to 20°	59.84 sq.km
5	Steep slope - 21° to 45°	45.20 sq.km
6	Very steep slope - >45°	0.09 sq.km

Moderate slope areas (11° - 15°) are found well distributed in the plateau portion.Most parts of the villages of Thinrtanur Nadu, Valappur Nadu, Vazhavandhi Nadu, Ariyur Nadu, Kunduni Nadu, Edapuli Nadu, Perakarai Nadu and Sittur Nadu have moderate slopes. A considerable area of the villages of Bail Nadu (northern and eastern parts), Thirupuli Nadu (small patches in southern,

GIS Analysis

Each thematic map such as Geology (Fig.2), Soil (Fig.3), Land use/land cover (Fig.4), Drainage density (Fig.6), Lineament density (Fig.8) and Slope (Fig.9) provides certain clues for the preparation of Landslide Hazard Zonation map.

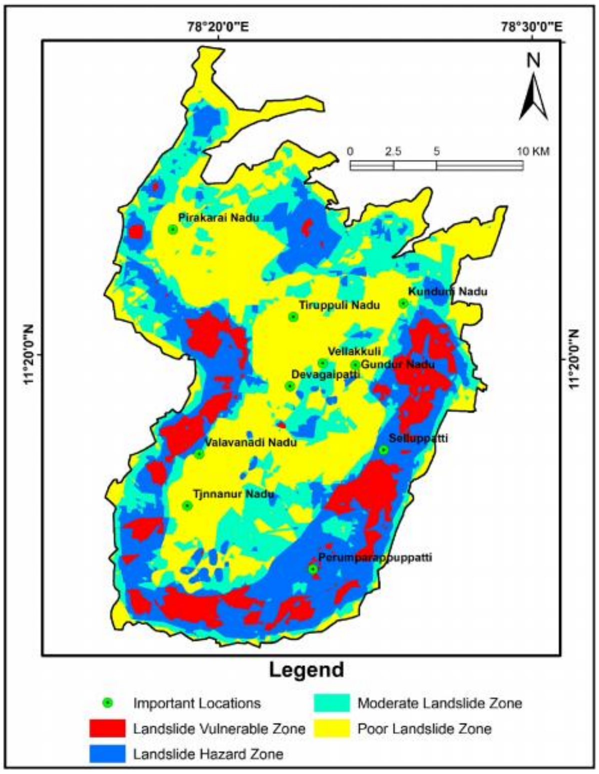

Fig. 10 Landslide Vulnerable and Hazards Zonation Map of Study Area

In order to g*et al*l these informations unified, it is essential to integrate these data with appropriate factor. Therefore, numerically these informations are integrated through the application of GIS. Various thematic maps are reclassified on the basis of weightage assigned (Table 7), and brought into the "Raster Calculator" function of Spatial Analysis tool for integration. A simple arithmetical calculation has been adopted to integrate various thematic maps. The final (Landslide Hazard Zonation) map (Fig. 10) was prepared showing the four zones, namely Landslide Vulnerable Zone, Landslide Hazard Zone, Moderate Landslide Zone and Poor Landslide Zone. This map was overlaid in GIS to know which stream order is controlling the landslide.

Table 7 Result of Landslide vulnerable and Hazards Zone

Sl.No.	Class	Area in Km^2
1	Landslide Hazard Zone	116.37 sq.km
2	Landslide Vulnerable Zone	53.44 sq.km
3	Moderate Landslide Zone	116.36 sq.km
4	Poor Landslide Zone	1.95 sq.km

It could be observed from the figure 10 that 53.44Km´of the area in higher susceptibility zone contains 116.37 Km^2 of existing landslides and 116.36 of the area contains 1.95 of existing landslides. This also reflects the validity of the landslide susceptibility map with existing slope instability conditions.

CONCLUSION

Landslides cause significant economic loss or even lives every year in mountainous areas. Therefore, landslide susceptibility mapping is important in such regions to assess the possible location of risk, to develop a reliable and practical mitigation program, and to plan hazard management. This paper objective is to map geology, slope and soil landslide hazards over a region by using the GIS analysis.

From this study it is interpreted that the distribution of landslides is largely governed by a combination of geo environmental conditions, such as geology, soil, land use/land cover, drainage density, lineament density and slope, high slope and drainage density zone. It is inferred that the presence of a combination of geo environmental conditions lead to landslide susceptibility of the terrain where the local discontinuity surfaces provide geology and slope action and pathways for the landslide activity to take place. Thus, the GIS-based methodology for integration of various rainfall, slope and drainage buffered zone datasets seems to be quite suitable for developing a landslide hazard zonation map.

Acknowledgement

The author expresses sincere thanks to the CSIR for providing fund facility through R & D projects to execute this work.

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