Demarcation of Landslide Potential Zones of Kasaragod Using Gis and Remote Sensing

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Research Article

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Abstract

The sudden mass movements of earth, rock or debris down a sloped land can be defined as landslides. There are various factors that makes the slope unstable. When a trigger such as rainfall etc. occurs on the existing unstable slope, the movement of land mass occurs which can also be stated as landslides. The present study is based on the various landslides occurred in, Kasaragod, a District of Kerala during year 2020. The study was carried out by integrating remote sensing and GIS applications. Various causative factors are identified for the purpose which includes slope, land use, relative relief, geology, geomorphology, roads, drainage density, soil and lineaments. The maps were digitized in ArcGIS software for the preparation of thematic layers. These maps were integrated for the analysis. The landslide susceptibility map divides the area into five different zones based on the severity of landslides. The critical zone covers an area of 33.94km^2, the highly unstable zone has an area of 37.224km^2, the moderately unstable zone with an area of 100.567km^2, the moderately stable zone having an area of 151.299km^2 and finally the stable zone which has an area of 1665.01km^2. Based on the map precautions can be taken on the susceptible areas to save the lives and property.

I. Introduction

Landslides are natural disasters that occur on the hills and steep slopes due to the instability of these slopes. Usually the triggering factor for the occurrence of this mass movement is rainfall. When heavy rainfall occurs in existing unstable slopes, the landslides or landslips occurs. Especially the people living in hilly areas are more affected due to these sudden movements of slopes, resulting in loss of life and property. The main reason for the slope instability is various anthropogenic activities at the toe portion of the hill, lack of drainage, deforestation and unscientific way of cutting roads. It is necessary to take this matter into consideration so that proper monitoring and maintenance of various activities can be done to save the lives and property. Kasaragod, a district of Kerala had experienced extreme rainfall events during the year 2020 (kerala.gov.in). The majority of rainfall occurred in the months of June to September which is the South-West Monsoon. During this period many people were shifted to disaster relief buildings as their properties were affected due to heavy rains.

Some of the areas had reported landslide as well as landslip. For the past 10 years, the area had not reported any such cases. The sudden movement lead to loss of properties of the people staying in the area which made the people panic. This matter was taken into consideration for the study purpose, so that based on the occurred landslides; a susceptibility map of the landslides can be done to mark the prone areas. This helps the people over the area to shift to safer places and save their lives.

The Geographical Information System (GIS) and remote sensing together plays an important role in landslide sus- ceptibility mapping (P Rajakumar et al., 2007). The remote sensing satellite with high resolution images gives more ac- curate information for detecting landslides (Ibrahim Shaik et al., 2019). Various methods can be used for the analysis of landslides using GIS and Remote sensing, some of which are the Weighted overlay analysis (Akhilesh Kumar et al., 2019), the analytical hierarchy process similar to Weighted overlay method is done by assigning weightage to various causative factors. The frequency ratio method is also used for the analysis (Satyanarayana Prasad Nerella et al., 2019). Some other methods such as Weighted Linear Combination method can also be used. This method is more flexible and can be used for multi-criteria evaluation (Elizabeth Aipe Michael and Sailesh Samanta., 2016). The analysis of landslides is done by considering various causative factors that include the relative relief, slope, aspect, curvature, lineaments, land use, geology, geomorphology, soil etc. (Tri Dev Acharya and Dong Ha Lee., 2018; S E Saranaathan et al., 2020). The landslide hazard zonation is done by using these causative factors which finally gives the landslide susceptibility map of the area. In this study, a landslide susceptibility map of Kasaragod is prepared using GIS and remote sensing. These maps are digitized using the base map for the preparation of thematic layers. The landslide susceptibility values are assigned to each factor which is used to calculate the landslide susceptibility Index for the purpose of analysis.

Ii. Study Area

Kasaragod District is situated at the Northern most part of Kerala (Fig. 1) located at 12.5-degree North 75degree East. Karnataka is the District boundary. The main crop cultivated over the area are coconut, arecanut, rubber, cashew, pepper and paddy. The production of cash crops is more compared to food crops. Major portion of the District is covered by laterite. As the laterite soil is highly porous, the dug wells constructed using this type of stones get recharged soon. The water level also falls down during the summer due to lack of summer showers. The District receives an average rain fall of 3500 mm/annum out of which the major portion is contributed by southwest monsoon. High temperatures are recorded during the summer season from March to May.

Iii. Data Collection And Methodology

The landslide susceptibility analysis consists of various processes which includes identification of causative factors, collection of various data's, spatial representation of these data's and finally the Landslide Hazard Zonation. About nine causative factors were considered for the study purpose. The factors are; slope, land use, geology, geomorphology, soil, lineaments, relative relief, drainage density and roads. The land use map of Kasaragod is clipped from the Kerala State Land Use Board. This map is digitized using ArcGIS. The Indian Remote Sensing satellite IRS P6 LISS III image is used for the preparation of land use map. This satellite has a resolution of 23.5m. ERDAS imagine is used for the preparation of this map. The geomorphological map is also prepared using the satellite IRS P6 LISS III. The slope map and relative relief map of the study area is derived from ASTER DEM. The Survey of India topo sheets is used for the preparation of drainage and road maps. The buffer was prepared for these maps at a distance of 50m, 100m, 200m, 300m, 400m and 500m in ArcGIS software. The base map for geology and soil are obtained from Geological Survey of India and National Bureau of Soil Survey which are then digitized in ArcGIS software. The details of previous landslide events were used for the study purpose which was obtained during the field investigation. The location details were taken at site using GPS location. The slope value was measured using clinometers and Brundon compass. The images are shown in Fig. 2 and Fig. 3. The details of the sites visited are provided in TABLE I.

TABLE I: Details of field survey

Sl. No	Latitude	Longitude	Slope (degree)	Name
1	12.34173	75.15993	44	Cherkarappady
2	12.40522	75.27814	45	Balal-Kottakkunnu
3	12.37681	75.38422	40	Konnakkadu
4	12.352	75.40466	47	Kottanjeri
5	12.39788	75.34477	40	Nambiar Mala
6	12.49624	75.39363	20	Kallapalli
7	12.48879	75.30907	33	Chamundikkunnu

The analysis was carried out by using a semi quantitative approach. A Landslide Susceptibility Value (LSV) is assigned to each of the causative factors based on its importance on the terrain conditions. The Landslide Susceptibility Values are provided in TABLE II.

TABLE II: Landslide Susceptibility Values

FACTORS	LSV
Slope	30
Land use	20
Relative Relief	10
Road Buffer	10
Geomorphology	10
Drainage Density	05
Lineaments	05
Geology	05
Soil	05

The Landslide Susceptibility Index values are computed by using LSV and landslide percentage per km^2 of each factor. The LSI values are calculated using the following equation: LSI = ((Landslide

The Landslide Susceptibility Index values are computed by using LSV and landslide percentage per km^2 of each factor. The LSI values are calculated using the following equation:

LSI = ((Landslide % per km^2 x LSV))/100 The spatial analyst extension tool is used for the integration of these factors in ArcGIS. The Landslide Susceptibility Index is
computed using Raster calculator of ArcGIS. The equation is as follows:

LSI=SlFr+LuFr+RrFr+RbFr+DdFr+LnFr+GgFr+GeFr+SoFr

Where; SlFr = Frequency Ratio of slope LuFr = Frequency Ratio of land use RrFr = Frequency Ratio of Relative Relief RbFr = Frequency Ratio of Road buffer DdFr = Frequency Ratio of Drainage Density LnFr = Frequency Ratio of Land use GgFr = Frequency Ratio of Geomorphology GeFr = Frequency Ratio of Geology SoFr = Frequency Ratio of Soil

Iv. Results And Discussions

The instability of slopes is the major reason for the occurrence of landslide which may be caused due to a number of various factors. About nie factors are considered for the study which combine together to make the slope unstable. The various causative factors considered for the study purpose are as follows;

A. Slope

Slope is an important parameter that are considered for the preparation of landslide hazard zonation map. The various slope categories of the area are obtained from ASTER DEM. The slope of the study area is classified into eight categories (Fig 4) that are <1, 1 – 3, 3 – 5, 5 – 10, 10 – 15, 15 – 20, 20 – 30 and >30. From the map it is understood that majority of the landslide had occurred in the area where slope is greater than 30 degrees. The LSI calculations are shown in TABLE III.

B. Land Use

The series of operations carried out on land is known as land use and the natural or planted vegetation is the land cover. The land use map of the study area is classified into 16 categories out of which plantation covers majority of the area. The plantation alone contributes to about 56.56% of total area of the district (Fig 5). Deep rooted plants or trees in a particular area reduce the chances of landslides. Out of the seven landslides considered for the study, four number of landslides occurred in the area where the land use was plantation (TABLE IV).

TABLE III: LSI calculation for slope

SLOPE	No. of Slides	Area(km^2)	LS/km^2	LS%/km^2	LSI
<1	0	48.12	0	0	0
1-3	0	223.18	0	0	0
3-5	0	276.12	0	0	0
5-10	0	655.06	0	0	0
10-15	0	393.92	0	0	0
15-20	0	210.21	0	0	0
20-30	1	158.92	0.0063	2.49	0.75
>30	6	24.33	0.247	97.51	29.25
TOTAL		1990.17	0.252895	100	30

C. Geology and Minerals

The geological formations happen due to continuous weath- ering actions of wind and water over hundreds and thousands of years. Certain kind of geological formations may be un- stable and can be the reason for landslide occurrence. The geological map is obtained from the Geological Survey of India (GSI). The study area mainly has five geological belts which include the Charnockite group in the Southern part, the Northern gneiss, the central part having Syenite pluton, the Warkali formation at the Coastal tract and Quaternary sedi- ments at the coastal plain. (Abbreviations of geological names are given in TABLE VI) Out of the seven landslides taken for the study, five of them were reported in the Charnockite group of rocks (Fig 6) contributing up to 29.2% of the total area. The LSI calculations are tabulated in TABLE V.

D. Drainage Density

It is the sum of drainage length per unit area. Drainage is one of the very important factors considered for landslide susceptibility analysis. The landslides may occur due to saturation of soil due to improper drainage network. In this study, the drainage density is classified based on the grid code (Fig 7) and it was found that majority of the landslides were present in gridcode of 3 (TABLE VII) that covers upto 41.21% of area.

E. Geomorphology

The various landforms, its formations and sediment de- position of the Earth’s crust is known as geomorphology.

TABLE IV: LSI calculation for Land Use

LAND USE	No. of Slides	Area(km^2)	LS/km^2	LS%/km^2	LSI
Plantation	4	1125.75	0.003553	14.11	2.82
Crop land (Paddy)	0	47.91	0	0	0
Land with scrub	0	292.57	0	0	0
Fallow	0	2.14	0	0	0
Villages (Rural)	0	72.19	0	0	0
Water bodies	0	2.36	0	0	0
River/stream	0	46.54	0	0	0
Town/cities (Urban)	0	10.09	0	0	0
Mining/Industrial wastelands	0	0.29	0	0	0
Sands (Riverine/Coastal/Desert)	0	6.94	0	0	0
Barren Rocky/Stony Waste/Sheet Rock	0	17.97	0	0	0
Degraded land under plantation crops	0	13.64	0	0	0
Deciduous (dry/moist)	1	229.74	0.004353	17.28	3.46
Evergreen/semi evergreen	2	115.73	0.017281	68.61	13.72
Land without scrub	0	0.61	0	0	0
Forest plantation	0	5.38	0	0	0
TOTAL		1990.17	0.025187	100	20

TABLE V: LSI calculation for Geology

GEOLOGY	No. of Slides	Area	LS/km^2	LS%/km^2	LSI
Charnockite	5	580.34	0.009	36.89	1.84
Laterite	0	119.19	0	0	0
Garnet-silimanite gneiss	1	73.69	0.014	58.10	2.91
Warkalli formation	0	55.29	0	0	0
Granite	0	3.28	0	0	0
Hornblende / diopside granulite	0	9.48	0	0	0
Quartzo-feldspathic gneiss	1	854.37	0.001	5.01	0.25
Fuchsite Quartzite	0	6.90	0	0	0
Guruvayur formation	0	85.10	0	0	0
Garnetiferous Quartzite	0	12.70	0	0	0
Quartzite	0	5.16	0	0	0
Periyar formation	0	58.31	0	0	0
Anorthosite	0	0.42	0	0	0
Hornblende-biotite gneiss	0	9.99	0	0	0
Viyyam formation	0	16.59	0	0	0
Syenite	0	65.50	0	0	0
Kadappuram formation	0	33.86	0	0	0
TOTAL		1990.17	0.023	100	5

TABLE VI: Abbreviations of geological names

An	Anorthosite
Ch	Charnockite
Fq	Fuchsite Quartzite
Gq	Garnetiferousquarzite
Gr	Granite
Hbg	Hornblendbiotite gneiss
Hdg	hornblend
Kh	Garnet silimanate gneiss
Lt	Laterite
Qfg	Quartzo-feldspathic gneiss
Qfm	Viyyam formation
Qfp	Periyar formation
Qm1	Guruvayur formation
Qm2	Kadappuram formation
Qz	Quartzite
Sy	Syenite
W	Warkali Formation

The remote sensing image gives the various geomorphological formation of the given area. The landslides usually occur in hilly regions. The valley portions are most affected due to the accumulation of these slided matters at the valley portion. Based on geomorphology, the study area can be classified as lower plateau, pediplain, weathered/buried residual hill, coastal plain, rock exposures, denudational hills, piedmont zone and denudational structural hills (Fig 8). Majority of the landslides were reported in denudational structural hill region (TABLE VIII) which covers about 11.17% of total area.

F. Relative Relief

The actual variation of height in a unit area is known as relative relief. It can also be explained as the difference between the maximum and minimum height per grid. The relative relief of the study area is obtained from DEM. About five classifications of relative relief is done which ranges from <100 to >400 (Fig 9). That is, <100, 100 – 200, 200 – 300, 300 – 400 and >400. About three landslides were reported in relative relief of 200 – 300 and two landslides each had occurred in relief ranges of 100 – 200 and 300 – 400 (TABLE IX).

G. Roads

Roads are also an unavoidable parameter considered for landslide susceptibility analysis. The road map is shown in Fig 10. The road buffer is prepared where a buffer is the reclassification of roads based on distance. The unscientific cutting of slopes for the construction of roads leads to landslides. The buffer map is prepared for a distance of 50m, 100m, 200m, 300m, 400m and 500m (TABLE X) for the purpose of this study. Other than the buffers ¡50 and 400 – 500 range, the landslides were reported in all other buffer ranges.

TABLE VII: LSI calculation for Drainage Density

DRAINAGE DENSITY	No. of Slides	Area(km^2)	LS/km^2	LS%/km^2	LSI
1	0	215.62	0	0.00	0
2	0	647.94	0	0.00	0
3	6	818.29	0.007332	67.47	3.37
4	1	282.85	0.003535	32.53	1.63
5	0	24.18	0	0.00	0
6	0	1.41	0	0.00	0
Total		1990.17	0.010867	100	5

TABLE VIII: LSI calculation for geomorphology

GEOMORPHOLOGY	No. of Slides	Area(km^2)	LS/km^2	LS%/km^2	LSI
Lower Plateau (Lateritic)	0	899.63	0	0	0
Pediplain Weathered/buried	0	223.13	0	0	0
Residual Hill	0	114.17	0	0	0
Water Body	0	45.23	0	0	0
Coastal Plain	0	77.26	0	0	0
Piedmont Zone	1	330.05	0.00303	5.31	0.53
Pediplain	1	31.75	0.0315	55.24	5.52
Flood Plain	0	2.37	0	0	0
Denudational Hills	0	44.18	0	0	0
Rock Exposure	0	0.00	0	0	0
Denudational Strctural Hills	5	222.37	0.0225	39.44	3.94
TOTAL		1990.17	0.057007	100	10

TABLE IX: LSI calculation for Relative Relief

RELATIVE RELIEF	No. of Slides	Area(km^2)	LS/km^2	LS%/km^2	LSI
<100	0	1107.7	0	0	0
100 – 200	2	639.48	0.003128	6.45	0.644951
200 – 300	3	148.63	0.020184	41.62	4.16237
300 – 400	2	79.43	0.025181	51.93	5.192678
>400	0	14.94	0	0	0
TOTAL		1990.17	0.048493	100	10

H. Lineaments

The underlying geological formation which represents a line feature such as faults, fractures and joints is known as lineaments (Fig 11). The lineament represents the weaker plane that reduces the strength of slope material. The reduction of strength of the slope material leads to failure of slopes. The buffer was created for lineaments for a distance of 50m, 100m,

200m, 300m, 400m and 500m. From the TABLE XI, it can be found that majority of the landslides were reported away from lineaments. About six landslides were reported away from lineaments which cover about 72.05% of total area.

I. Soil

The area is classified into six different varieties of soil (Fig 12) based on its texture. That are gravelly clay, loam, sandy, clay, water body and gravelly loam. Clayey soils are more prone to landslides. These type of soil has finer texture and the movement of soil moisture is also less rapid. Majority of landslides were reported in clayey region which covers about 87.2% of total area (TABLE X11).

J. Mapped Landslide Hazard Zones

Based on the Landslide Susceptibility Index (LSI) values, the total area of the District is classified into five different zones namely stable, moderately stable, moderately unstable, highly unstable and critical zones (Fig 13). The classifications of landslide hazard zones are tabulated below (TABLE XIII):

1) Stable Zone: Majority of the area comes under this category. The area where the Landslide Susceptibility Index values are less than 15 are the stable zone. This zone does not require any restrictions and are said to be stable. The area that comes under this category is 1665.01km^2.

2) Moderately Stable Zone: The area where the Landslide Susceptibility Index values ranges between 15 – 20 is said to be the moderately stable zone. Based on the present conditions, this area is said to be safe from mass movements. However, uncontrolled soil erosion or improper land use or developmental activities may in future cause slope instability. The area that comes under this zone is 151.299km^2.

3) Moderately Unstable Zone: These are the zones were the Landslide Susceptibility Index values ranges from 20 – 25. The slopes coming under this category are at present stable. There are chances of slope failure in the coming days as a result of various land use activities. The various land use and other anthropogenic activities in this zone should be done in such a way that it does not affect the slope stability. The landslide may also occur in this area if the drainage is disrupted. The area that comes under this category is 100.567km^2.

4) Highly Unstable Zone: The areas where the Landslide Susceptibility Index values ranges from 25 – 30 can be said as highly unstable zone. The area coming under this category requires immediate attention. At these area, the quarrying needs to be restricted, contour bunding needs to be done to ensure proper drainage and the natural vegetation should be regenerated. Unless proper mitigatory measures are not taken at this zone, it would soon reach the critical state. The localities residing at this area should be shifted to safer places. 37.224km^2 of area comes under this category.

5) Critical Zone: This is the most unstable zone. The Landslide Susceptibility Index value for this zone is greater than 30. In order to protect the lives and property, the natural vegetation of the area should be soon regenerated. The entire population residing at the area should be completely shifted. The various anthropogenic activities, developmental projects, unscientific land use practices and quarrying needs to be

banned at this area which may lead to huge loss of life and property. The total area coming under this category is 33.94km^2.

TABLE X: LSI calculation for Roads

ROAD BUFFER	No. of Slides	Area(km^2)	LS/km^2	LS%/km^2	LSI
>500	2	504.29	0.003966	17.51	1.750548
400 – 500	0	189.36	0	0	0
300 – 400	1	242.18	0.004129	18.23	1.822585
200 – 300	2	455.96	0.004386	19.36	1.936119
100 – 200	1	197.25	0.00507	22.38	2.237784
50 – 100	1	195.92	0.005104	22.53	2.252964
<50	0	205.22	0	0	0
TOTAL		1990.17	0.022656	100	10

TABLE XI: LSI calculation for Lineaments

LINEAMENT BUFFER	No. of Slides	Area(km^2)	LS/km^2	LS%/km^2	LSI
0	6	1434.1	0.004184	18.36	0.918106
50	1	53.76	0.018601	81.64	4.081894
100	0	54.38	0	0	0
200	0	110.38	0	0	0
300	0	112.27	0	0	0
400	0	113.31	0	0	0
500	0	111.90	0	0	0
TOTAL		1990.17	0.022785	100	5

TABLE XII: LSI calculation for Soil

SOIL	No. of Slides	Area	LS/km^2	LS%/km2	LSI
gravelly clay	1	1438.75	0.000695	2.17	0.11
loam	0	0.28	0	0	0
sandy	0	84.55	0	0	0
clay	3	297.95	0.010069	31.38	1.57
waterbody	0	27.92	0	0	0
gravelly loam	3	140.69	0.021324	66.45	3.32
TOTAL		1990.17	0.032088	100	5

TABLE XIII: Landslide Susceptibility Zones

Sl.No	HAZARDOUS ZONES	LSI RANGE
1	Stable	<15
2	Moderately Stable	15 - 20
3	Moderately Unstable	20 - 25
4	Highly Unstable	25 - 30
5	Critical	>30

V. Conclusion

The study revealed that, the slope of the area exceeding 30 degree reported more landslides. Majority of the landslides were found at the relative relief ranging from 200 – 300. The area having plantation as the main land use activity had more number of landslides. The geological formation having charnockite group of rocks were prone to more landslides. The geomorphological feature having denudational structural hills were more susceptible to landslides. Lack of proper drainage is also an important parameter which makes the slope unstable and leads to landslides. The areas having clayey soils were more vulnerable due to its smaller particle size and least porosity.

The Landslide Hazard Zonation of the area is classified into five different categories viz; stable, moderately stable, moderately unstable, highly unstable and critical zones. The critical zone has the least area that covers up to 33.94km^2. The highly unstable zone has an area of 37.224km^2, the moderately unstable zone with an area of 100.567km^2 and the moderately stable zone with an area of 151.299km^2. Majority of the area comes under the stable zone with 1665.01km^2 of total area.

Proper mitigation measures are to be taken to prevent the impact of these landslides. Proper planning and awareness need to be made among the localities. The people living under the critical area needs to soon shifted to safer places. Regeneration of plants and trees are to be done to make the slope stable. Some other safety measures such as rock bolting, netting, catch fenches and anchoring can also be adopted as a precautionary measure.

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Figures

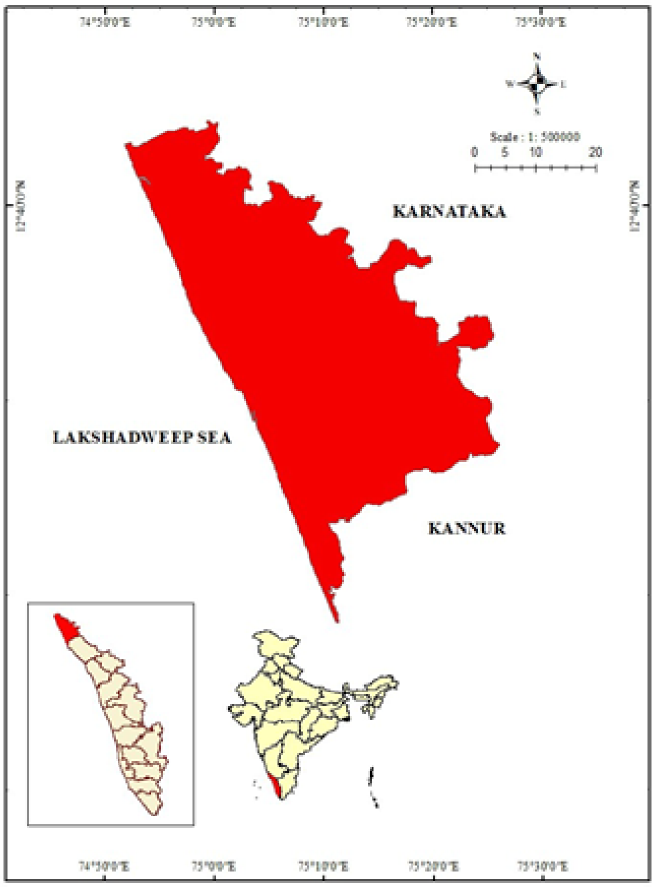

Figure 1

Location map

Figure 2

Landslide at Balal-Kottakkunnu

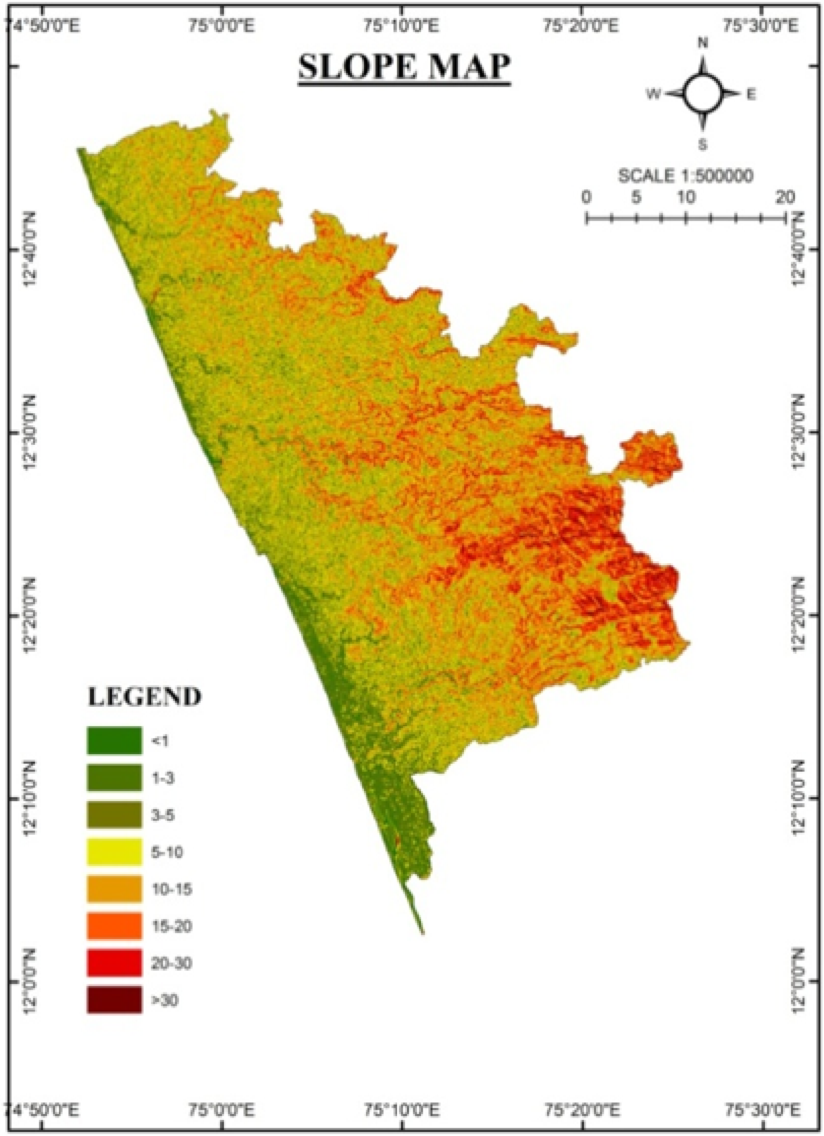

Figure 4

Slope map of Kasaragod

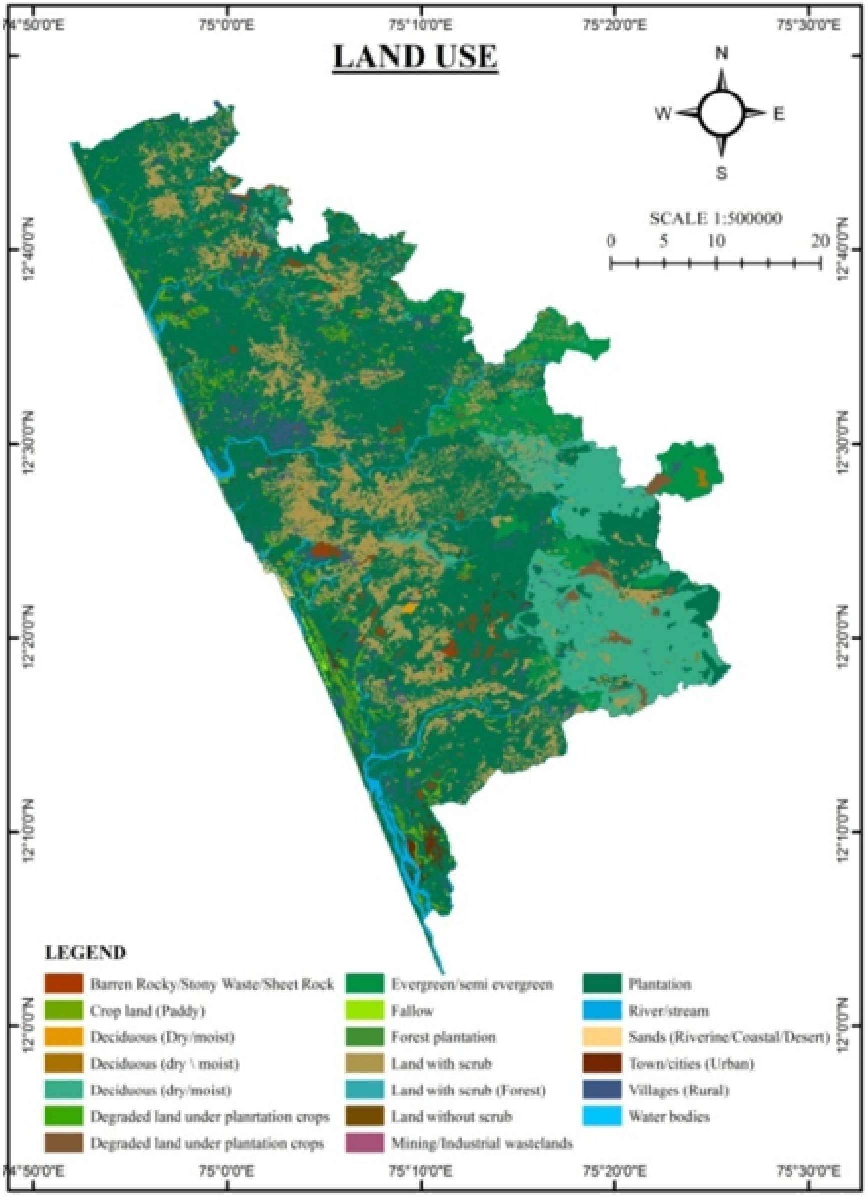

Figure 5

Land Use map of Kasaragod

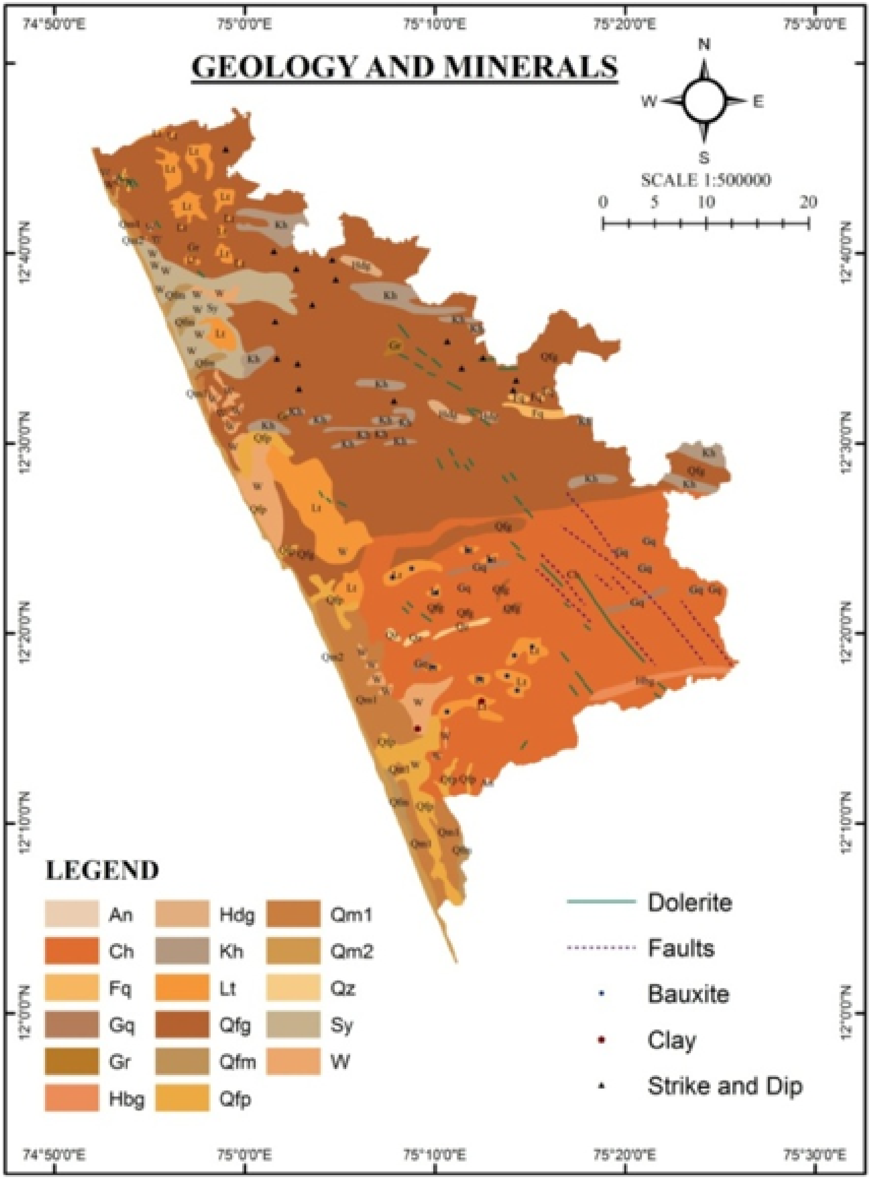

Figure 6

Geology map of Kasaragod

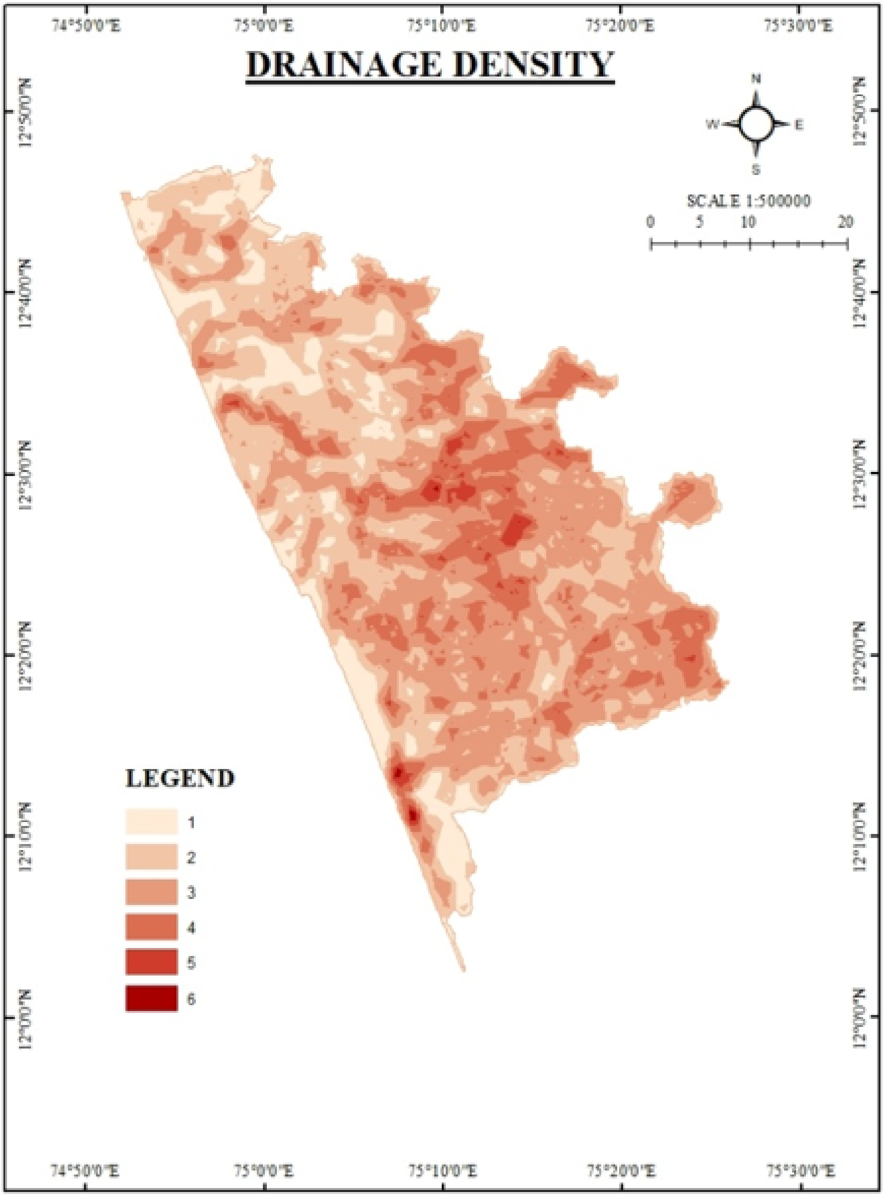

Figure 7

Drainage Density map of Kasaragod

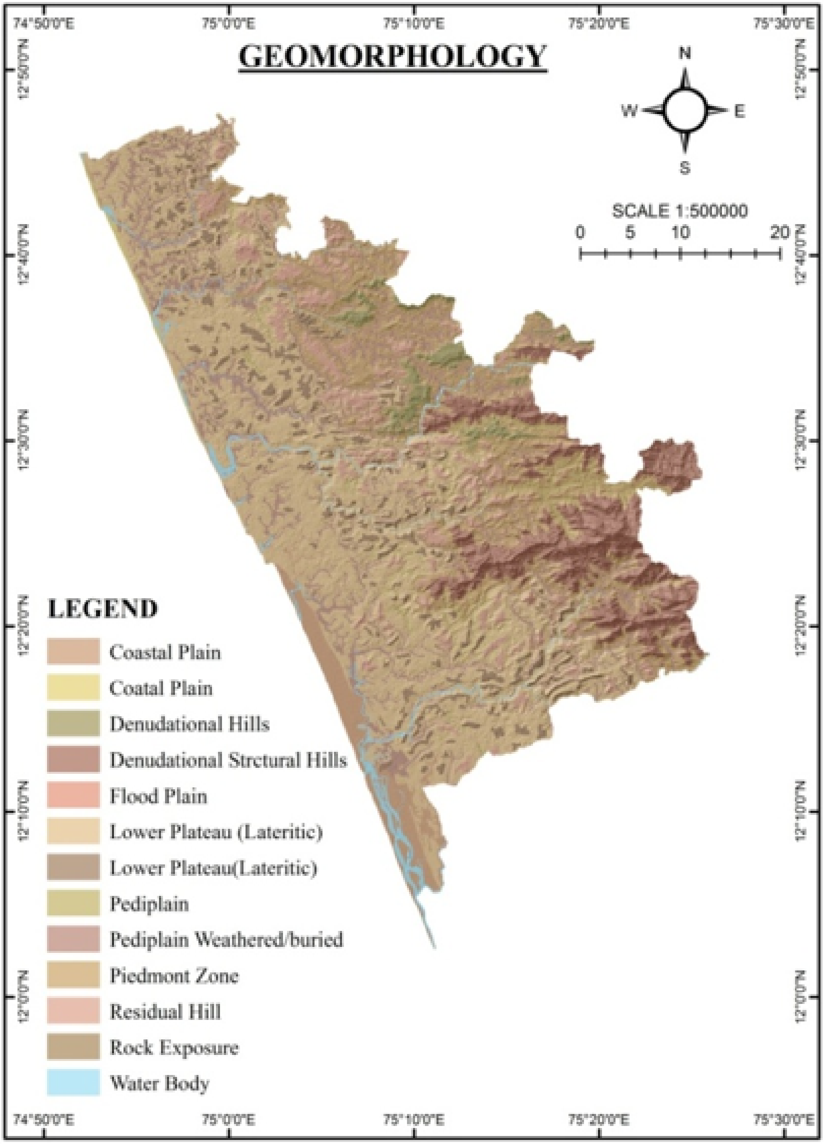

Figure 8

Geomorphology map of Kasaragod

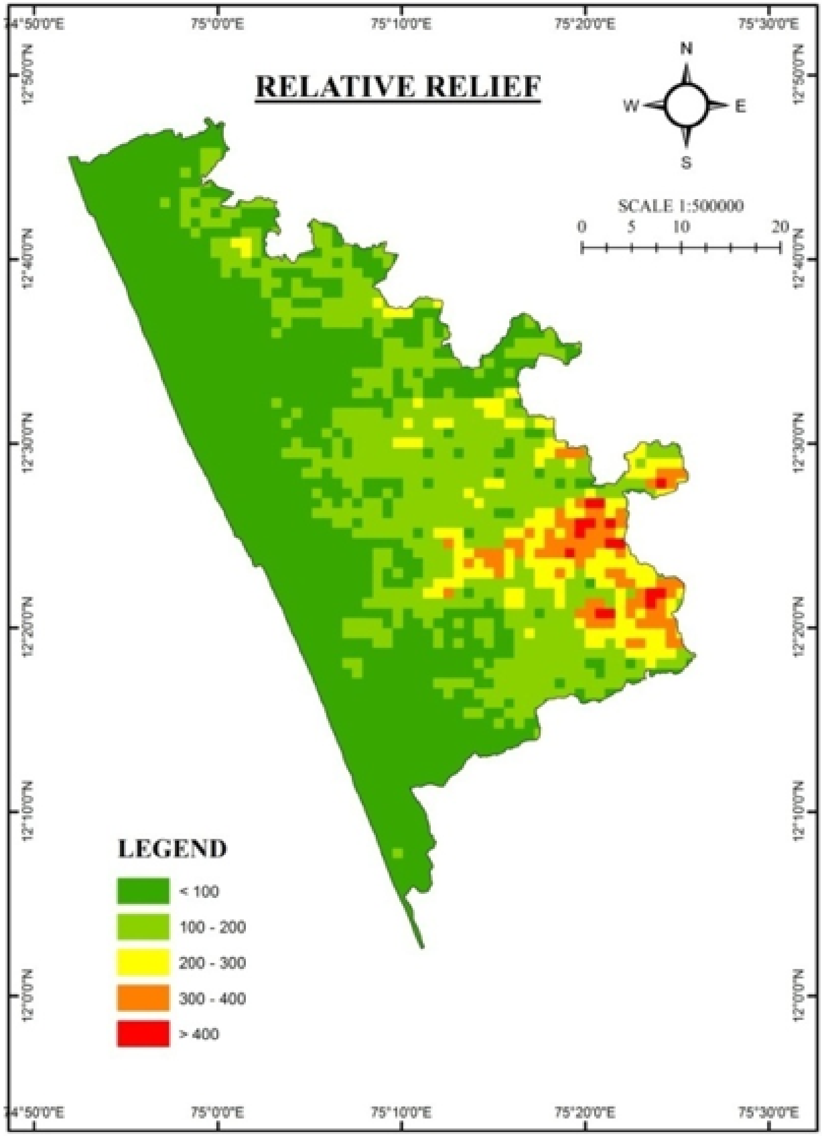

Figure 9

Relative Relief map of Kasaragod

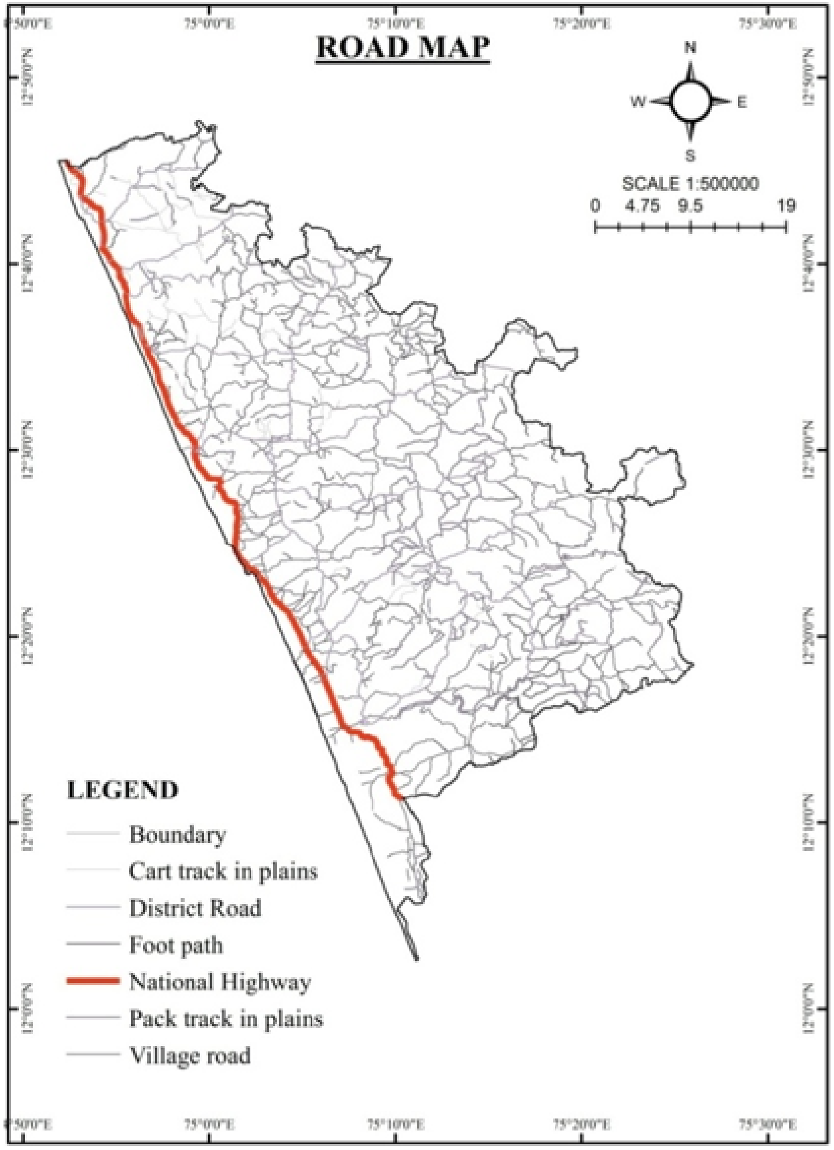

Figure 10

Road map of Kasaragod

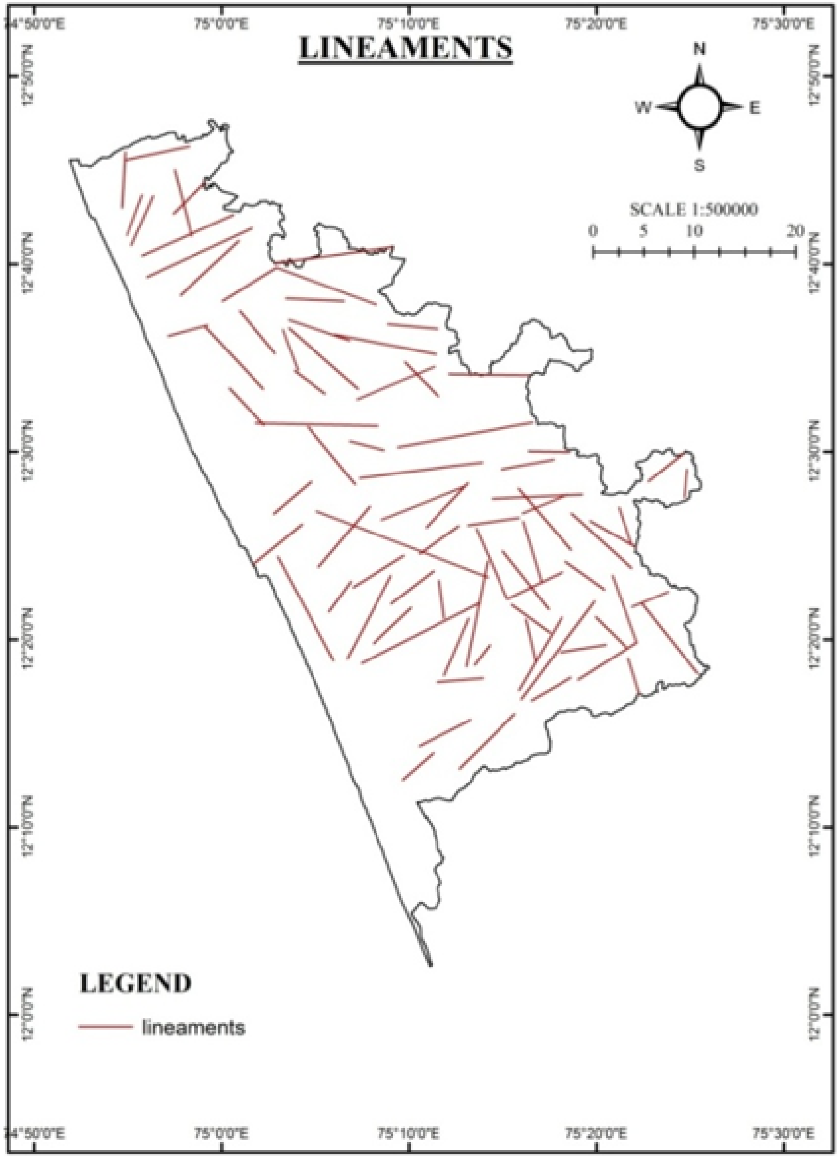

Figure 11

Lineament map of Kasaragod

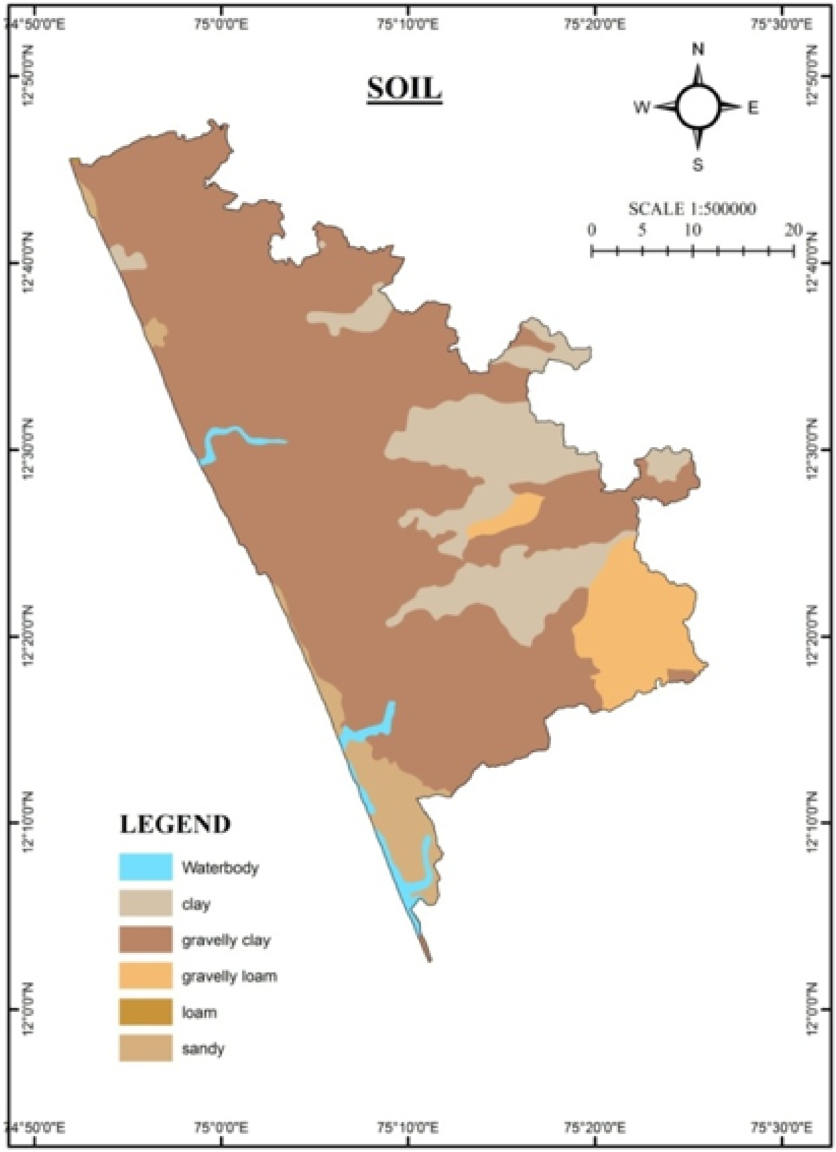

Figure 12

Soil map of Kasaragod

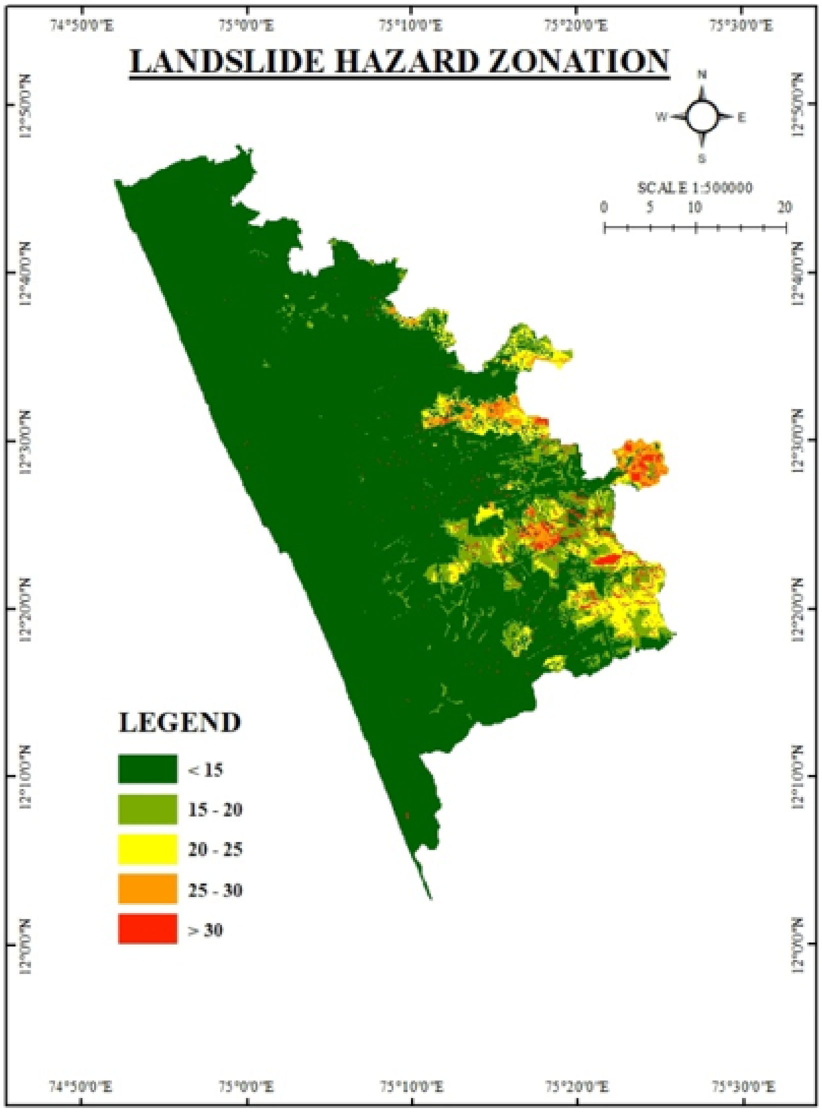

Figure 13

Landslide Hazard Zonation Map