Original Research Article

LANDSLIDE SUSCEPTIBILITY ANALYSIS USING FREQUENCY RATIO MODEL IN A TROPICAL REGION, SOUTH EAST ASIA

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ABSTRACT

Landslides are very frequent and disastrous phenomena in the Western Ghats regions of South East Asia during the monsoon season and it occurrence is triggered by many factors. Hence, itis essential to develop a landslide hazard assessment map to find out the areas at risk, so that potential disasters can be reduced. The present study clearly aims to delineate the landslide susceptibility zones so that landslide hazard and risk can be properly managed. The landslides occurred in Amboori region, the southeastern part of the Thiruvananthapuram district, Kerala, India has been analyzed using GIS and remote sensing techniques to identify the landslide susceptibility zones. Frequency Ratio analysis is made use of in this study. The landslide hazard zonation has been done based on various terrain parameters as well as various thematic layers that affect directly or indirectly slope failure process. The results of landslide analysis not only helps to map and monitor landslides, but also to predict future slope failures which is valuable for a decision maker in landslide prone areas.

Keywords: Landslide, Remote Sensing, Frequency Ratio Model, Susceptibility

1. INTRODUCTION

Landslide is one of the most alarming disasters to life and property of humans around the globe. Every year we may read report about significant human losses caused by landslides [1]. A natural hazard escalates into a natural disaster when an extreme event caused harm in significant amounts and overwhelms the capability of people to cope with and respond. Natural and man-made hazards are the most threatening factors to human life and are the main reasons behind serious worldwide disasters [2, 3, 4, 5, 6, and 7]. Landslide hazard zonation refers to "the division of the land in homogeneous areas or domains and their ranking according to degrees of actual / potential hazard caused by mass movement" [8]. According to [9], at least 90 % of landslide losses can be avoidable if the problem is recognized before the development or deforestation begins. Landslide hazard poses a rigorous risk to life, property and infrastructure. Landslide susceptibility mapping may be defined as qualitative or quantitative, and direct or indirect mapping [10]. Landslide susceptibility mapping was done on the basis of multi-dimensional analysis of terrain parameters in a GIS environment after assigning rank and weight, for different classes in a thematic map and for different thematic maps respectively, using a subjective rating analysis done under a supervised weighting method [11]. Terrain parameters like geology, structures, geomorphology, slope, land use/land cover, drainage density and frequency, soil, soil erosion, weathering and paleo-landslides were considered for the analysis. Throughout the world it is possible to find many studies on landslide susceptibility assessment, the basic concepts of landslide susceptibility was first introduced by Rabbruch (1970).[12] and [13] summarized most of the landslide susceptibility mapping studies.

Western Ghats, the most prominent physiographic feature in Kerala has played a major role in shaping the climate of the state by creating conditions for the orographic precipitation during southwest monsoon.The western flank or the windward slope of Western Ghats is identified as one of the major landslide prone areas of the country [14] [15] [16].Western Ghats witnesses landslides very often during the monsoon [17,18]. Kerala lies in the western slope of Western Ghats and are exposed to landslides, which are common during the monsoon season [15, 19 ,11 and 19] . Thus Kerala experiences several types of landslides, of which debris flows are the most common. They are called ''Urul Pottal'' in the local vernacular.The landslides in the state include rock falls, rock slips, debris flow and in a few cases rotational types of slides can also seen. But the most prevalent recurring and disastrous type of earth or tectonic movement noted in Kerala are the debris flow ,(urulpottal) characterized by the swift and sudden down slope movement of highly water saturated overburden ranging in size from soil particles to boulders destroying and carrying with it everything that is lying on its path. About 1500 sq. km area in the Western Ghats is prone to landslides [16]. Every year with the onset of monsoon, land slips and landslides are reported. Population growth and high rain fall are identified as the major driving forces behind the land sliding.

Landslides occur due to many triggering factors. So it is necessary to identify and analyze the factors leading to landslide. The accurate detection of the location of landslides is very important for landslide hazard analysis.The landslide inventory of the study area consists of 40 past landslide locations including the minor ones occurred for the last 25 years. A spatial data set containing landslide causative factors namely, slope, aspect, relative relief, soil, drainage density, lineament density lithology, geomorphology, landuse, and rainfall were analysed. The assumption behind Landslide Hazard Zonation is that future landslides will occur under similar conditions as past and present landslides [20]

Attempt has been made to map and monitor the landslides and to predict future slope failures in one of the most landslide susceptible areas in the tropical region.

2. STUDY AREA

The study area covers five panchayats including Amboori, Kallada,Kuttichal,Aryanad,Vithura and Peringamala in Thiruvananthapuram district(Fig. 1(a)). Amboori has witnessed a large landslide in 2001 which claimed the life of 39 people.The area is situated in the southern tip of Western Ghats, surrounded by hills and its south east of the regionis the state of Tamil Nadu.It has central longitude/latitude value of 8.5041° N, 77.1916° E.The eastern part is covered by densely forested Neyyar Wildlife Sanctuary. The area is well known for its high-yielding rubber plantations; however, the area also cultivates coconut, pepper, herbs, and medicinal plants. Amboori lies near the Neyyar Wildlife Sanctuary and is separated from the populated area by the catchment area of Neyyar Reservoir. The area is covered by Archean rocks covered by unconsolidated materials such as boulders, colluvium, laterite, and saprolite [22] which are susceptible to movement especially for landslides [23] It is noted that a tropical region like Amboori with a combination of hills capped by overburden and monsoon can results in landslide.On the day of the Amboori landslide, the area experienced an exceptionally high amount of rainfall of 82.4 mm, which together with other landslides occurred in this part during monsoons points toward the role of rainfall in triggering landslides [24]

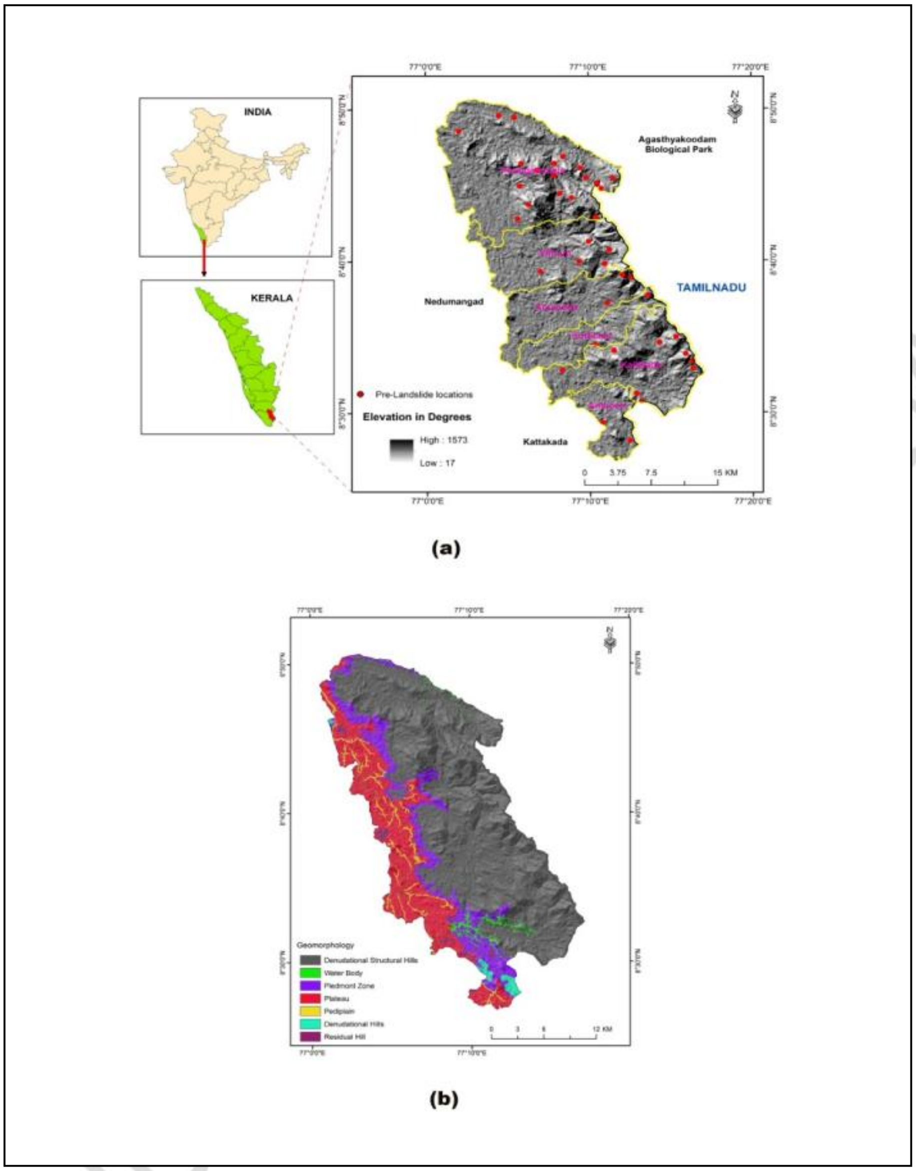

Fig :1 (a) Study Area(b) Geomorphology

3. MATERIAL AND METHODS

As the triggering factors behind landslides are diverse, it is necessary to identify and analyze the factors that lead to landslide activities. The accurate detection of the location of landslides is very important for landslide hazard analysis. The landslide inventory of the study area consists of 40 past landslide locations including the minor ones occurred for the last 25 years. A spatial data set containing landslide causative factors namely, slope, aspect, relative relief, soil, drainage density, lineament density lithology, geomorphology, landuse, and rainfall were analyzed. The assumption behind Landslide Hazard Zonation is that future landslides will occur under similar conditions as past and present landslides [20]

When evaluating the probability of landslide within a specific period of time and within a certain area, it is of major importance to recognize the conditions that can cause the landslide and the process that could trigger the movement. The correlation between landslide areas and associated factors that cause landslides can be allocated from the connections between areas without past landslides and the landslide-related parameters. In order to prepare the landslide susceptibility map quantitatively, the frequency ratio method was implemented using GIS techniques. Frequency ratio methods are based on the observed associations between distribution of landslides and each landslide-related factor, to expose the correlation between landslide locations and the factors in the study area. Using the frequency ratio model, the spatial associations between landslide location and each of the factors contributing landslide occurrence were derived. The frequency is calculated from the analysis of the relation between landslides and the attributed factors. Therefore, the frequency ratios of each factor's type or range were calculated from their relationship with landslide events. The frequency ratio was calculated for sub-criteria of parameter, and then the frequency ratios were summed to calculate the landslide susceptibility index (LSI) .Using the frequency ratio model, the spatial relationships between landslide-occurrence location and each of the factors contributing landslide occurrence were derived. The frequency is calculated from the analysis of the relation between landslides and the attributed factors. The factors chosen, such as the geomorphology, land use/land cover , geology,soil,lineament,drainage density, relative relief, slope and rainfall were evaluated using the frequency ratio method to determine the level of correlation between the location of the landslides in the study area and these factors. The approaches are based on the observed relationships between each factor and the distribution of landslides.
The frequency ratios were calculated for the nine causative factors influencing the landslides were used in hazard mapping. Each of the factors has been categorized and the percentage of landslide happened in each category was calculated. Finally the frequency ratios for each category of the causative factors were calculated in order to analyze the level of correlation between the pre- landslide location in the study area and the causative factors.

The factors were converted in the form of 30 x 30 m 2 grid cells to calculate a landslide susceptibility index (LSI). For each class the frequency ratio was calculated by dividing the percentage of landslides in the particular class by its percentage of pixels. During the overlay, the Landslide Susceptibility Index was calculated by summation of each factor's frequency ratio value according to the following formula;

$LSI = \Sigma Fr$ (where Fr = the frequency ratio of each factor's type or range).

4. RESULTS AND DISCUSSION

The frequency ratio of each factor's type or range calculated from their relationship with landslide events is given in Table 1.

a) Geomorphology

A large majority of landslide occurrence are geomorphologically related in which the area comprises the geomorphic features like denudational structural hills, water body, piedmont zone, plateau, pediplain and denudational hills. Majority of the study area covers the denudational structural hills (63.95%) followed by the plateau. A major share of landslide (92.5%) happened in the area is also in the denudational structural hills showing high probability to landslides .The denudational hill which covers only a small portion of the area (0.09%) having 5 % of landslide occurences exhibits highest frequency ratio when compared to other geomorphic landforms (Fig: 1 (b)). The active slides in the areas are developed along denudational structural hills. The denudational structural hill is transitional zone between denudational and structural hills. Most of the old and active landslides are noticed in this unit [25]

b) Land use

Land use practices have a direct effect on landslide activities.The nature of land cover, as per BIS guidelines is considered indirect indicator of stability of hill slopes [25] .The study area experienced a variety of landuse types such as forest, water bodies, agricultural land, wastelands, Built up and grasslands. A major portion of the area constitute the forest area followed by agricultural land. Majority of landslide with higher frequency ratio (1.52) occurrences were reported in the buildup areas and in the adjoining forested tracts (1.33) experienced the maximum landslide effects which clearly shows the unsustainable land use practices in the forested tracts(Fig: 2 (c)).Higher landslide frequency ratios reported in the built up and forested area category of the land use type can be quoted as the example of unsuitable land use practice.This is in agreement with the observation that the intensity of landslides increased since the population expansion in the late 19th century [26]. Unsustainable land use practices like intensive agriculture on steep slopes, illegal mining and quarry, construction of roads and buildings on unfavorable slopes, drastic reduction in forest cover and human interventions has resulted in the loss of natural ecosystem causing massive and frequent landslide [27]

c) Lithology

The response of the underlying rocks to the processes of weathering and erosion has been considered as the main criteria for landslide activities. So the landslides reported were examined with the lithology of the area. Most of the study area falls within the Khondalite group of rocks (78.91%) with geological age of 3070 million years followed by Migmatite which is from the protorozoic era ie approximately 2500million years (11.21%), and Charnockite group of rocks which has geological age of 2780 million years[28] (8.95%).Higher percentage of landslides was exhibited in the Charnockite group and Migmatite complex rocks which directly implies their positive role on landslides. Comparing the number of landslides and the area belongs to each lithology category, higher frequency ratios were reported in Charnockite group rocks as number of landslides were higher when compared to its area [29] Fig: 2 (d)).

d) Soil

Soil is the final product of weathering and an important conditioning factor in the occurrence of landslides.The physico-chemical properties of the soils are mostly consistent with the lithological diversities of the rocks as well as the physiographic and vegetation distribution pattern [23]. Hence, soils when saturated with water, always have the tendency to flow because, the loss of shear strength resulting from increase in pore-water pressure.So while considering the texture of the soil, gravelly loam and clay exhibits higher frequency ratio values when compared to other types (Fig: 2 (e)). Generally gravelly clay loam is considered as more unstable compared to other textures [30].

e) Lineaments

Most of the mega and intermediate type of lineaments coincide with faults/emplacements/ fractures in the basement rocks [31].Landslides are generally related to the proximity to lineament and it is generally considered the probability of landslides occurring is greater in highly fractured areas [32].Here the highest lineament density (< 2.5 -5m/km2) is noticed in the eastern portions of the study area exhibiting a higher landslide frequency ratio when compared to other categories (Fig: 2 (f))

f) Drainage density

The rivers and streams plays a significant role in soil erosion and triggering landslides. Highest drainage density of the area shows a directly proportional trend to landslide frequency ratio Landslide occurrence is relatively high in high drainage density areas when compared to low drainage densities. Here the density of drainage ranges from <1->5 m/km2) Accordingly the frequency ratio value is higher in the high drainage density areas (4-5 m/km 2) (Fig: 2 (g))

g) Relief

Relief, which is the difference between the maximum and minimum elevation in an area, is a measure of the ruggedness of the terrain. The relief of a terrain reflects the geomorphological history of that area. The relative relief does not take into consideration the dynamic potential of the terrain, but is closely linked with slopes and hence is useful in understanding morphogenesis [33]. The more the intensity of dissection (particularly vertical erosion), the greater is the relative relief. Hence, landslide occurrences are directly related to the relief [33] .In the study area relative relief was found to be varying between 200 to 600 m. The wide contrast in the relief pattern reveals the extreme ruggedness of the terrain in the area.High and very high relative relief categories have resulted in high landslide frequency values which is observed in the range of > 600m [28] (Fig: 2 (h))

h) Slope

Slope is, perhaps, the single most important geomorphological attribute to be considered in any landslide analysis [32].The probability of landslide occurrence in a terrain is largely depended on its slope. Majority of mass movements in Kerala occur in hill slopes above 20 along the Western Ghats scarps [16]. The study experienced a varying range of slope ranging from <5 - >40 degree. Among the slope categories, high landslide frequency ratio is observed in moderate to high slope category (20-40 degrees). In steep slopes, the mass of the possible moving material under gravity will be more as compared to a moderate slope .So the steep slope will be more vulnerable compared to other areas [34]

i) Rainfall

Rainfall is an important triggering mechanism in landslide occurrences. It induces shallow landslides, mostly soil slip and debris flows, initiated by a transient loss of shear strength resulting from the increase in pore-water pressure, caused by intense rainfall on loose surface soil underlying finer less permeable bedrock [35]. Rainfall percolation can cause decrease in resistive strength of slope material [36] resulting in landslides. The study area experiences heavy showers than the state average annual rainfall (300 cm), [23].The area observed a rainfall varying from 1421-3035 mm.Very high rainfall area with more than 2800 mm shows high probability of landslide frequency values(Fig: 2 (j)) .

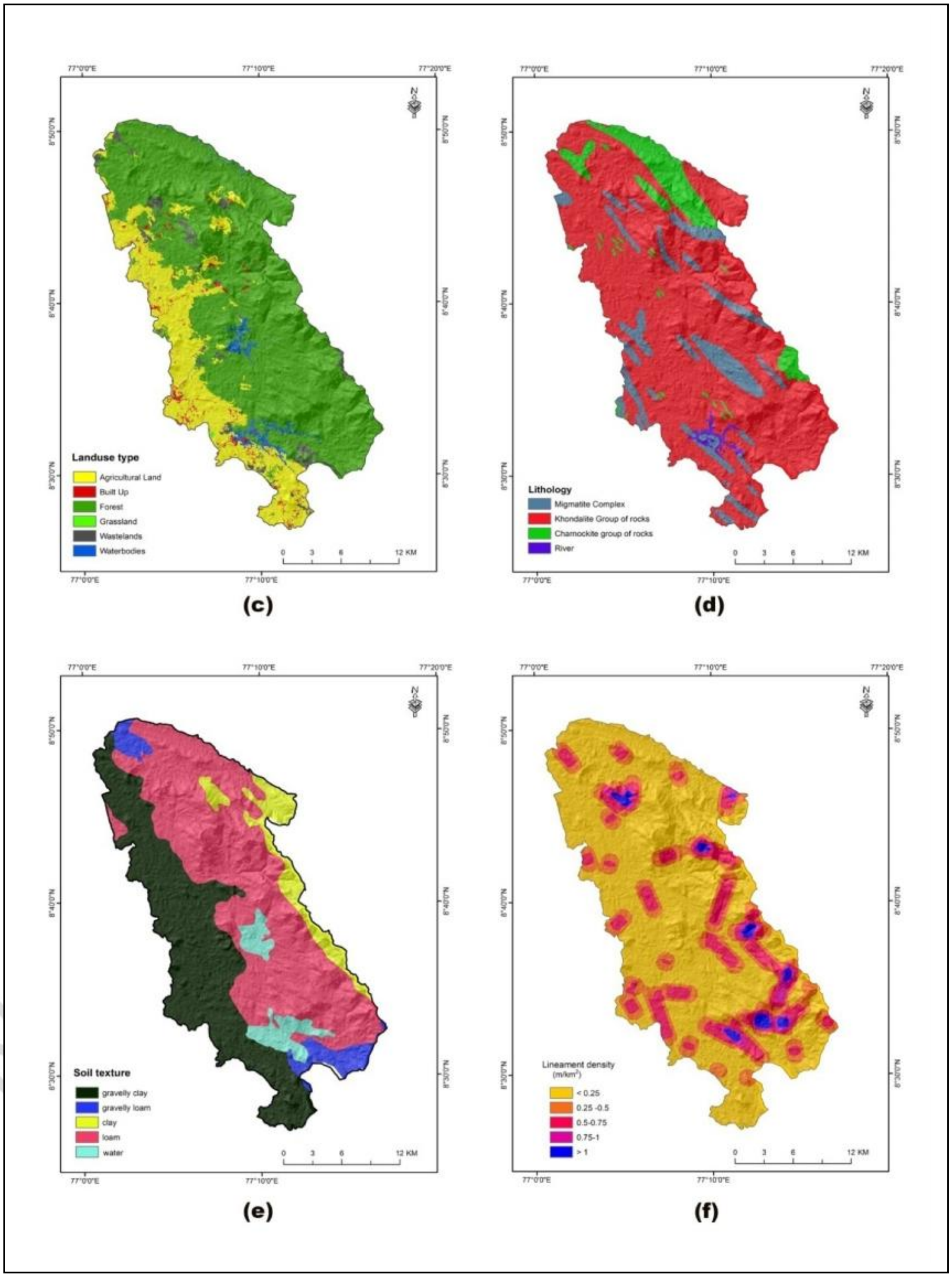

Fig: 2 (c) Land use (d) Lithology (e) Soil texture (f) Lineament density

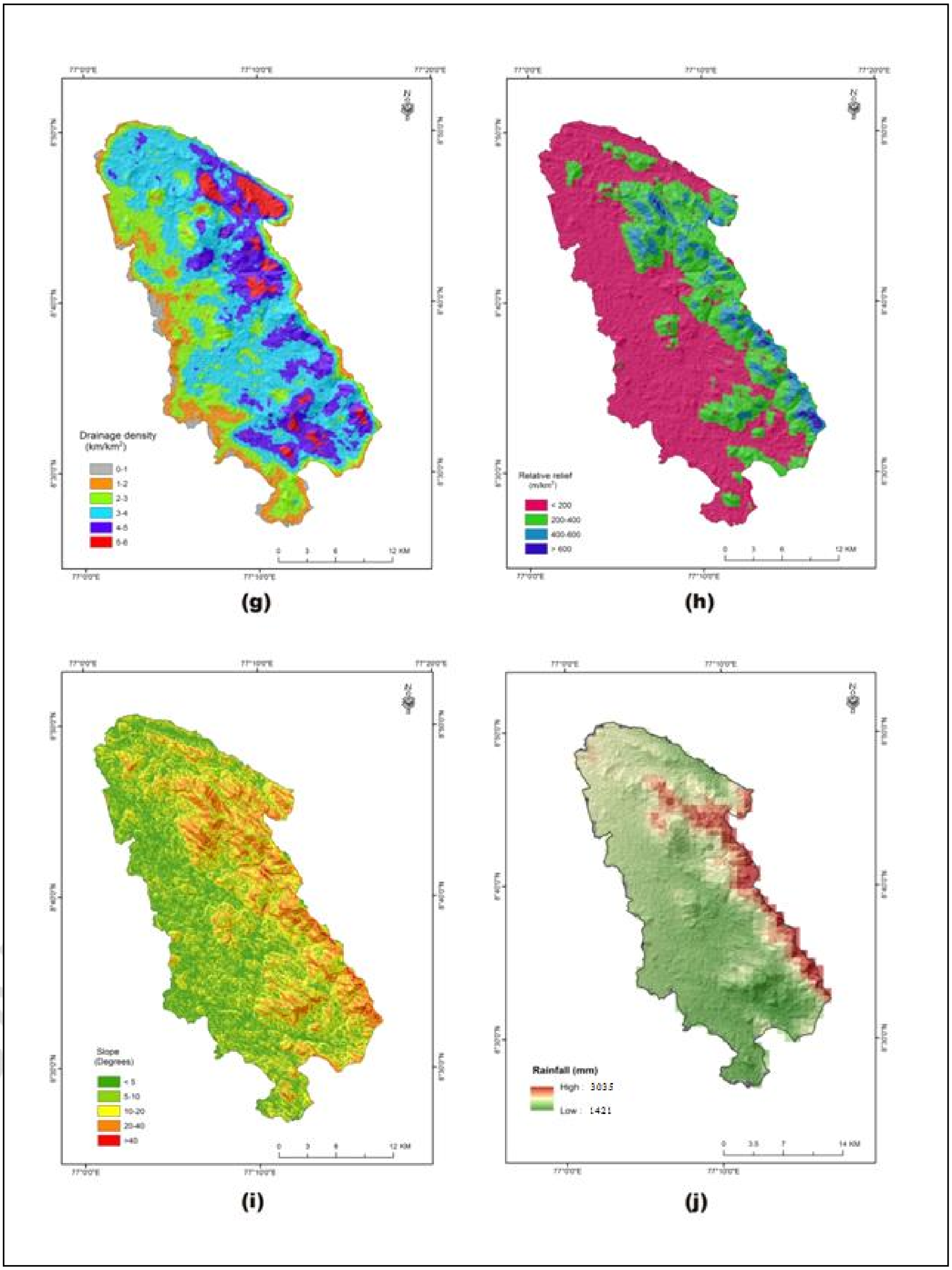

Fig: 3 (g) Drainage density (h) Relative relief (i) Slope (j) Rainfall

Factor	Class	No of pixels in domain	No of landslide	% of pixels in domain	%of landslides	FR
	Denudational Structural Hills	460486	37	63.95	92.50	1.45
	Water Body	10224	0	1.42	0.00	0.00
	Piedmont Zone	82513	0	11.46	0.00	0.00
Geomorphology	Plateau	138417	1	19.22	2.50	0.13
	Pediplain	15899	0	2.21	0.00	0.00
	Denudational Hills	6492	2	0.90	5.00	5.55
	Residual Hill	6022	0	0.84	0.00	0.00
	Forest	499794	37	69.41	92.50	1.33
	Water bodies	15239	0	2.12	0.00	0.00
Landuse	Agricultural Land	161730	1	22.46	2.50	0.11
	Wastelands	19823	1	2.75	2.38	0.86
	Built Up	11285	1	1.57	2.38	1.52
	grassland	306	0	0.04	0.00	0.00
	Migmatite Complex	80720	6	11.21	15.00	1.34
Lithology	Khondalite Group of rocks	568195	28	78.91	70.00	0.89
	Charnockite group of rocks	64429	6	8.95	15.00	1.68
	Water body/River	6706	0	0.93	0.00	0.00
	gravelly clay	243313	4	33.79	10.00	0.30
	gravelly loam	33775	2	4.69	5.00	1.07
Soil	Clay	50564	7	7.02	17.50	2.49
	Loam	356106	27	49.46	67.50	1.36
	Water	34744		4.83	0.00	0.00
	< 0.25	475642	24	66.06	24.00	0.363
	.25-.5	128059	11	17.78	11.00	0.618
Lineament	.5-.75	88228	5	12.25	5.00	0.408
	.75-1	16884	0	2.34	0.00	0.00
	>1	11240	0	1.56	0.00	0.00
	<1	12186	0	1.69	0.00	0.00
	1-2	70150	2	9.74	5.00	0.51
Drainage Density	2-3	165688	4	23.01	10.00	0.43
	3-4	296191	16	41.13	40.00	0.97
	4-5	144364	15	20.05	37.50	1.87
	>5	31474	3	4.37	7.50	1.72
	<200	455803	11	63.30	27.50	0.43
	200-400	197743	13	27.46	32.50	1.18
Relative relief	400-600	62590	14	8.69	35.00	4.03

	>600	3917	2	0.54	5.00	9.19
Slope	<5	160759	5	22.33	12.50	0.56
	5-10	209770	4	29.13	10.00	0.34
	10-20	217713	12	30.24	30.00	0.99
	20-40	128084	18	17.79	45.00	2.53
	>40	3712	1	0.52	2.50	4.85
Rainfall	<1500	134417	1	18.38	2.50	0.14
	1500-1600	142425	1	20.47	2.50	0.12
	1600-1700	121084	4	17.47	10.00	0.57
	1700-1800	103513	6	14.47	15.00	1.04
	>1800	218743	28	29.20	70.00	2.40

Table:1 Frequency ratio values for the landslide causative factors

The resultant Landslide Susceptibility Index map (LSI) map with values ranging from 10-28 was further equally classified as low,moderate high and very high . From that the eastern regions of the study area have highly unstable zones and are vulnerable to landslide activities (Fig:4). This region has steep sloping topography with heavy rainfall during the monsoon season which can cause a heavy landmass movement. The occurrence of debris flow in this region is high during an intensified rain.From the Landslide Susceptibility Index map, it is estimated that around 15 % of the area falls under very high landslide susceptible region which covers almost eastern portions of the region covering the Western Ghats .This area has a steep slope covering more than 40degrees slope angle. 36 % coming under high susceptible region adjoining the very high landslide susceptible area with a medium slope , moderate susceptible region spreads around 28% and 19 % falling below and low hazard zones covering the low sloping terrain (Table 2) . The upslope of Neyyar river catchment is identified as the most landslide-prone region in the district with Amboori landslide being the most significant of them[16].Amboori event is the worst natural disaster that has been reported from Kerala in the recent past. These are areas in the thick naturally forested Neyyar Wildlife Sanctuary (Babu et al. 2000). The highly unstable region lies mostly towards the areas of Amboori, Eastern side of Vithura and Neyyar wildlife sanctuaries which are situated in the steep slopes of Western Ghats.The Peppara reservoir catchment is another region susceptible to landslides with a major landslide event reported in 1992 . Other regions of the study area namely Anachari and Mooppanmala experienced rock falls and Venkulam, Mattikettukunnu and Akamala experienced soil creep. The pre landslide locations have been overlaid in the final Landslide Susceptibility Index Map .Most of the prelandslide points coincides with the very high and high landslide zonation regions which increases the accuracy of the LSI map. .So it is clear that the future landslide is mostly depended on pre landslide locations and conditions prevailed.

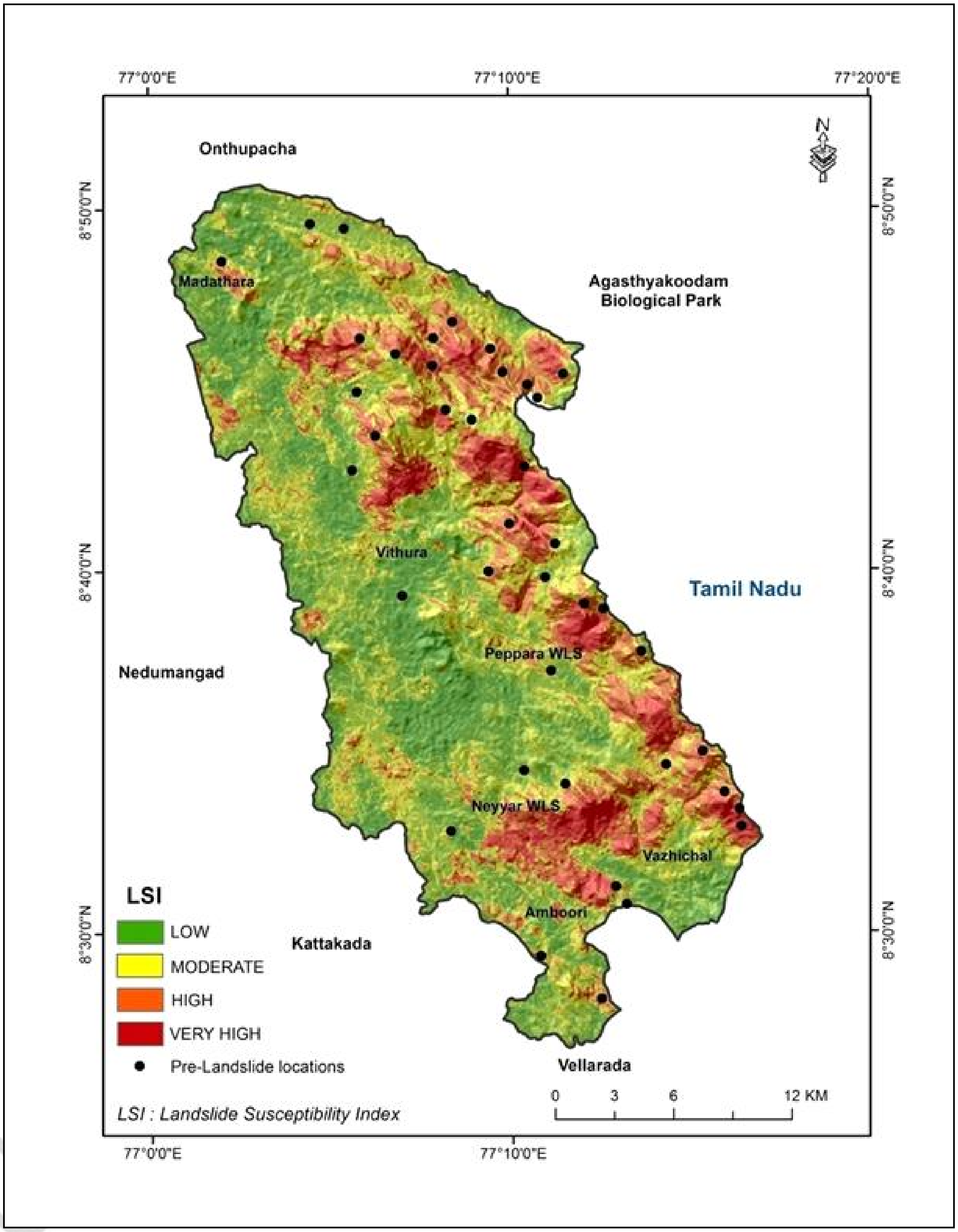

Fig: 4 Landslide Susceptibility Index Map

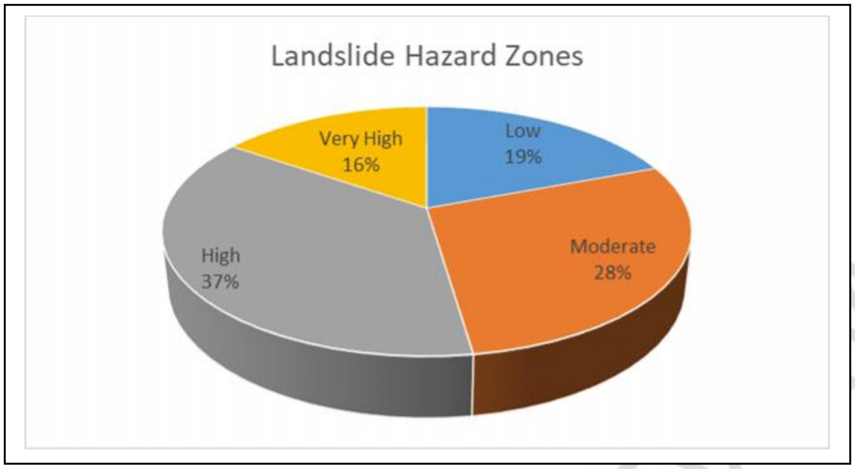

Fig: 5 Landslide hazard zones

5.CONCLUSION

The assumption behind landslide hazard zonation is that future landslides will occur under similar conditions as past and present landslides. Analysis of landslide frequency ratio indicates the importance of contributing factors on landslides. Topographic attributes are found to have good association with landslide incidences. Although the single day rainfall is regarded to be the most critical factor for triggering landslides in the Amboori region. Along with this the antecedent rainfall experienced also play a leading role by increasing the pore-water pressure of the soil. Migmatite complex and charnockite group of rocks have been identified in the area having higher frequency ratio to landslide. Considering the geomorphology of the area highest frequency ratios were observed in the denudational structural hill which are susceptible to landslides. Remote sensing and GIS technique along with frequency ratio method can be effectively used in the preparation of hazardous zonation maps, which will help planners and engineers to reduce losses of life and properties through prevention and mitigation measurements.

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