Landslide Susceptibility Assessment and Preparedness Strategies, Thiruvambaadi Grama Panchayath, Kozhikode District, Kerala.

(DM/328/2016/SDMA dated 6-10-2016)

MAJOR RESEARCH PROJECT

KSDMA
THIRUVANANTHAPURAM

Submitted by
Dr. S Sreekumar
2019

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Dr. S Sreekumar

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INTRODUCTION

1.7 GENERAL INTRODUCTION

A landslide is a rapid mass wasting process that cause the downslope movement of a mass of rock, debris or earth material under the influence of gravity. Landslides are one of the most important and major natural hazards that mankind is facing all over the world and plays an important role in evolution of landforms. The landslide phenomenon is very common in the hilly terrains. Landslide occurrence depends upon different parameters such as geological and geomorphological processes, changes in vegetation cover, landuse and hydrogeologic conditions. Landslides are triggered by many factors including heavy precipitation, earthquakes and human activities (Safae et al. 2010; Alkevli and Ercanoglu 2011). In addition to loss of lives, landslides destroy residential and industrial area and negatively affect water quality in rivers and streams (Schuster, 1996).

1.8 LANDSLIDES IN INDIA

Landslides are the increasing concern India due to rapid population expansion in hilly mountainous terrain. India is now housing 17 % of world's total population. In India the occurrence of landslides is an annual and recurring event in the various hill and mountain ranges. Environmental degradation on account of heavy pressure of population, decline in forest cover, change in agricultural practices, industrial and infrastructure development on unstable hill slopes etc. are some of the factors aggravate the incidence of landslides. This has made a significant negative impact on the environment and human settlements in the region. The hill areas are susceptible to landslides from low threat to severe landslide risk. Two regions most vulnerable to landslides are Himalayas and the Western Ghats. The Himalayan mountain belt comprise of tectonically unstable younger geological formations subjected to severe seismic activity. The Western Ghats and Nilgiris are stable but have uplifted plateau margins influenced by neo tectonic activity. Thus, the two regions have different geological setting leading to characteristic types of landslides. The monsoon has a significant bearing on the occurrence and distribution of landslides in India. Large volumes and high intensity rainfall and the consequent pore water pressure development are considered as the principal triggering factor of landslides in the Himalayas (Joshi and Kumar, 2006 ; Vinod Kumar et al.,

2008) and the Western Ghats (Sreekumar 2009). The regional extent of these hilly regions, it is estimated as about 15% of these land areas in India possess terrain conditions favorable for the generation of mass movements in fragile zones.

In past years, there have been some serious and fatal landslides in India. Guwahati landslide, in Assam took place on September 18, 1948 due to heavy rains. Over 500 people died in the landslide and according to the reports, the landslide buried an entire village. The Darjeeling landslide, West Bengal landslide happened around October 4, 1968. The landslide was triggered by floods and the 60 km long highway was cut in 91 parts. As per reports, thousands of people died in the landslide. Consecutives landslides occurred in Malpa, Uttarakhand between August 11 and August 17 in 1998 in the village of Malpa where over 380 people died as the entire village washed away in the landslide. The Amboori landslide, Kerala was known as the worst landslide in Kerala's history. The landslide occurred on November 9, 2001 due to heavy rains and around 40 people died in the incident. Kedarnath landslide in Uttarakhand: The landslide took place on June 16, 2013 and was the result of Uttarakhand floods. Over 5700 were reported dead and over 4,200 villages had been affected by the floods and post-floods landslide. Disastrous landslide occurred on July 30, 2014, in Malin village at Maharashtra. The landslide occurred due to heavy rainfall and around 151 people died and 100 people went missing after the disaster.

1.9 WESTERN GHATS

The Western Ghats is the main peninsular hill ranges extending over 1400 km and runs parallel to the west coast of India at a distance of about 40 km inland from the sea shore. The Western Ghats region is increasingly becoming an area of interest from the point of view of landslide studies. Occurrence of minor and major landslides has been reported all along the regions from its southern tip to the northern extremity. Landslide occurrences are particularly wide spread in areas where developmental activities are intense. The climatic condition of Western Ghats has influenced the process of weathering and landslides in this mountainous tract along the southwest coast of India. During the monsoon period, landslides are common in the Western Ghats, and its intensity depends upon the thickness of the loose unconsolidated soil formed by the process of weathering. Debris landslides with a combination of saprock, saprolite and soil, indicate the role of weathering in landslide occurrences. The western flank of the Western Ghats receives an annual rainfall of more than 2000 mm whereas the eastern region is a rain shadow area.

The Western Ghats of the Kerala region is the southern narrow strip of highland east of the coastal low land and midland region of the state, the eastern flank located in Tamil Nadu and Karnataka. Highland form an important physiographic province occupying 20.35% of the area of the State (Soman, 2002). The Western Ghats of Kerala is prone to shallow landslides and consequent debris flows. Their increased frequency has been associated with deforestation and unfavorable land-use practices in cultivated areas.

1.10 LANDSLIDES IN KERALA

Kerala is the third most densely populated state in India, of which 47% is occupied by the Western Ghats of peninsular India. Slope failures are very common along the hill ranges of Kerala particularly during the Monsoon period. In the hilly regions, instability of slope is one of the major natural hazards that cause losses to lives and property. The west facing Western Ghats scarps that runs the entire extent of the mountain system is the most prone physiographic unit for landslides. The highlands of the region experience an annual average rainfall as high as 500 cm from the South-West, North-East and Pre-Monsoon showers. All 13 of the 14 districts of Kerala except the coastal district of Alappuzha are prone to landslides. About 8% (1,400 Km^2) of area in the Western Ghats of Kerala is classified as critical zone for mass movements (Thampi et al. 1995). Different types of slope failures such as debrisflow, landslide, slump and rockfall have been reported by Seshagiri et al. (1982); Sankar (1991) and Sreekumar and Arish Aslam (2010). Kozhikode district is prone to deep seated landslides, while Idukki and Kottayam are prone to shallow landslides (Sekhar et al. 2009).

1.11 TYPES OF SLOPE FAILURES

The Western Ghats of Kerala region experience several types mass movements such as debris flow, landslides, slump and rock fall. Thampi et.al (1998) and Sreekumar (1998) has identified Highly Hazardous Zone for mass movement in Idukki district of Kerala. The most prevalent, recurring and most disastrous type of mass movement noted in Kerala are ‘debris flows’. The causative factors and triggering mechanisms are site specific. The studies by

Simoni et al (2004) indicated that the pore water pressure is considered as an important factor that trigger landslide. Melelli and Tharmalli (2004) concluded that initiation of the debris flows originates in topographic depressions depicted by concave contours called hollows. The study critically examined the causes and mechanism of previous slide and examined whether the chances of further failure still exist in the area.

The nature of landslide and material involved vary from location to location and it is observed that it is not a single factor that causes the failure but cumulative effect of many parameters leads to disaster. Mass wasting is a broad term that involves the downward transport of soil and rock material under the gravitational influence. The types of mass wasting processes in Kerala may be classified into Debris flow (Urulpottal), rockslide, rotational slump and rock fall. The causative factors responsible for the landslides in Kerala can be broadly classified into two major categories such as inherent factors and external factors. The inherent factors are inherent characteristics of the slope which can be studied and evaluated. Factors such as lithology, structure, slope morphometry, relative relief, thickness of soil, orientation and frequency of discontinuities, land cover, hydrogeological conditions fall under this category. The external factors include seismicity and rainfall. The instability is accentuated by human activities.

1.12 PREVIOUS LANDSLIDE STUDIES IN KERALA

Many researchers have carried out evaluation studies in terms of landslide mitigation in parts of Western Ghats Kerala, which does detailed observation of the contributing factors to land sliding (Thampi et al. 1998; Krishnanath and Sreekumar 1996; Sankar 1991; Sekhar et al 2009; Sajinkumar et al. 2011; Biju Abraham and Shaji 2013). The studies evaluate the selected area using quantitative zonation approaches based on assigning relative weightage for discerned causative parameters such as hill slope, soil thickness, land use, relative relief, drainage, land form and rainfall. The reports opine that the most commonly occurring types of landslide in Kerala are debris flow. The micro level landslide hazard zonation of road cutting along 110 km stretch of Kottayam – Kumaly road has been carried out based on rain fall, lithology, orientation of discontinuities, slope, material properties of overburden such as cohesion and friction angle. The chance of wedge failure is high in hard rock cuttings where as the rotational slump in laterite road cuttings. Studies have proved that the slope failures in Western Ghats are generally confined to the over burden. Kerala State Land Use Board

(1996) has documented paleo slides from various part of Kerala Western Ghats. Pitchaimuthu and Muraleedharan (2005) reported that the Amboori landslide of 9th November 2001 was due to the obstruction of surface run off in hill slopes by the contour bunds during the rain and effect canopy plantation on evapo-transportation and consequent higher infiltration and over saturation of the over burden. According to Sankar (1991) the causative factors for debris flows in Koodaranji (Kozhikode) are contour bunding which blocked the drainage network on slopes and the infiltration due to excess water.

Predicting landslide hazard on a regional scale, namely the assessment of actual and potential mass movement over large area is carried out using Remote Sensing and GIS (Prasannakumar and Vijith 2012; Sreekumar and Arish Aslam, 2013). From various investigations it is under stood that Landuse / land cover, especially of a woody type with deep root and strong roots helps to keep the material intact (Gray and Leiser, 1982). Rainfall induced debrisflows frequently cause disruption to the road network. A regional assessment of debrisflow hazard and risk allows risk reduction actions to be targeted effectively.

CHAPTER 2

LANDSLIDES IN KOZHIKODE DISTRICT

Kozhikode District lies between N 11^0 7’22” and 11^0 48’32’’ and east longitude 75^0 30’ and 76^0 8’20” (Fig. 2.1). It has a total area of about 2345 sq.km. Kozhikode district is bounded on the north by Kannur district, on the east by Wayanad district, on the south by Malappuram district and on the west by Lakshadweep Sea. The highland region constitutes about 26.80% of the total area.

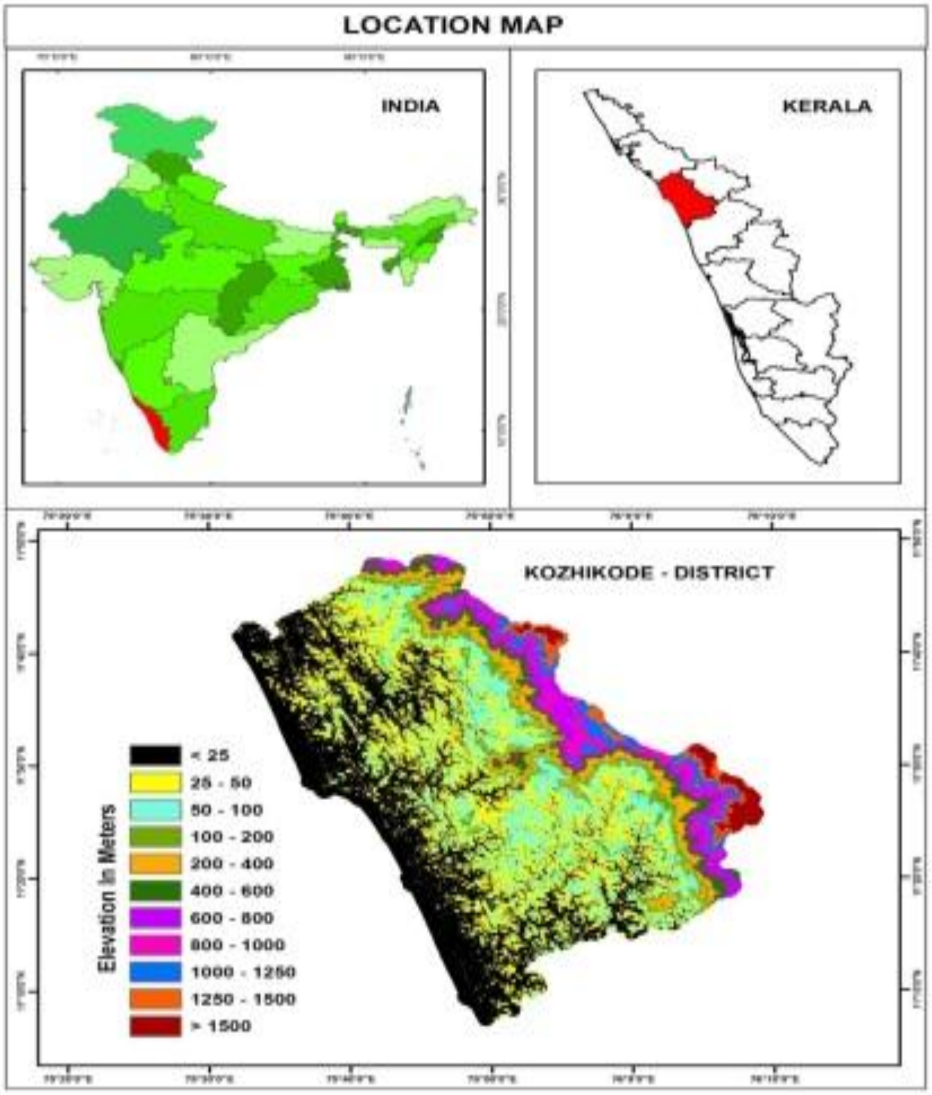

Fig. 2.1. Kozhikode map

2.1 ADMINISTRATION

The Kozhikode District is divided into 3 taluks and 12 developmental blocks and 77 panchayats for administrative purposes. The district has one corporation (Kozhikode) and two Municipalities namely Quilandy and Badagara. It has a total of 117 revenue villages. The district has a total population of 30, 89,543 persons as per 2011 census. As in the case of many other districts of Kerala, the female population exceeds the male population and in Kozhikode District for every 1000 males there are 1097 females. The density of population is 1318. The decadal population (2001-2011) growth rate of the district is 7.31%.

2.2 CLIMATE

The climate here is tropical. The climate of the area is divided in to four seasons – summer, South West Tropical Monsoon period, North East Tropical Monsoon period and winter. The SW and NE monsoons mainly contribute rainfall in the area with 82.77 % of the rainfall. The average annual temperature in Kozhikode is 27.3°C. Precipitation here averages 3205 mm. The driest month is January, with 4 mm of rain. With an average of 847 mm, the most precipitation falls in July. April is the warmest month of the year.

2.3 GEOLOGY

The district can be divided into three geological belts

1. A linear NW-SE trending gneissic belt, along the middle extending from north to south
2. A charnockite occupying large areas in the north east and south, extending to the adjacent districts and also occurring as pockets with in the gneissic terrain.
3. Narrow coastal belt

Granite gneiss belonging to the peninsular gneissic complex is the oldest unit of the area. Charnockite belongs to the charnockite group has a very wide distribution especially in the northeast and south with variations like boitite-hypersthene gneiss, boitite-hornblende-hypersthene gneiss and hornblende-hypersthene gneiss. Magnetite quartzite, another unit of this group, occurs as narrow linear bodies with in charnockite. Hornblende-boitite- gneiss of the migmatite complex extends from north to south and is well foliated. Garnetiferrousquartzo feldspathic gneiss, another member of migmatite complex, occurs as lenses with in charnockite in the east. NW-SE trending dolerite dykes transverse these older rocks.

Pebble bed occurs on the coast and along the banks of Beypore river. The pebble bed is associated with grit and clay, and is laterised. It comprises well rounded pebbles of quartz, granite, quartzite and granulite. It considered to be of Pleistocene origin. Sporadic laterite is recorded from the charnockite country to the south west. Quaternary deposits are of marine and fluvial origin. Periyar formation is a fluvial deposit comprising an admixture of sand silt and clay. Guruvayur formation is a strand line deposit of palaeo-marine origin and mostly comprises medium to fine sand. Kadappuram formation represents contemporary marine deposits, constituting the present beach and barrier beach. The detailed geology and areal extend of formations were provided in Fig. 2.2.

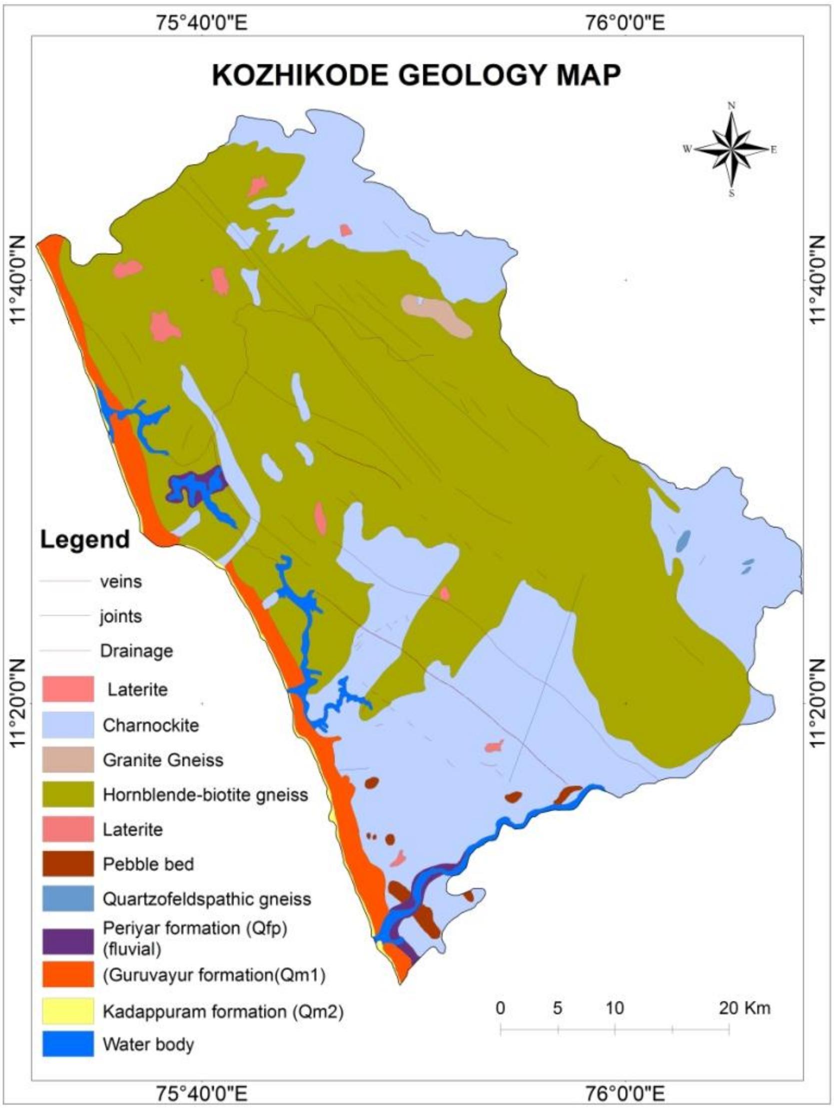

Fig. 2.2. Geology map.

2.4 GEOMORPHOLOGY AND SOIL TYPES

The physiographic divisions of Kozhikode district are low land (<7.6 m amsl), mid land (7.6 to 76m amsl) and high land (above 76 m amsl). The low land extends as a narrow stretch of land lying along the coast from South Kadalundi to North Mahe. The plain is interrupted by steep laterite cliffs and rock outcrops. The low land forms 6.7% of the total area of the district.

The midland area may be further classified into low rolling terrain and moderately undulating terrain. The low rolling terrain has a slope of less than 15%. It consists of rolling laterite hills surrounded by valleys. The moderately undulating terrain covering large area of the district has a slope between 15 and 25%. The highland is in the eastern part of the district. The area is prone to landslides and land slips and comprises of steep slopes and barren rocks. The landform units identified in Kozhikode are alluvial plain, flood plain, valley fill, linear ridge, hillcrest, sloping terrain, rocky slope (scarp face) and hilly terrain. The flood plain and valley fill are the major fluvial landforms whereas moderately sloping terrain, highly sloping terrain, rocky slope (scarp face), linear ridge and hillcrest are major denudational landform units. The fluvial and gently sloping terrains are promising zones of groundwater.

The soils of the district are alluvial soil, lateritic soil and forest loam. Alluvial soil is seen mostly along the coastal plain and valley. They are coastal alluvial soil and river alluvial soils. Majority of the area under riverine alluvium was once occupied by paddy cultivation. Lateritic soil is derived from the laterite under tropical climate with alternate wet and dry conditions. It is reddish in colour and well drained gravelly to clayey. They are found mostly along the midland portion of the district. Laterites on high grounds are more compact when compared to the low-lying areas. Forest loam is deep or very deep and well drained loamy to clayey textures. They are rich in organic matter, nitrogen and humus. Forest loam is dark reddish brown in colour formed by weathering under forest cover with loamy to silty loam texture.

2.5 FEATURES OF LANDSLIDES IN KOZHIKODE

Debris flow and slumping are the major type of slope failures prevailing in the region. They are most common during and just after heavy rain. The water enters the pores and increases the overburden load, increase the pore water pressure, thus weakening the stability of slopes. The areas suffering from this natural disaster during almost every rainy season are Kakkayam, and Thalayad. The landslides mainly destroy houses, agricultural land and block communication arteries. Rehabilitation of affected people and restoration of the area to normalcy involve a very heavy expenditure to the government.

An occurrence of flash floods and debris flows at Koorachundu in Kozhikode district was reported on 31st October 1990. Naripatta, Kavilumpara, Chorani, Chathanthodu are areas were landslides occurred and hectares of the agricultural land destroyed during the period 1992 to 1995. The slide happened on a $+20^0$ slope which was subjected to intense cultivation of seasonal crops. Contour bunding prevalent in the zone with total disruption or blockage of natural drainage which prevented escape of excess storm water flow during high intensity rainfall was ascribed as the main reason for the slope failure (Chandrakaran et al, 2006). A major rockfall was reported in Chengodumala during 1989. The rock fall occurred in a steep slope of +25 of fractured hornblende-biotite gneiss. Deforestation has been cited as the reason which culminated in the slope instability. The deforestation aided removal of vegetation cover leading to removal of overburden by erosion and the absence of root anchoring contributed to the instability. In 2004 a major slide has been reported in Kakkayam and has taken 3 lives. Many houses have been reported to be damaged. Similar one has been reported in Kuttiyadi in 2005. More than 10 small and medium-scale landslips occurred at Thalayad, near Thamarassery in 2009 which resulted in huge damage of roads and agricultural land. Several houses and a water supply system were washed away in the disaster. Multiple debris flows occurred in Pullurampara in Kozhikode district on Aug. 7, 2012, took the lives of 8 people, damaged settlements, infrastructure and acres of agricultural land. The debris resulted from the slide snapped the communication arteries and damaged power lines. The settlements got isolated and power failure remained for days together. The area lies 44 km east of Kozhikode town. The hill slopes of Kodakkadpara, Cherussery Mala is mainly inhabited by small scale agriculturist. The slide locations fall under Ward 4,3 and 17 of Thiruvambadi Grampanchayath. A series of landslides occurred during 2018 monsoon period due to heavy rainfall. A devastated landslide which occurred in Kattipara tooks 12 lives and also causes loss of acres of agriculture and number of houses. Which is mainly due to combined effect of anthropogenic and natural causes. Death due to landslides was also reported on Kadupini and Kannappankund. No.of minor and major slope failure events were reported all over the hill areas of the district. Slump, debris flow and subsidence are the type of slope failure reported in the district. Cracks developed on the ground surfaces were also reported.

2.6 LANDSLIDE SUSCEPTIBILITY MAPPING KOZHIKODE DISTRICT (QUANTITATIVE ZONATION METHOD)

A better assessment of the area could be arrived at by using a semi-quantitative approach. A numerical weightage called Landslide Susceptibility Value (LSV) is assigned to each of the parameters based on their relative importance depending upon the terrain condition (Table 2.1). The terrain factors selected for hazard zonations are Slope, Relative relief, Curvature, Drainage density, Drainage frequency, Landuse, Road buffer and Drainage buffer.

Table 2.1 Factors and corresponding LSV values

Factor	LSV
Slope	30
Relative relief	10
Aspect	5
Curvature	5
Drainage density	7
Drainage frequency	7
Drainage buffer	8
Landuse	20
Roadbuffer	8
Total	100

After assigning landslide susceptibility values, a Landslide Susceptibility Index (LSI) is computed for all categories of each factor with a correlation of landslide percentage per km^2 of that category and the LSV assigned to it. The LSI is calculated using the formula

$$LSI = \frac{\text{Landslides \% per } km^2 \text{ x LSV}}{100}$$

Next step is all the factors were taken to the spatial analyst extension of the ArcGIS software for the integration. The Landslide Susceptibility Index (LSI), equation (1), is calculated by summation of each factor's ratio value using the raster calculator option of the software.

LSI = L Fr + Sl Fr + As Fr + Rr Fr + Dd Fr + Df Fr + RoBr Fr + DrBr Fr + C Fr….(1)

Where, L Fr is frequency ratio of land use; Sl Fr is frequency ratio of slope; As Fr is frequency ratio of aspect; Rr Fr is frequency ratio of relative relief; Dd Fr is frequency ratio of drainage density; Df Fr is frequency ratio of drainage frequency RoBr Fr is frequency ratio of distance from road; DrBr Fr is frequency ratio of distance from drainage and C Fr is curvature respectively. Thus, LSI maps corresponding to the Quantitative Zonation Model been prepared.

The LSI values have been classified into five classes to yield five landslide susceptibility zones (Fig. 2.2), viz. Stable, Moderately Stable, Moderately Unstable, Highly Unstable and Critical. The LSI values of Kozhikode are found to lie in the range from 0 to 33. If the LSI value is high, it means a higher susceptibility to landslide; a lower value means a lower susceptibility to landslides. The five susceptibility zones and areas covered under each zone are given in Table 2.1 13.88% of the total area falls under moderately unstable areas and 9.54% of the area falls under highly unstable area. 0.52% of the area is identified as critical.

Table 2.2 Area % falling under each susceptibility zone

ZONE	RANGE	AREA(Km^2)	AREA %
STABLE	0 – 6.6	1269.04	54.19
MODERATELY STABLE	6.6 – 13.2	519.07	22.16
MODERATELY UNSTABLE	13.2 – 19.8	324.97	13.88
HIGHLY UNSTABLE	19.8 – 26.4	223.53	9.54
CRITICAL	26.4 – 33.00	12.29	0.52

2.7 RISK ANALYSIS OF KOZHIKODE DISTRICT

Slope failures have wide ranging impact on the people of the affected area in terms of the dangerous caused to property and human live. The magnitude of the destruction depends on the location of area. In many areas susceptible to landslide hazards are inhabited by the people. Local Self Government is not aware of the critical areas where the risk is high. Therefore the panchayath with more critical and highly unstable areas have been categorized into Critical, Highly unstable, Moderately Unstable, Moderately stable and Stable to indicate very high to very low damage potential the areas coming under each class in panchayath is presented in table 2.2. This includes Chakkittapara, Kavilumpara, Kodencheri, Koodaranji, Kurachundu, Puthuppadi and Thiruvambadi.

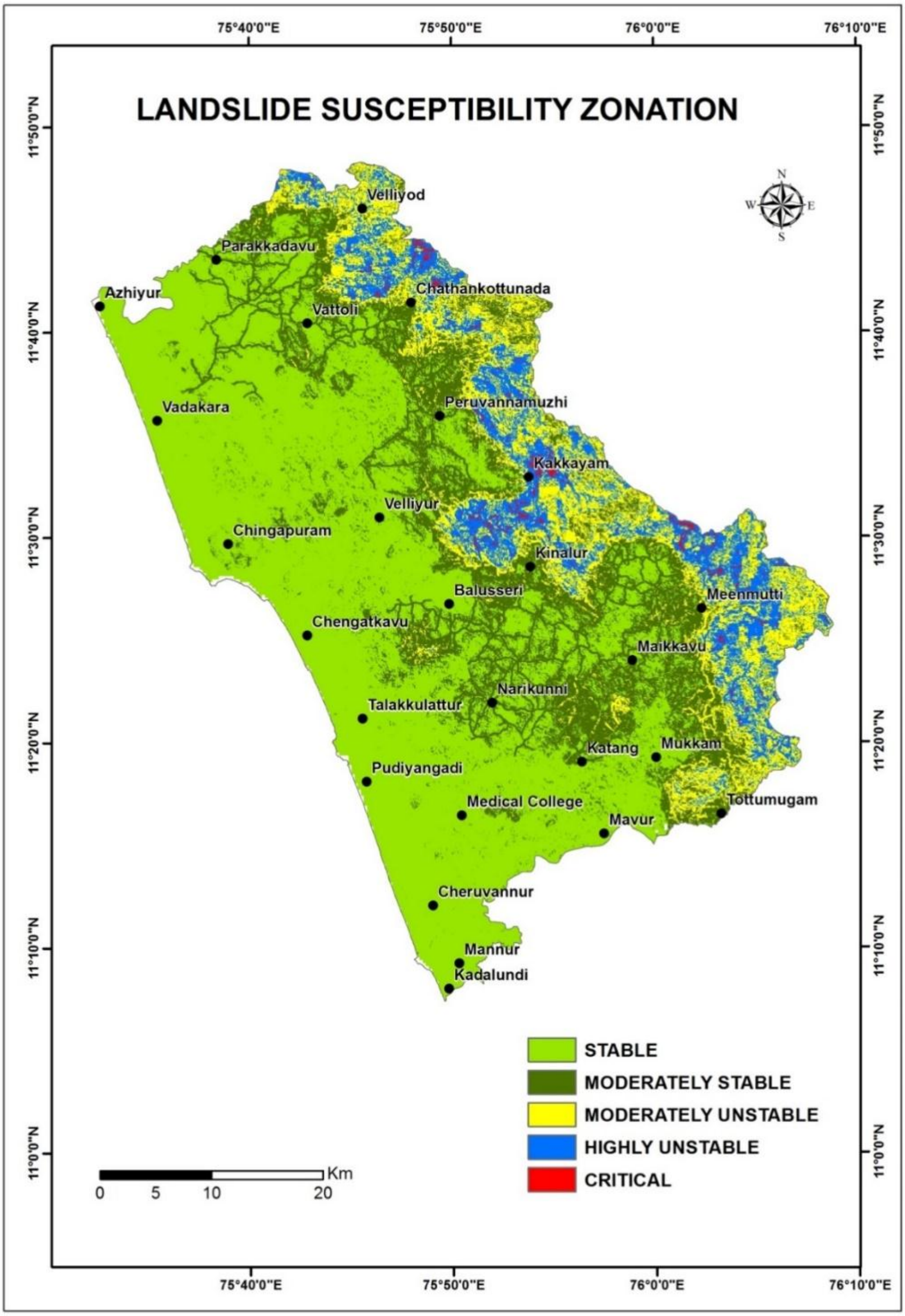

Fig. 2.3. Landslide Susceptibility Zonation map of the Kozhikode district.

Table 2.2 Distribution of panchayath areas (Km^2) in different risk zones.

Panchayats	Stable	Moderately Stable	Moderately Unstable	Highly Unstable	Critical	Total
Chakkittapara	19.67	35.45	26.20	21.35	0.69	103.36
Kavilumpara	2.51	24.06	38.76	25.30	2.21	92.83
Kodencheri	12.28	18.60	6.33	7.99	0.82	46.02
Koodaranji	1.16	20.37	46.98	34.20	1.05	103.77
Kurachundu	6.34	20.20	47.97	46.01	4.25	124.76
Puthuppadi	14.35	19.28	14.34	11.29	1.23	60.48
Thiruvambadi	10.14	20.78	29.95	22.28	0.81	83.96

The risk map prepared in Gramapanchayath level can be used by panchayath officials in the wake of an and event this helps the LSG's to do preparedness measures and allocates money for disaster management. As the critical and unstable zones are delineated in the panchayath maps, the local area management can take preventive action to meet the impending challenge rather than to wait for the disaster to happen. The relief and long term rehabilitation measures are to be worked out once the disaster has struck.

The extent of damage depends on the existing landuse pattern of the area. The modification of slope by local people likely to induces failure of slope and the risk is a function of hazard probability and damage potential. The classification of the areas into Critical, Highly unstable, Moderately Unstable, Moderately stable and Stable is based only on the field visit and visual estimation of likely loss. A detailed socio-economic survey and comprehensive study of the natural resources of the area should be made to evaluate the impact of landslide on natural resources in terms of their economic values to the livelihood of the people.

CHAPTER 3

LANDSLIDES THIRUVAMBADI GRAMAPANCHAYATH

Thiruvambadi is a major hill town in Kozhikode district. Thiruvambadi Grama Panchayath is under Koduvally Block Panchayat and Thamarassery Taluk. Thiruvambady Gramapanchayath was established on 1 January 1962 and consists of 17 wards covering an area of 83.96 Km^2 (Fig. 3.1).

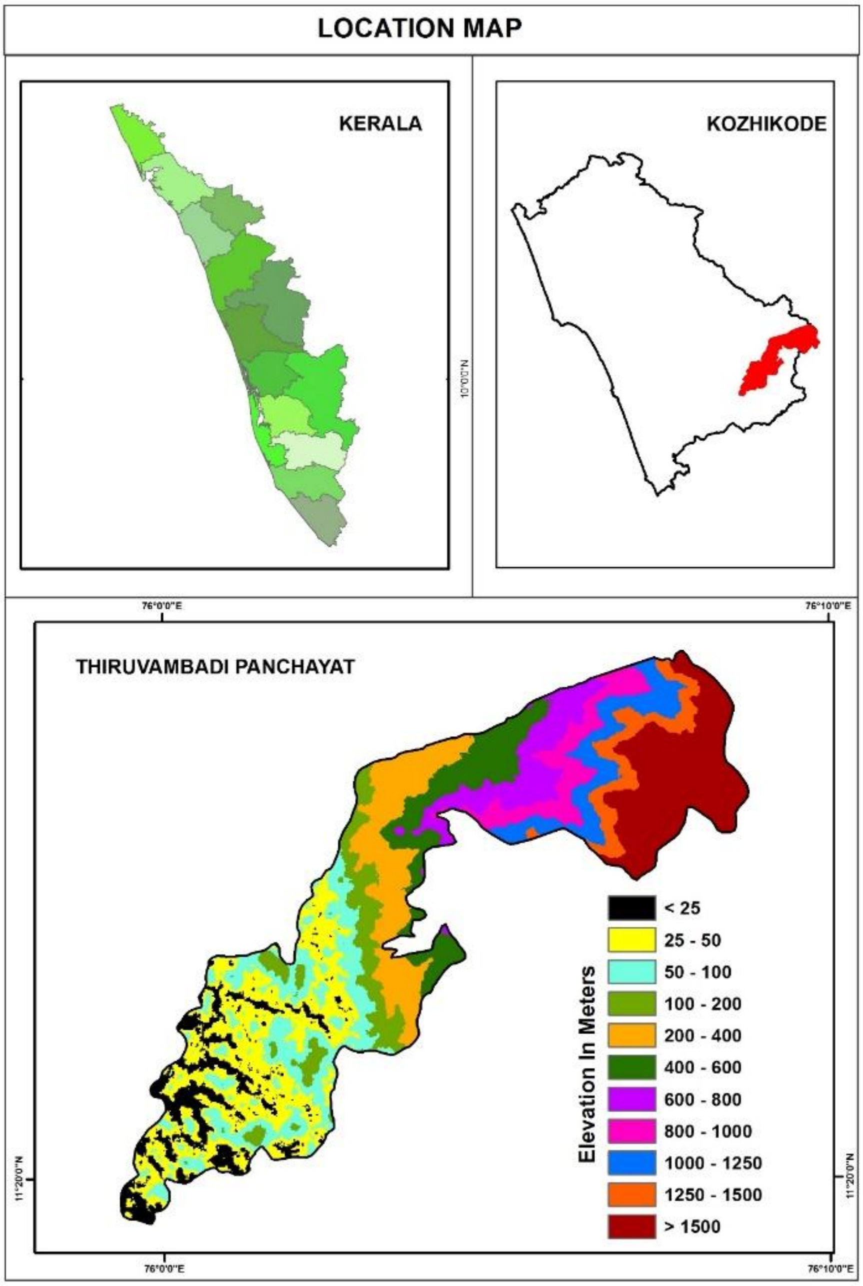

Fig. 3.1 Thiruvambadi Grama Panchayath

Thiruvambadi village is on the banks of the Iruvanjippuzha River, which is a major tributary of the Chaliyar River. The town is surrounded by mountains, valleys, and waterfalls, such as Thusharagiri Falls and Aripara Falls. Thiruvambadi is one of the major agricultural areas in Kozhikode district. The main cash crops are rubber, coconut, areca nut, paddy, ginger, turmeric, and pepper. Thiruvambadi has a total population of 28,820 peoples.

3.1 LANDSLIDE HISTORY

Multiple debris flows occurred in Pullurampara on August 7, 2012, took the lives of 8 people, damaged settlements, infrastructure and acres of agricultural land. The debris resulted from the slide snapped the communication arteries and damaged power lines. The settlements got isolated and power failure remained for days together. The area lies 44 km east of Kozhikkode town. The hill slopes of Kodakkattupara, Cherussery Mala is mainly inhabited by small scale agriculturist. The slide locations fall under Ward 4, 3 and 17 of Thiruvambadi Grama Panchayat. All together 35 scars of slope failures were located. Debris flows and slumps are the different types of slope failures observed in the area. Nine locations where the debris flow caused maximum damage in Kodukattupara, Mele Kodakattupara, Cherusseri mala, Joy Road, and Manchod (Table 3.1). The maximum elevation of the affected area is 1078 m and the minimum elevation 340 m. Dendritic drainage is observed in the area. The slope in general ranges from 40 to 60 degrees. The major rock type of the area is Hornblende gneiss and Charnockite. Weathering has produced thick layer of overburden and it ranges from 3 to 7 m. the Lateritic layer is thin compared to the weathered hard rock zone and top soil. A prominent fault is seen laying on the western side of the affected area in the direction NE-SW. The amount of rainfall obtained on the day of the event at the various rain gauge stations around the area is Kakkayam (182mm), Panniyur (122.10 mm), Nilambur (89mm) and Vythiri (232mm). the average rainfall obtained on the day is 156.2 mm and hourly rainfall is roughly estimated as 6 mm. The natural factors such as steepness of hill slope, relative relief, thickness of the overburden, attitude of joints and fracture in rock, hydraulic conductivity and less coherent nature of the overburden make the slope vulnerable to slope failures. The recent minor seismic tremor occurred in June 2012 might have reduced the factor of safety of slopes. The shallow rooted trees, agricultural practices in hill slope also have contributed to the enhancement of the dimension of debrisflow and consequent damage. The continuous and copious rainfall on the day of the event and penultimate day acted as the catalyst for triggering debris flow in Pullurampara.

Table 3.1 Locations of debris flow during Monsoon 2012

Locations	Latitude and Longitude
Kodukattupara -1	N 11º 24.823 E 76º 03.522
Kodukattupara -2 (Mercy Bhavan)	N 11º 24.809’ E 76º 03.306’
Mele Kodakattupara-1	N 11º 24.905’ E 76º 03.780’
Mele Kodukattupara- 2	N 11º 24.917’ E 76º 03.852’
Mele kodukattupara-3	N 11º 25.114’ E 76º 04.047’
Male kodukkatupara-4	N 11º 25.096’ E 76º 04.148’
Cherusseri mala	N 11º 25.160’ E 76º 03.736’
Joy Road	N 11º 25.387’ E 76º 03.224’
Manchuvad	N 11º 25.304’ E 76º 03.154’

Several slope failures occurred in Thiruvambadi GP during south west monsoon of period of 2018. Acres of agricultural land, particularly aracanut tree plantation have been lost due to debris flow at Karimb. The debris flow occurred in a private land which was cultivated by cocco, jaathi and arecanut. Width of the scar is less than 3 meters. The debris run off distance is 500 m and damaged 300 arecanut trees, communication arteries totally on its way downward.

Debris slide is reported in Maripuzha is located at longitude and lattitude N 11º 26’56.16” & E 076º 06’ 4.2”. The height of the scar is 10 m and width 52 m. The main type of vegetation is arecanut, pepper and coconut. The event occurred on 14th August 2018. The thickness of the overburden is 2- 3 m. The top red coloured and high clay content. It is initiated by continuous heavy rainfall. The Debrisflow which occurred in Vellarimala in the previous days have contributed to activate the debris slide at Maripuzha. The Vellarimala debris flow scar is situated on the SE side of the Maripuzha Debris slide. Both the failures are associated with perennial streams of first order. Evidences of sub surface tunnel erosion (Soil piping) could be observed at the scar face (Plate 1). Large amount of water was discharging through the two tunnels formed at the toe of the slip face. among these two tunnels at the bottom of the slip face have discharged large amount of water. The slide debris destroyed the road and Agricultural properties. Perched boulders can be seen on scar faces this can be a threat in future if prolonged rainfall exist. Charnockite is the main rock type of the area. Highly weathered Charnockite and laterites observed. General hill slope of the area is 25º.

Plate 1: Sub surface tunnel erosion (Soil piping)

3.2 METHODOLOGY

Survey of India Toposheet, the satellite imageries of the area were examined and GPS locations of already failed hill slopes were collected. Data regarding paleoslide, date of occurrence, frequency of occurrence have been procured from administrative records in thaluk offices, Panchayath, newspapers and by interviews with local people. Data regarding the rain fall received has been procured from the nearest rain gauge station. The data regarding the orientation of discontinuities such as joints, fault etc, and their location in profile, variation in lithology and texture of formation, details of vegetation and ground water table levels of the locality, thickness of soil etc are documented. Slope morphometric map, detailed lineament map, landuse map and vegetation map, relief map, drainage map, have to be prepared. After the identification and location of high hazardous zones sites are selected for detailed investigation.

Samples have been collected from the weakest zones of selected four failed areas for geotechnical studies. The locations include Tharippapoyil, Manchuvad, Joy road and Karimb.

Properties such as cohesion, friction, angle bulk density were determined in geotechnical laboratories.

Appropriate analytical methods were used for each sites to determination of factor of safety of slopes. Geometrical analysis using stereographic projection (Hoek and Bray 1981 and Krishnanath and Sreekumar S, 1996) is used for hard rock profiles. The factor of safety of lateretic profile were be determined using principles of soil mechanics. Site specific landslide mitigation strategies were developed for selected sites. Total station survey is carried out for Karimb and Manchuvad location. Detailed geological mapping was carried out for these locations.

The drainage network, landuse and communication arteries of the area are delineated using toposheets and imageries. The SRTM data is to be used to derive the elevation of the area. The numerical weightage is assigned to each of the different thematic layers such as Slope, relative relief, aspect, curvature, drainage density, drainage frequency, landuse/landcover, road buffer and drainage buffer corresponding to the causative factors for the slope failure was prepared by using Remote Sensing and informations derived from Toposheets. For spatial analysis Arc GIS and ERDAS is to be used. Appropriate modeling is used for the generation of a landslide hazard zonation map (Vijith and Madhu, 2007).

A risk map in the ward level is generated by incorporating the extend of damage and factor of safety of slopes. Site specific landslide mitigation strategies are developed for selected sites.

3.3 SCOPE OF THE STUDY

Several workers have carried out investigations on slope failures in different parts of Western Ghats and prepared Landslide Hazard Zonation maps in macro level. Micro level slope stability analysis using geological and geotechnical tools is necessary to reduce the vulnerability and risk towards the disastrous slope failures. This will help the identification of vulnerable areas to landslides. Categorizations of prone areas help the administrators to take preparedness during monsoon period. Risk evaluation helps the LSG's to provide post disaster relief to the affected people in the case of an event. Ultimately this will help in the socio-economic development of the panchayaths.

3.4 OBJECTIVES.

- Collection of data regarding paleoslides in the grama panchayath
- Detailed Geological and Geotechnical studies of selected failed hill slopes.
- Assessment of changes in land use pattern
- Preparation of landslide hazard zonation map using GIS.
- Suggest mitigation strategies in high risk zone.

CHAPTER 4
IDENTIFICATION OF HAZARDOUS AREAS

The areas prone to landslide in Thiruvambadi Grama Panchayath are demarcated using GIS technique. Techniques such as landslide susceptibility mapping and frequency ratio model are used in this study.

4.1 METHODOLOGY

The data sources for the present study are the GPS location of landslides, Survey of India toposheets, Geological map prepared by GSI and Remote Sensing Data. The Survey of India Toposheets for Kozhikode provided the, drainage network, land use and road network of the area. The SRTM data was used to derive the elevation of the area. Nine landslide inducing factors are considered in the present study for calculating the probability of the landslides. The susceptibility study is based on the previous occurrence landslides locations which were collected using GPS. The locations were then digitized as point layer. Then create a database to assess the surface area and number of landslides in the study area. The thematic maps of geo factors such as slope, relative relief, aspect, curvature, drainage density, drainage frequency, landuse, road buffer and drainage buffer were generated in a GIS after extensive image interpretation and field work. The terrain factors selected for hazard zonation are slope, relative relief, curvature, drainage density, drainage frequency, drainage buffer, land use, and road buffer (Section 2.6)

The Digital Elevation Model (DEM) of the study area is derived from SRTM data. Using this slope, aspect, relative relief and curvature is generated. The slope of the study area ranges from 0 - 45 degrees. They are classified into nine classes. The aspect of the area derived from the DEM is classified into nine classes (Flat, N, NE, E, SE, S, SW, W and NW). The curvature of the area is classified into three classes concave, flat and convex. The relative relief of the area is derived using the neighborhood statistics of the spatial analyst is classified into 8 classes.

The drainage network of the study area as derived from the topographic sheets was digitized and saved as line layer. In addition, the distance from drainage was calculated. For this a drainage buffer was calculated at 150 meters interval and classified into 4 classes

Moreover the Drainage density and frequency is also derived from streams using spatial analyst of ARC GIS 9.2. The total study area is then classified into 6 drainage density zones. Drainage frequency is also calculated using the same method. On the basis of drainage frequency distribution, the study area is divided into 4 classes.

Land use also derived from the toposheets and finalized after the adequate field survey. The landuse is classified into 10 classes and digitized and saved as polygon. The road network of the study area as derived from the topographic sheets was digitized and saved as line layer. Road buffer was calculated at 100 meters interval and classified into 7 classes

4.1.1. SLOPE

Hill slope is a very important parameter in the preparation of landslide hazard zonation map of an area. The map defines various slope categories of the study area and has been prepared by transforming the SRTM data into slope angles at any given point. In Thiruvambadi GP majority of the landslide occurred in the slope ranging from 15°- 20°. In all, 9 slope categories are identified and areas falling under each category have been worked out (Table 4.1). The distribution pattern of slopes indicates that 53.03 % of the total area lies between 5° - 20° (Fig. 4.1).

Table 4.1 Slope categories and area falling in each category

Slope	Area (Km^2)	Area (%)	No. of Events
0 - 5	8.67	10.32	0
5 - 10	16.65	19.83	4
10 - 15	15.77	18.78	4
15 - 20	12.10	14.42	6
20 - 25	9.08	10.82	2
25 - 30	6.87	8.18	2
30 - 35	5.27	6.28	2
35 - 45	6.36	7.57	0
> 45	3.18	3.79	0

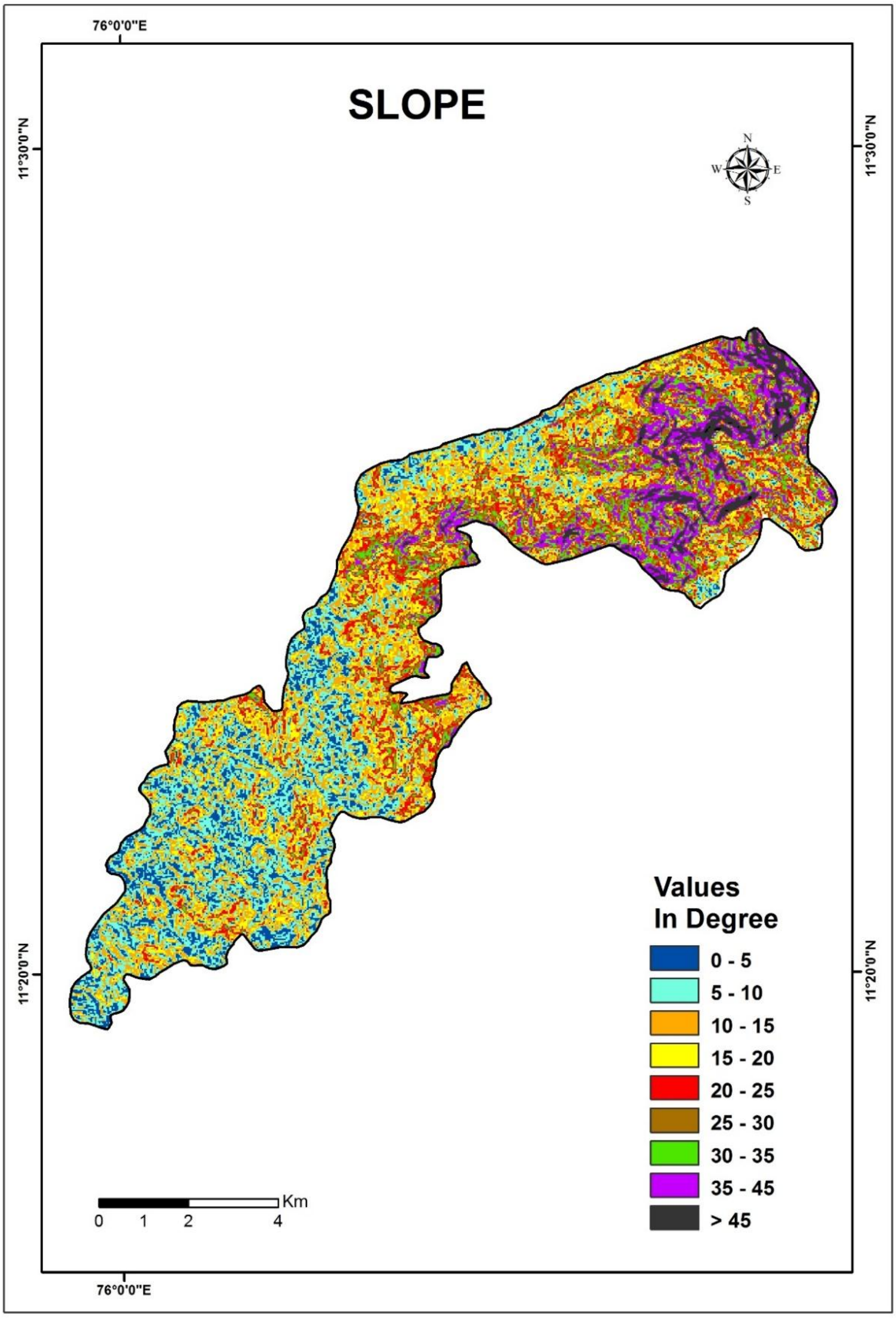

Fig. 4.1. Slope map of the study area.

4.1.2. RELATIVE RELIEF

It is the difference in height between the highest and lowest point per unit area. Thampi et al 1988 reported that the maximum slide is associated with a relief of 200-400m range. In Thiruvambadi GP also maximum number of slides associated with200-400 m range (Table 4.2 and Fig. 4.2). In Thiruvambadi GP 22.9 % of the total area falls under this category.

Table 4.2. Relative Relief categories and area falling in each category

Relative relief	Area (Km^2)	Area (%)	No. of Events
<50	0.00	0.00	0
50 – 100	13.95	16.62	0
100 – 200	19.85	23.64	2
200 – 300	7.70	9.17	8
300 – 400	11.53	13.73	7
400 – 500	10.61	12.64	3
500 – 600	8.77	10.44	0
>600	11.56	13.76	0

4.1.3. ASPECT

Another highly significant factor in slope stability determination is the aspect. It represents the direction of slope and refers to the direction in which a mountain/hill slope faces a possible amount of sunshine and shadow. Slope aspect influence terrain exposure to storm fronts (Rajakumar et al., 2007). It also effect the fluctuation of porewater pressure and mechanical weathering process. Degree of saturation of slope forming materials is also a major factor controlling the occurrence of landslide. Moisture retention and vegetation is reflected by slope aspect. The contrasting steepness and southwest slopes appear to be explained in terms of difference in exposure (Hack and Goodlett, 1960). The north facing slopes are sheltered more than south west facing slopes from drained wind and sunrise and as a result retain more moisture. The more moist slope is consistently steeper than the drier south west slope due to the greater intensity of the surficial process acting on the drier slope flattening it more easily. In Thiruvambadi GP more events (12) are associated with W and NW trending slopes (Table 4.3 and Fig. 4.3). 37.89 % of the area falls under this category.

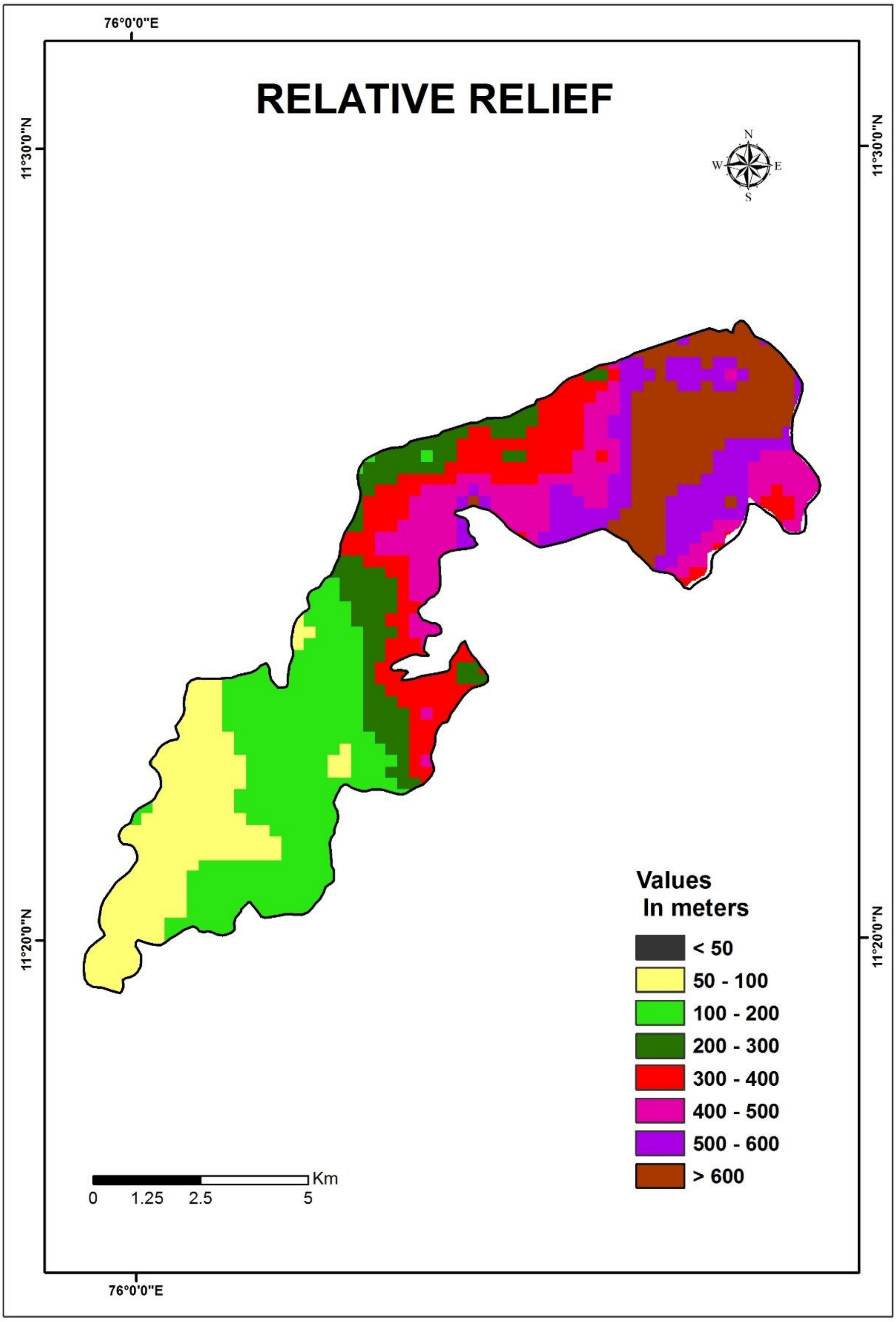

Fig. 4.2. Relative Relief map of the study area.

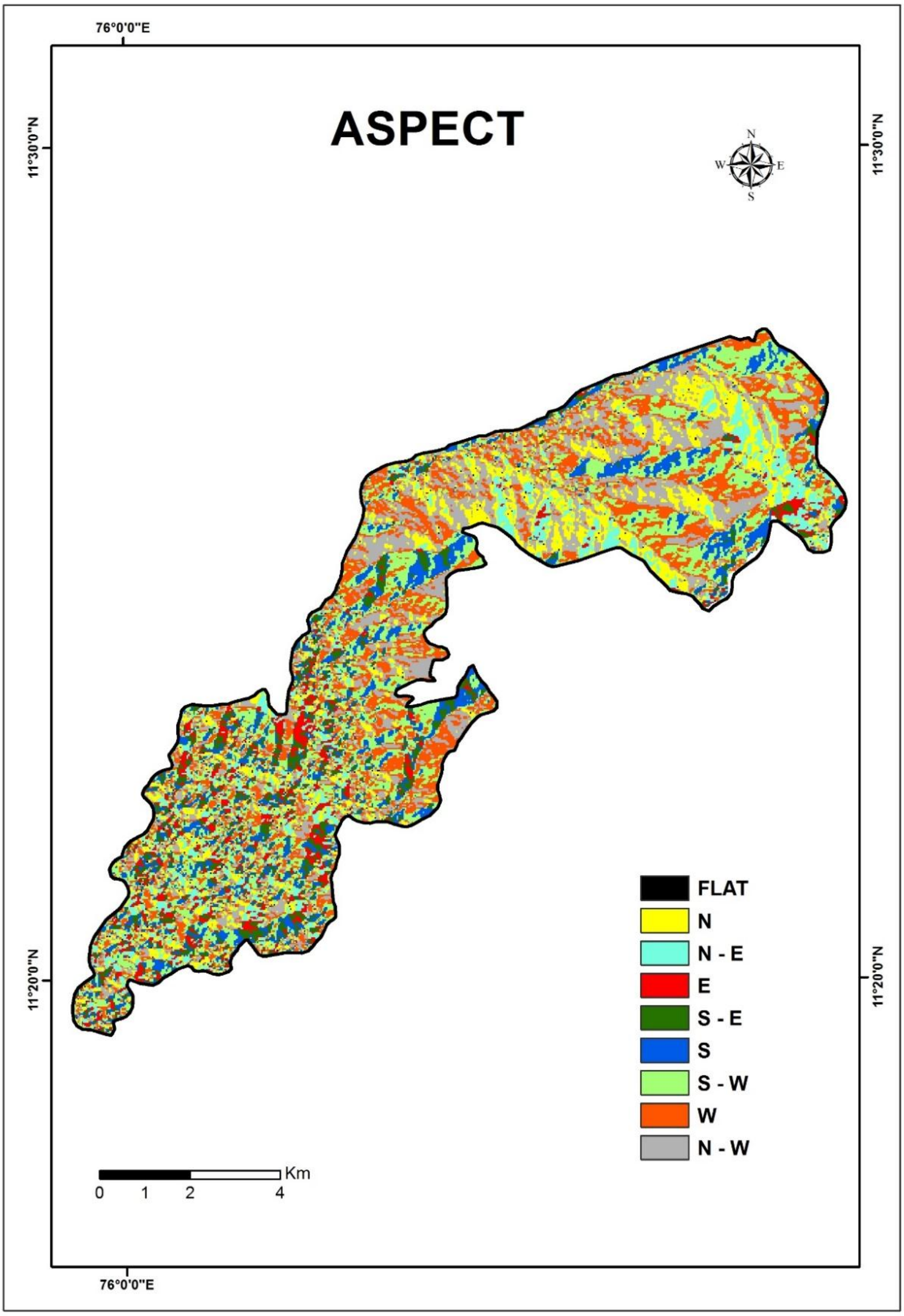

Fig. 4.3. Aspect map of the study area.

Table 4.3 Aspect categories and area falling in each category

Aspect	Area (Km^2)	Area (%)	No. of Events
Flat	0.32	0.38	0
N	11.21	13.35	1
NE	7.88	9.39	0
E	4.76	5.67	0
SE	4.98	5.93	0
S	8.51	10.14	4
SW	14.49	17.26	3
W	15.92	18.97	6
NW	15.88	18.92	6

4.1.4. CURVATURE

Based on the curvature of the slopes it has categorized into 3 types, concave, convex and flat. In this GP slightly concave curvature exhibited the maximum slides (Table 4.4 and Fig.4.4). 49.33 % of the area of this GP falls under Concave curvature and followed by convex curvature (46.82).

Table 4.4 Curvature categories and area falling in each category

Curvature	Area (Km^2)	Area (%)	No. of Events
Concave	41.42	49.33	13
Flat	3.23	3.85	0
Convex	39.31	46.82	7

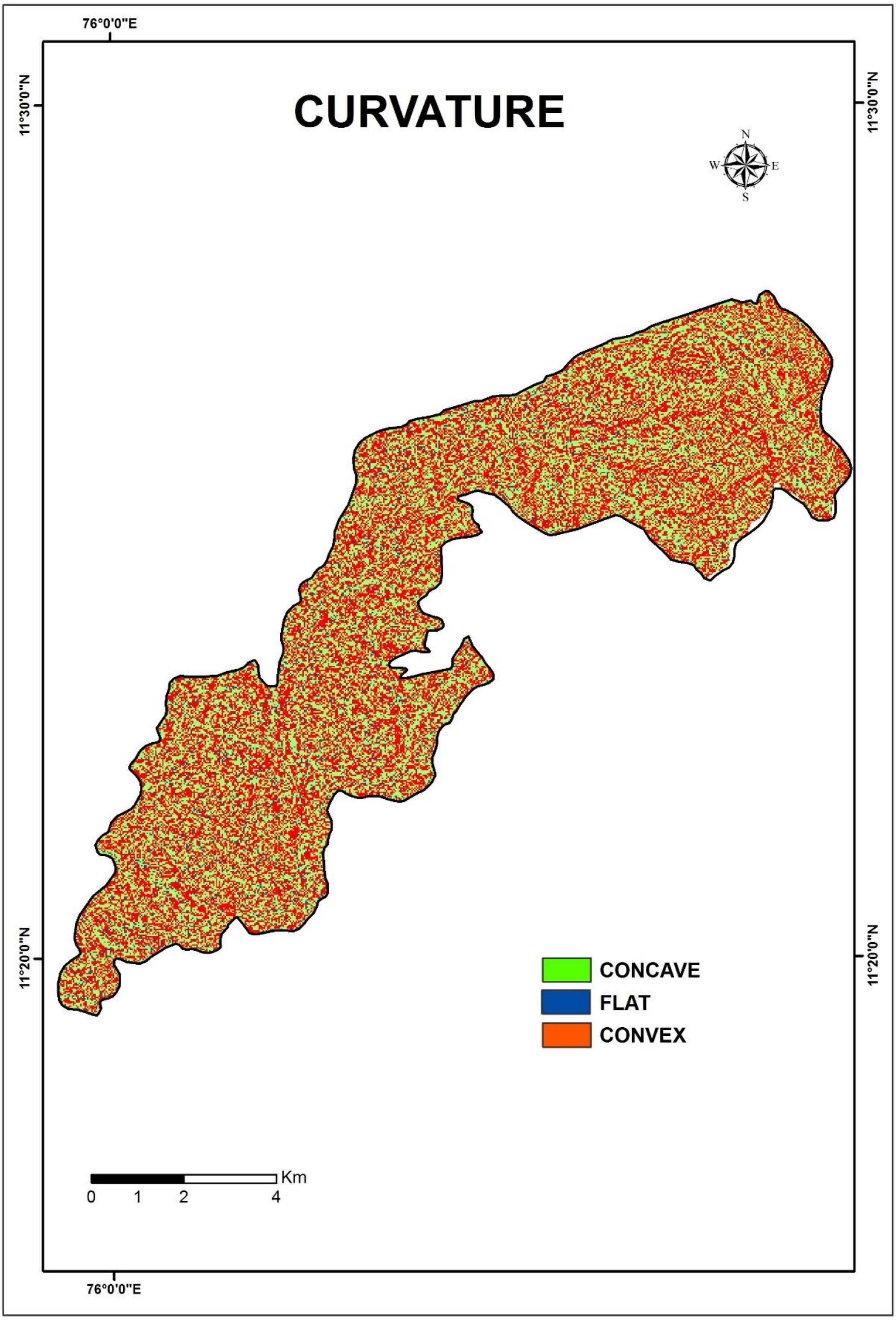

Fig. 4.4. Curvature map of the study area.

4.1.5. DRAINAGE DENSITY

The natural method of landscaping of a region in Western Ghats is mainly carried out by rivers and its distributaries. The running water is very important geological agent in effecting transportation of the weathering product from an elevated area to lowland area. Therefore it is necessary to evaluate the drainage characteristics of the terrain. An understanding of the drainage network helps us to learn how this factor involved in land degradation. The initial fingertip tributaries are called the first order streams when two first order streams join a second order stream and two second order stream join to form a third order and so on. The number, length, gradient etc of streams can be evaluated in terms of total drainage density. Drainage density is defined as the ratio of the total length of streams to the total area. High drainage densities are indicative of impervious strata, high rainfall, little vegetation and active stream incision all of which may be associated with mass movement (Cook and Doornkamp 1978). In Thiruvambadi GP maximum number of landslides (65 %) are associated with drainage density class 1- 1.5, followed by 1.5 – 2 (35%). The total area falls under these categories were 82.82% of the total area (Table 4.5 and Fig.4.5)

Table 4.5 Drainage density categories and area falling in each category

Drainage Density	Area (Km^2)	Area (%)	No. of Events
0 -.5	0.00	0.00	0
.5- 1	7.75	9.23	0
1 – 1.5	25.85	30.79	13
1.5 – 2	43.71	52.05	7
2 – 2.5	6.66	7.93	0
> 2.5	0.00	0.00	0

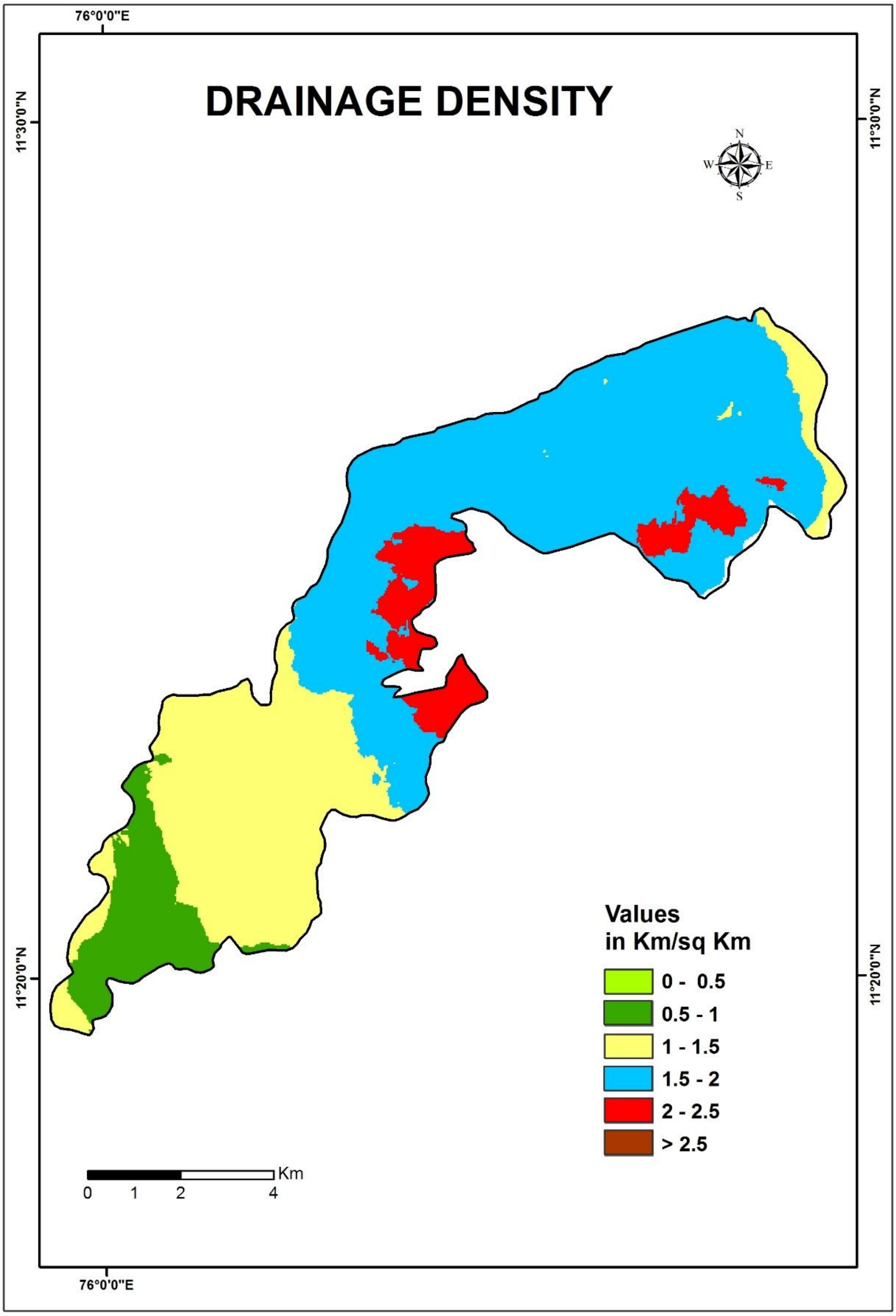

Fig. 4.5. Drainage density map of the study area.

4.1.6. DRAINAGE FREQUENCY

The drainage map was overlied by grid cover of size 1 square kilometer. The number of drainage lines present in each grid is counted which will give the drainage frequency value. The study area has been classified into four types based on the number of drainage incidences. Most of the landslides are associated with drainage frequency class 2-3 in Thiruvambadi GP.

57.01 % of the area of this GP comes under this category (Table 4.6 and Fig. 4.6)

Table 4.6 Drainage frequency categories and area falling in each category

Drainage Frequency	Area (Km^2)	Area (%)	No. of Events
0 -1	0.16	0.19	0
1 – 2	22.74	27.08	0
2 – 3	47.86	57.01	19
3 – 4	13.20	15.72	1

4.1.7. DRAINAGE BUFFER

As a distance from the drainage line increases landslide frequency generally decreased because the seepage of water near the drainage network is more compared to distant one. The water seepage can reduce the shear strength of the slope material and can activate landslides. The earlier study on drainage frequency and density reveals that the area has a good drainage network. In Thiruvambadi GP all the slides have happened with in 300 m from the drainage line (Table 4.7 and Fig 4.7). Maximum numbers of incidences (75 %) are reported close to the drainage line (0-150).

Table 4.7 Drainage buffer categories and area falling in each category

Drainage buffer	Area (Km^2)	Area (%)	No. of Events
0 -150	56.33	67.10	15
150 -300	22.15	26.38	5
300 – 450	4.21	5.02	0
>450	1.26	1.51	0

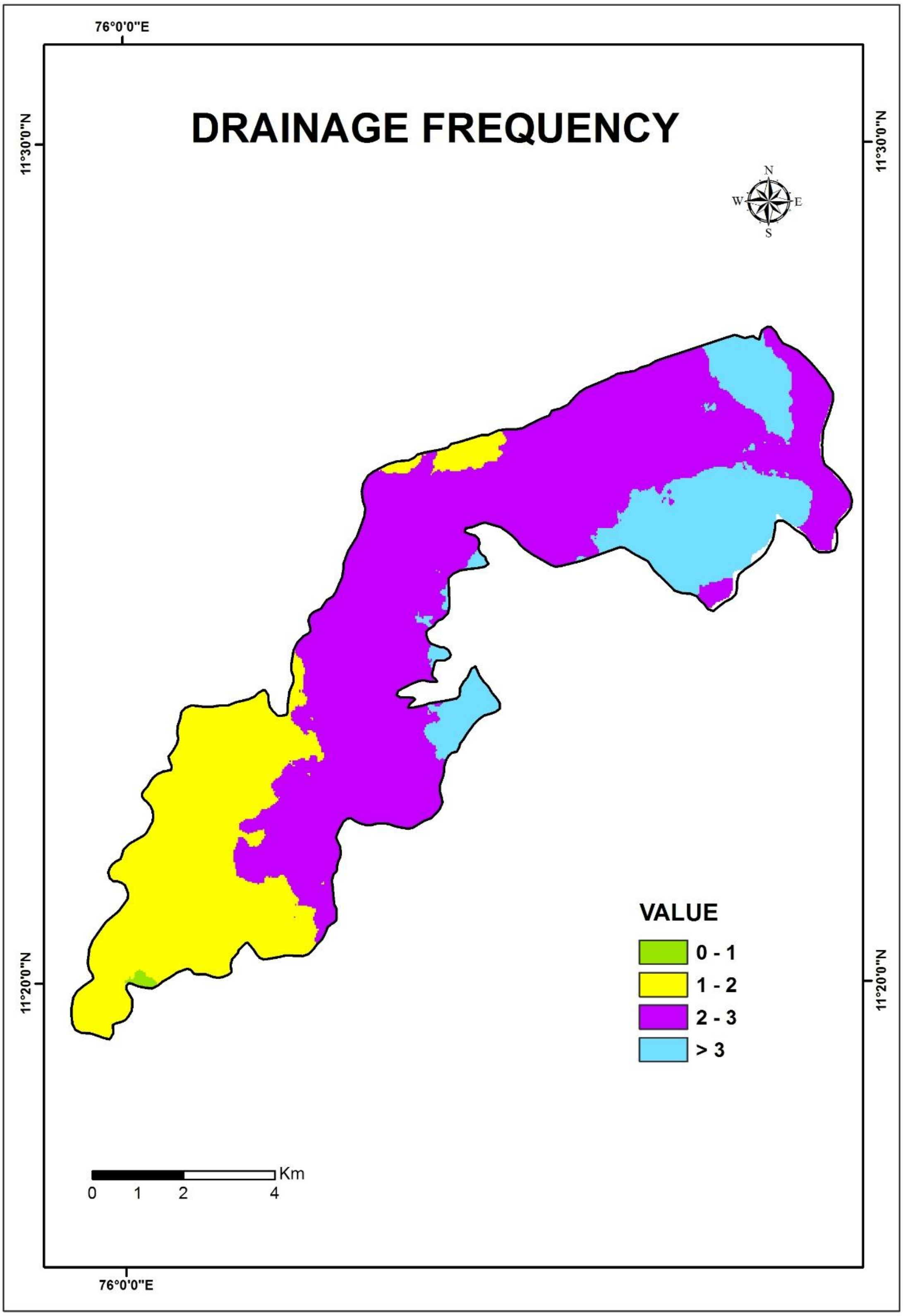

Fig. 4.6. Drainage frequency map of the study area.

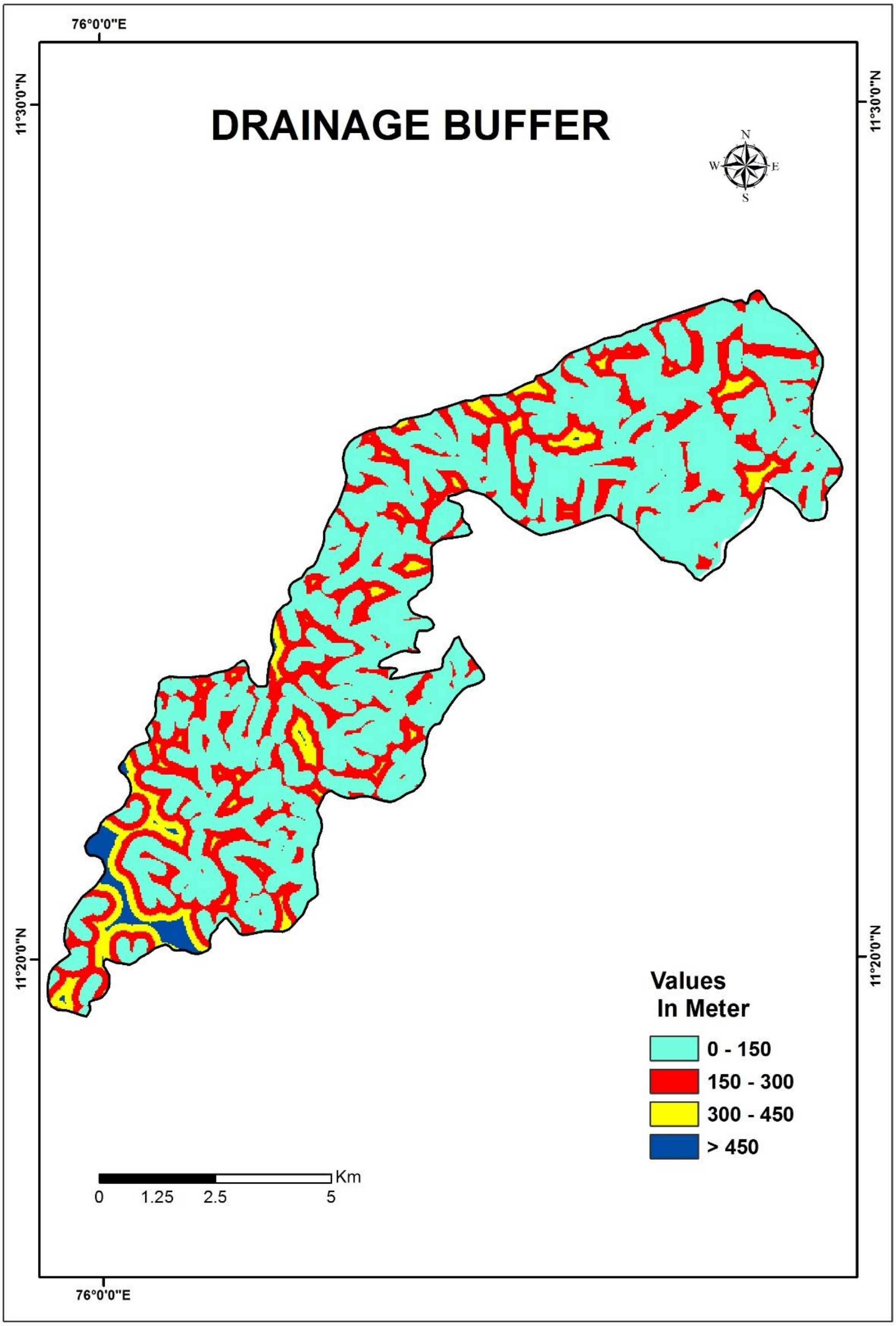

Fig. 4.7. Drainage buffer map of the study area.

4.1.8. LANDUSE / LAND COVER

Slope failures in the Western Ghats are generally associated with the monsoon period. Vegetation cover is found to be an important factor that is influencing the landslide occurrence during this period. From various investigations it is under stood that Landuse/ land cover, especially of a woody type with deep root and strong roots helps to keep the material intact (Gray and Leiser, 1982). The natural features on the slope undergo continuous change. Most of the slides (13) occurred in Deciduous Forest in the GP. The total area comes under this category is 41.63% (Table 4.8 and Fig. 4.8)

Table 4.8 Landuse categories and area falling in each category

Land use / land cover	Area (Km^2)	Area (%)	No. of Events
Paddy Cultivation	0.62	0.74	0
Mixed Cultivation	3.83	4.56	0
Coconut Plantation	28.66	34.13	1
Rubber Plantation	6.94	8.26	5
Built-up	0.53	0.63	0
Open Scrub	4.61	5.49	0
Forest Scrub	3.49	4.16	1
Deciduous Forest	34.95	41.63	13
Evergreen Forest	0.01	0.01	0
Water River/stream	0.33	0.39	0

4.1.9. ROAD BUFFER

The micro level study has revealed that many slopes are at the threshold of failure. During continuous and excess rainfall three or four days during monsoon can result in the reduction of factor of safety and leads to failure. The heavy traffic along the road produces vibration and this can act as a triggering force in such locations. The proximity to communication arteries is definitely a factor in making the slope vulnerable to slide. Depending upon the distance of the slope from the road six categories has been defined. Majority of slides comes under the category >500m (Table 4.9 and Fig. 4.9).

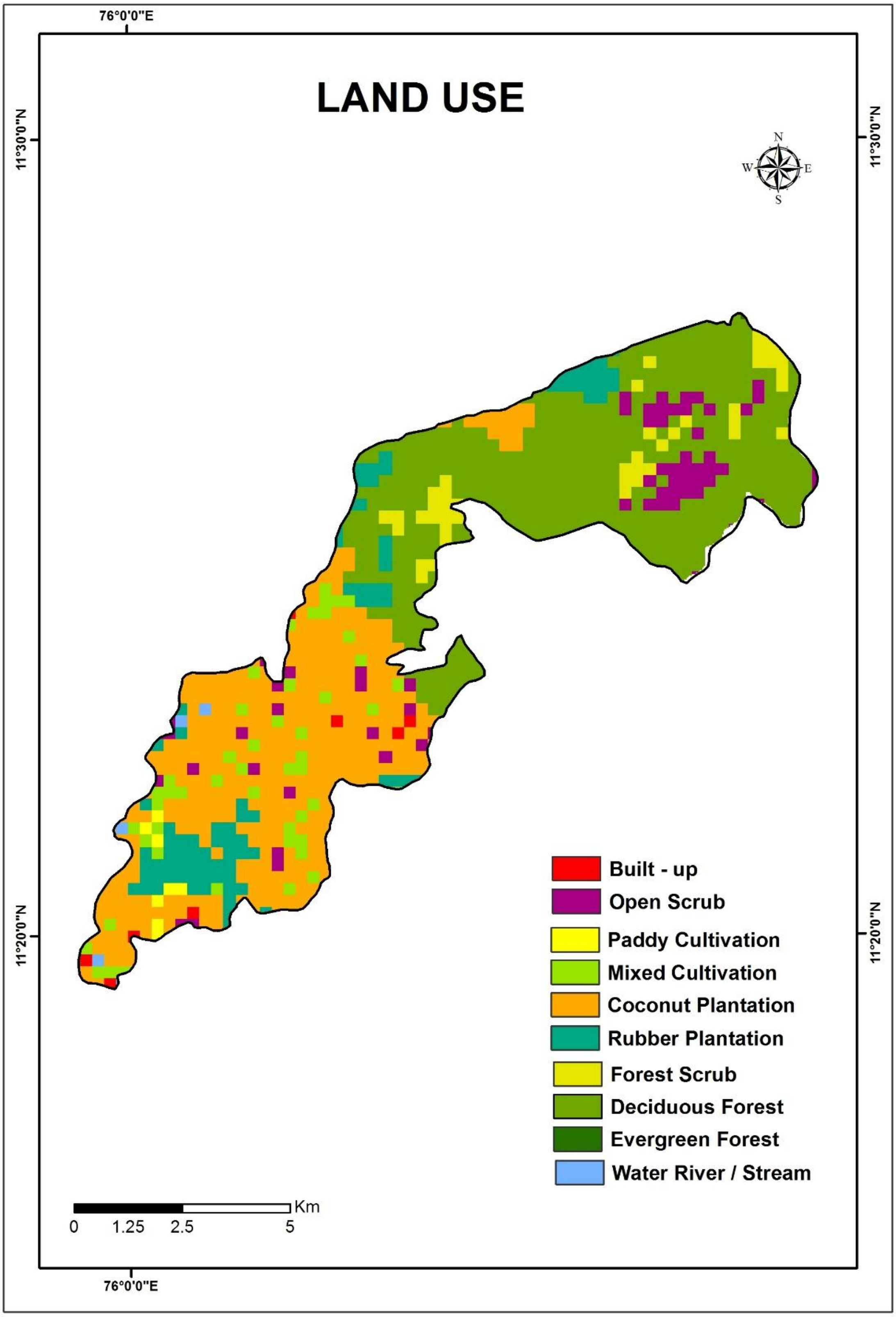
76°0'0"E
LAND USE
11°30'0"N
N
W
E
S
11°20'0"N
Built - up
Open Scrub
Paddy Cultivation
Mixed Cultivation
Coconut Plantation
Rubber Plantation
Forest Scrub
Deciduous Forest
Evergreen Forest
Water River / Stream
Km
0
1.25
2.5
5
76°0'0"E

Fig. 4.7. Landuse map of the study area

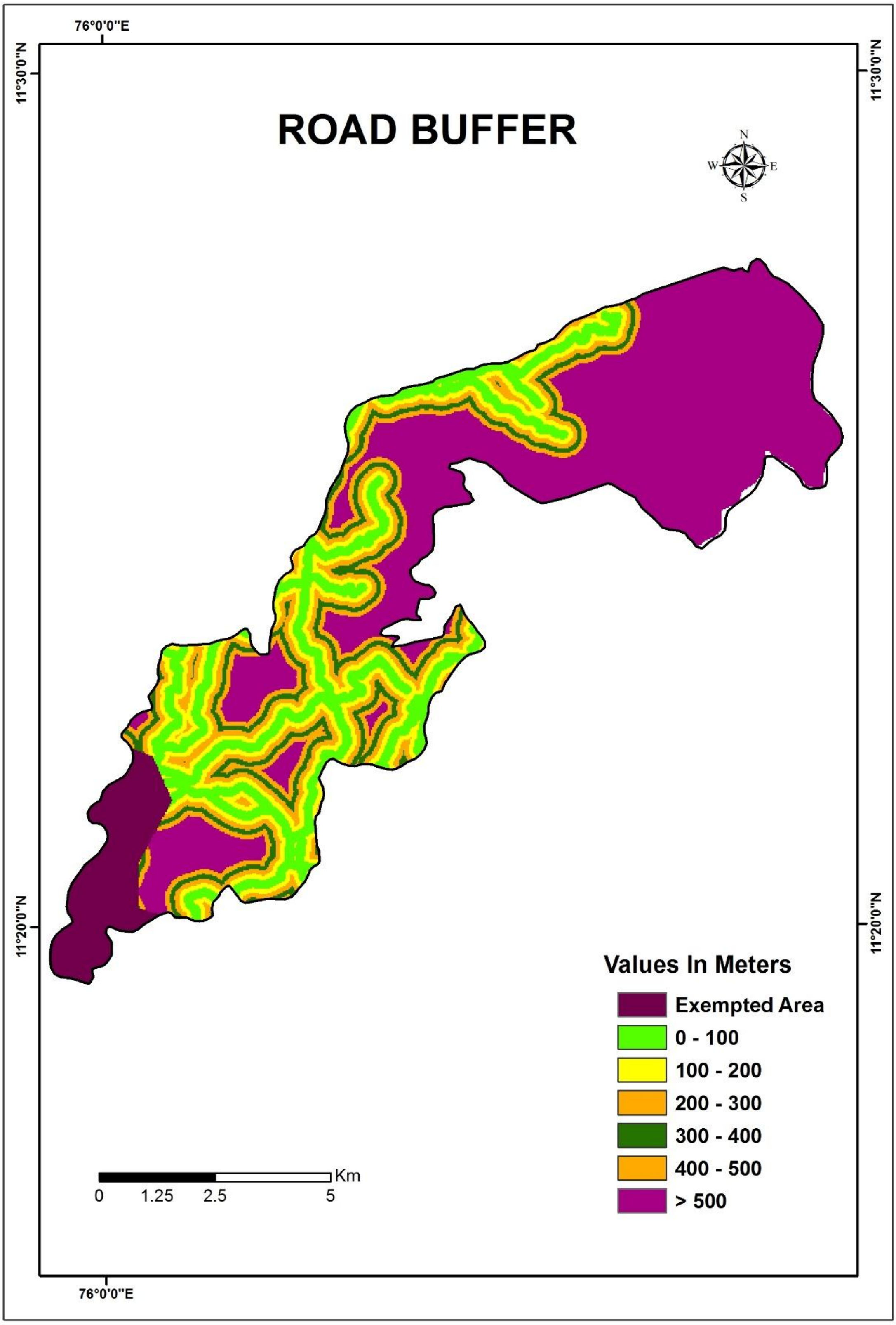

Fig. 4.8. Road buffer map of the study area.

Table 4.9 Road buffer categories and area falling in each category

Road buffer	Area (Km^2)	Area (%)	No. of Events
Not consider	6.34	7.55	0
0 – 100	11.23	13.37	7
100 – 200	9.20	10.96	0
200 – 300	7.61	9.07	2
300 – 400	5.93	7.07	2
400 – 500	4.94	5.88	0
>500	38.71	46.10	9

4.2 LANDSLIDE SUSCEPTIBILITY MAPPINGBY QUANTITATIVE ZONATION METHOD

The LSI values have been classified into five classes to yield five landslide susceptibility zones, viz. Stable, Moderately Stable, Moderately Unstable, Highly Unstable and Critical.

- **Critical zone -** This is a very unstable zone where landslides are likely to occur in view of the prominent causative factors present. The area is almost degraded to such a state that it is practically impossible to evolve economically and socially acceptable remedial measures which can positively prevent recurrence of the hazard. The area has to be entirely avoided for settlement or other developmental purposes and preferably left out for regeneration of natural vegetation and attainment of natural stability in course of time through the physical processes active in the area.

- **Highly unstable Zone -** These areas are prone to landsliding. Terrain setting is comparable to the first category and in many cases the landslides initiated in the first category will have its impact on this zone also. The area needs urgent attention in the form of mitigatory measures like regeneration of natural vegetation, reforestation, drainage correction and restriction of seasonal tilling activity and contour bunding to ensure proper drainage etc. Unless immediate action plans are implemented this zone will soon deteriorate to the critical category. The settlement as far as possible is to be avoided and permitted only in localised safe areas.

- **Moderately unstable** - These are areas which are stable in the present condition but future landuse activity is to be properly planned so as to maintain its present status. However, if natural drainage is disrupted/slope modified landslides could be triggered.

- **Moderately stable zone** - For all practical purposes these areas are safe from mass movements by virtue of its present geoenvironmental set up. However, many slopes falling within this zone could be destabilized by uncontrolled erosion, improper landuse practices and development activities.

- **Stable zone** - A very stable zone where no restrictions are warranted as reasonable human activity of any form do not possibly threaten the balance.

In Thiruvambadi GP, 35.67 % of the total area falls under moderately unstable areas and 26.54 % of the area falls under highly unstable area. 0.96 % of the area is identified as critical (Table 4.10).

Table 4.10 Area falling under different landslide susceptibility zones

Class	Area (Km^2)	Area %
Stable	10.14	12.08
Moderately stable	20.78	24.75
Moderately unstable	29.95	35.67
Highly unstable	22.28	26.54
Critical	0.81	0.96
Total	83.96	100

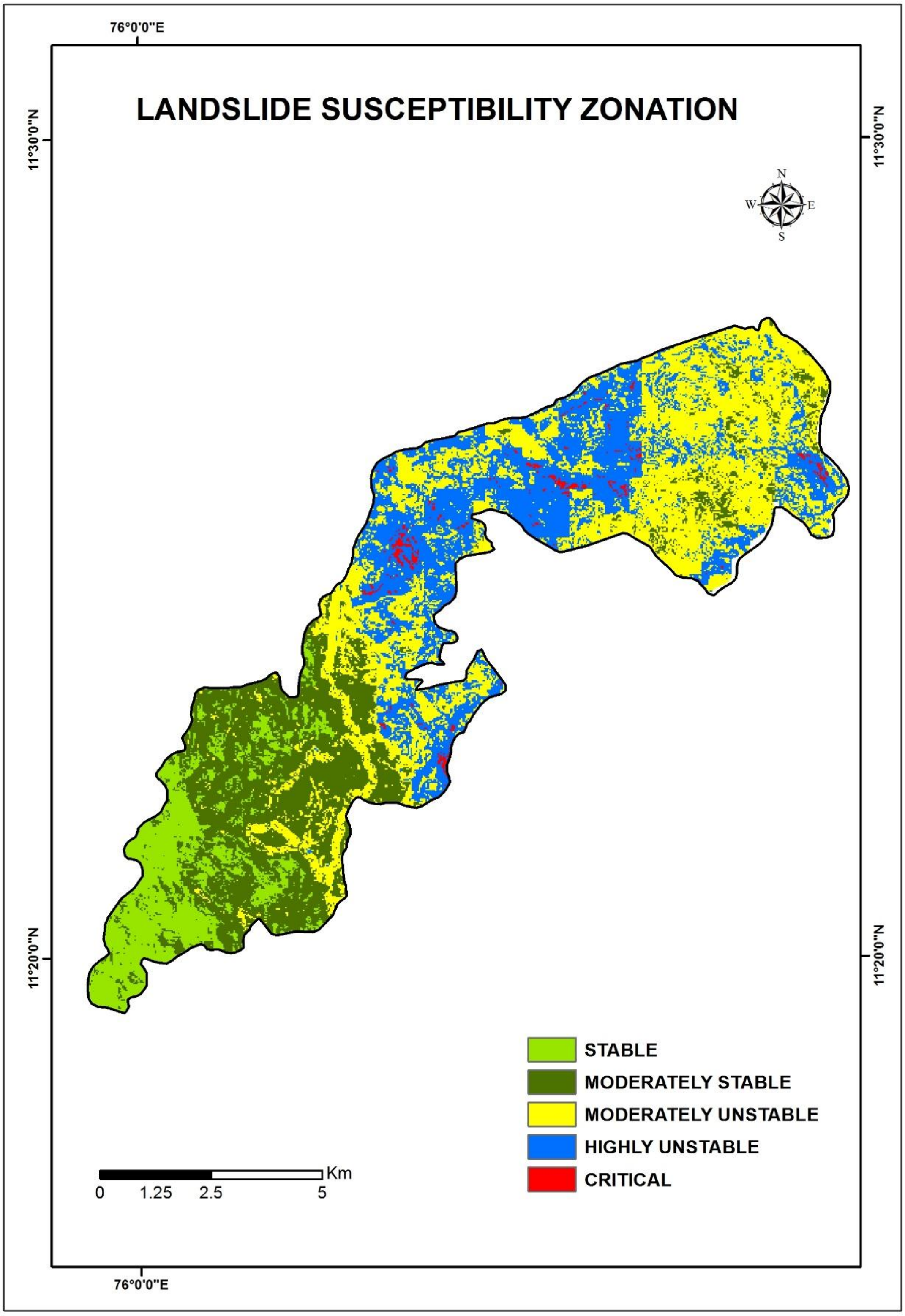

Fig. 4.10. Landslide susceptibility map of Thiuvambaadi Grama Panchayath**.**

Landslide Susceptibility of 17 wards were calculated. In this panchayath, 23.69 % of the total area falls under moderately unstable areas and 23.79 % of the area falls under highly unstable area. 1.04 % of the area is identified as critical (Table 4.11 and Fig.4.11). ward 1 and & 2 have maximum area under highly unstable and critical category.

Table 4.11: Ward wise area falling under different susceptibility zones

Ward	**Stable**	**Moderately stable**	**Moderately unstable**	**Highly unstable**	**Critical**
1	0.00	0.03	1.48	2.22	0.03
2	0.00	0.00	0.83	2.13	0.14
3	0.00	0.00	1.17	1.40	0.02
4	0.00	0.02	1.04	2.67	0.20
5	0.00	1.24	2.11	0.94	0.01
6	0.00	0.17	1.86	2.30	0.10
7	0.17	2.73	1.00	0.04	0.00
8	0.00	1.20	0.24	0.00	0.00
9	1.01	1.83	0.11	0.00	0.00
10	2.66	2.11	0.10	0.00	0.00
11	1.86	0.18	0.00	0.00	0.00
12	0.90	0.05	0.00	0.00	0.00
13	0.66	0.07	0.00	0.00	0.00
14	0.81	2.80	0.97	0.01	0.00
15	0.62	2.19	0.22	0.00	0.00
16	0.80	2.79	0.10	0.00	0.00
17	0.13	0.50	1.42	1.01	0.05
Total	9.64	17.90	12.67	12.72	0.55
Area %	18.02	33.47	23.69	23.79	1.04

 # Total area falling under 17 GP's is 53.47 Km2. The remaining areas 30.48 Km^2 comes under reserved forest

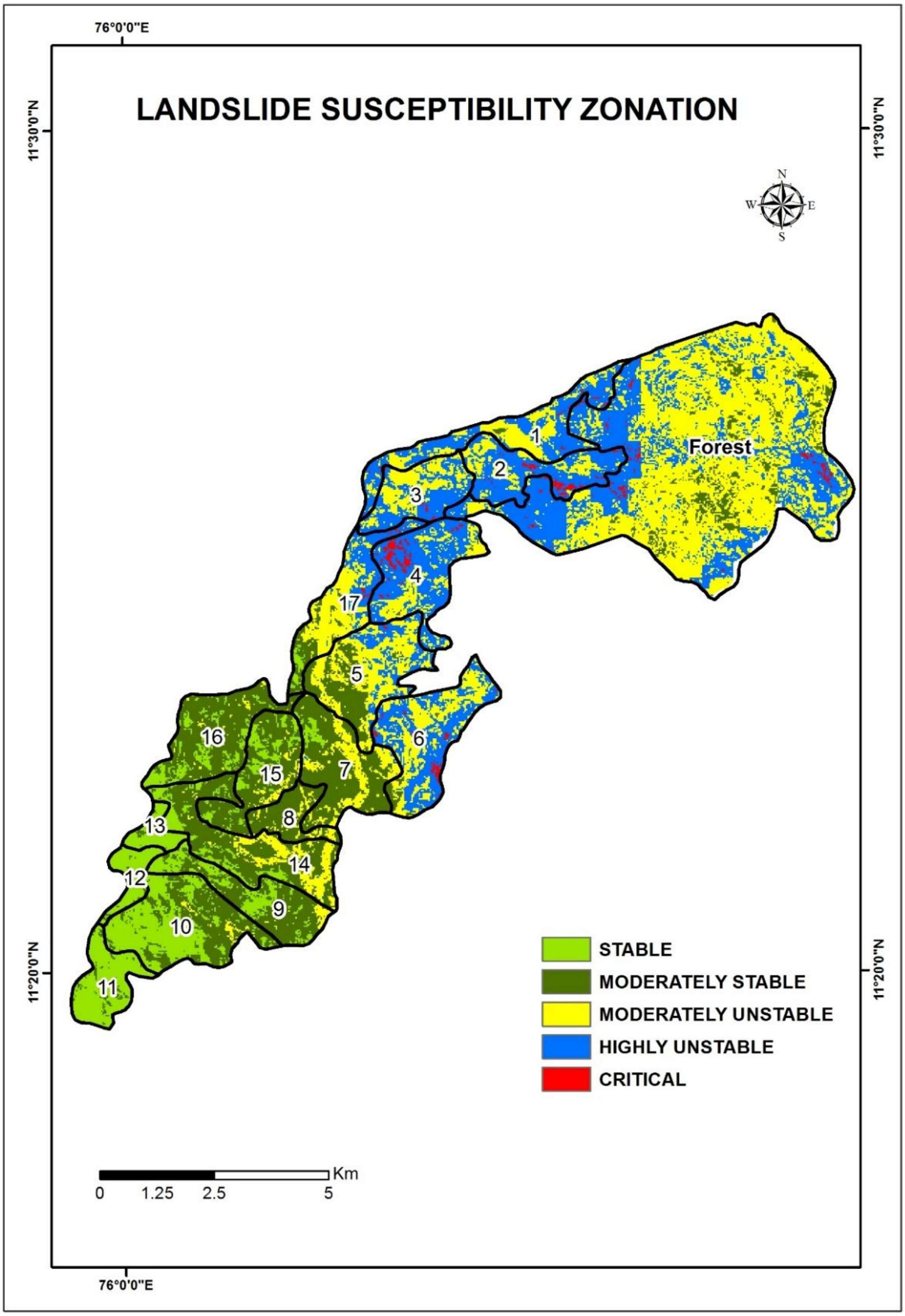

Fig. 4.11. Ward level susceptibility map of Thiuvambaadi Grama Panchayath**.**

CHAPTER 5
SITE SPECIFIC STUDIES

5.1 INTRODUCTION

Four failed locations have been selected for detailed study. Geological and geotechnical features of the profiles were studied in detail. The selected locations are Tharippapoyil, Manchuvad, Joy Road and Karimb. (Table 5.1)

Table 5.1. Geographical coordinates of the selected locations

S R No.	Location	Lattitude	Longitude	Date of event
1	Tharippapoyil	N 11^{O} 24.809’	E 076^{O} 03.306’	7- Aug -2012
2	Manchuvad	N 11^{O} 25.304’	E 076^{O} 03.154’	7- Aug -2012
3	Joy Road	N 11^{O} 25.387’	E 076^{O} 03.224’	7- Aug -2012
4	Karimb	N 11^{O}25’51.63”	E 076^{O} 05’ 6.63”	12–June- 2018

5. 2 METHODOLOGY

Geological and geotechnical attributes of the 4 sites were studied in detail. The samples were collected from weakest zones of each profile. The textural analysis was carried out in sedimentological laboratories. The geotechnical properties such as liquid limit, plastic limit, friction angle and cohesion were determined in geo technical laboratory of Department of Civil Engineering, Government College, Thrissur. The data with regard to discontinuities and orientations, lithology, type of vegetation and kind and extend of human interference were collected. The areas were slide occurred in the past and which falls under high hazardous zone has been selected for detailed stability analysis. Geological mapping is carried of two stations. Total Station Survey has been carried out in these locations (Plate 2). The mechanism of slope failures has been found out from the nature of the palaeoscar and pre-existing discontinuities. An attempt is also made to evaluate further chances of failure in these areas. Geometrical analysis of discontinuities and its relationship with the general hill slope is used for finding the chances of failure and failure type (Hoek and Bray, 1987). The existence of cracks and joints on slope will effect the pore water pressure and slope stability.

There fore slope stability analysis considering the cracks is very important (Mukhlisin and Khiyon, 2018).

Plate 2. Survey using Total station

Undisturbed samples were collected from each location (Plate 3). Samples were sealed in a polythene cover to avoid moisture loss during transportation (Plate 4). The samples collected from the field were subjected to textural analysis using a set of sieves. The clay silt fractions were determined in the laboratory. Plastic limit and Liquid limit were carried out as per IS Standards. Friction angle was determined by conducting direct shear test. Shear strength test were carried out in a saturated condition. A range of normal pressure viz. one Kilogram/ square cm, 3 Kilogram/ square cm were applied for general shear stress versus normal stress graph. Cohesion is determined from the graph plotted.

Plate 3. Sampling for the determination of geotechnical properties.

Plate 4. Core samples

5.3 MATERIAL PROPERTIES OF SLOPE MATERIALS

The liquid limit, plastic limit, friction angle, silt +clay percentage, cohesion of the samples were determined and presented in Table 5.2.

Table 5.2 Engineering properties of soil.

Sl No.	Location	Liquid Limit %	Plastic Limit %	Friction Angle	Silt + Clay %	Cohesion kN/m^2
1	Tharippapoyil	39	Non plastic	22	35.8	3.5
2	Manchuvad	39	Non plastic	21.04	28.10	3.2
3	Joy Road	36	Non plastic	40.3	28	7
4	Karimb	30	Semi plastic	24	39	3.1

5.4 THARIPPAPOYIL

Tharippapoyil is situated in Thiruvambadi Grama Pachayath. Debris flow occurred in 7^{th} August 2012 (Plate 5). Friction angle determined as 22^0 with cohesion 3.5kN/m2. Total silt clay percentage is 35.8. Non-plastic soil with liquid limit 39. General slope is 28° N 210.The prominent joints observed are 30° N 110, 35° N 270, 40° N 180, 44° N 160 and 10° N 20. The intersection of joint planes J2 and J4 fall with in the crescent shaped area, which is the potential slide surface. The chances of wedge failure are high in the locality (Fig. 5.1). Continuous rainfall for 2 or 3 days and it exceeds 120 mm chances of failure exist in the area. The factor of safety of the area can be lowered down by the infiltrating water and can cause further slope failures. Progressive failures may be initiated by water seeping into joints and cracks, raising pore water pressure and thus weakening joints (Bishop, 1967). Factor of safety less than in 1 in both dry and wet conditions.

Plate 5. Plate House collapsed due to the impact of debris flow at Tharippapoyil

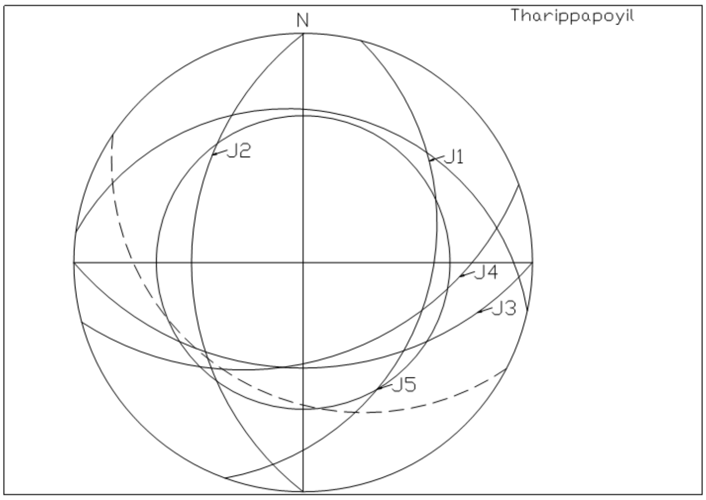

Fig. 5.1. β diagram of joint planes. Complete circle represents the friction angle. Dotted arc represents hill slope and continuous arc represents joint plane.

5.5 MANCHUVAD

It falls within the Thiruvambadi Grama Panchayath. As a result of debris flow on 7th August 2012, settlements were collapsed, agricultural farm spread over one acre was devastated (Plate 6). The slope is characterized by rubber, arecanut and coconut. The length of the flow is 400 m and general slope is 21° N 180. The host rock is charnockite. The thickness of overburden 3 to 3.5 m. Weathering has produced thick layer of overburden. A thin Lateritic layer is encountered in the weathered zone. The thickness of the top soil from 1 to 2 m. Relative relief is very high. Forest vegetation occupy at the top portion of the scar. The detailed geological map is presented in Fig. 5.2. The total length of the scar was 1.2 km. on the top portion width was 150 m and middle 90m and bottom portion width reduced to 30 m. Total height of the scar is 240m. rocks are outcropping along the boundary of the scar. Arecanut and rubber plantations present both sides of the scar. Five houses were completed damaged. Large rock boulders are seen in scar face. The total volume of debris moved through the scar is estimated as 10540 m^3. Geo technical an analysis shows that the friction angle determined as $21.04^0$and cohesion 3.2kN/m2. Total silt clay percentage is 28.10. Soil is non- plastic with liquid limit 39. Three joint planes are observed are 28° N 180, 32° N 185 and 60° N 175. The joint plane J2 parallel to the hill slope identified as potential surface for plane failure (Fig 5.3). Factor of safety less than in 1 in both dry and wet conditions.

Plate 6. The debris flow controlled by joint planes

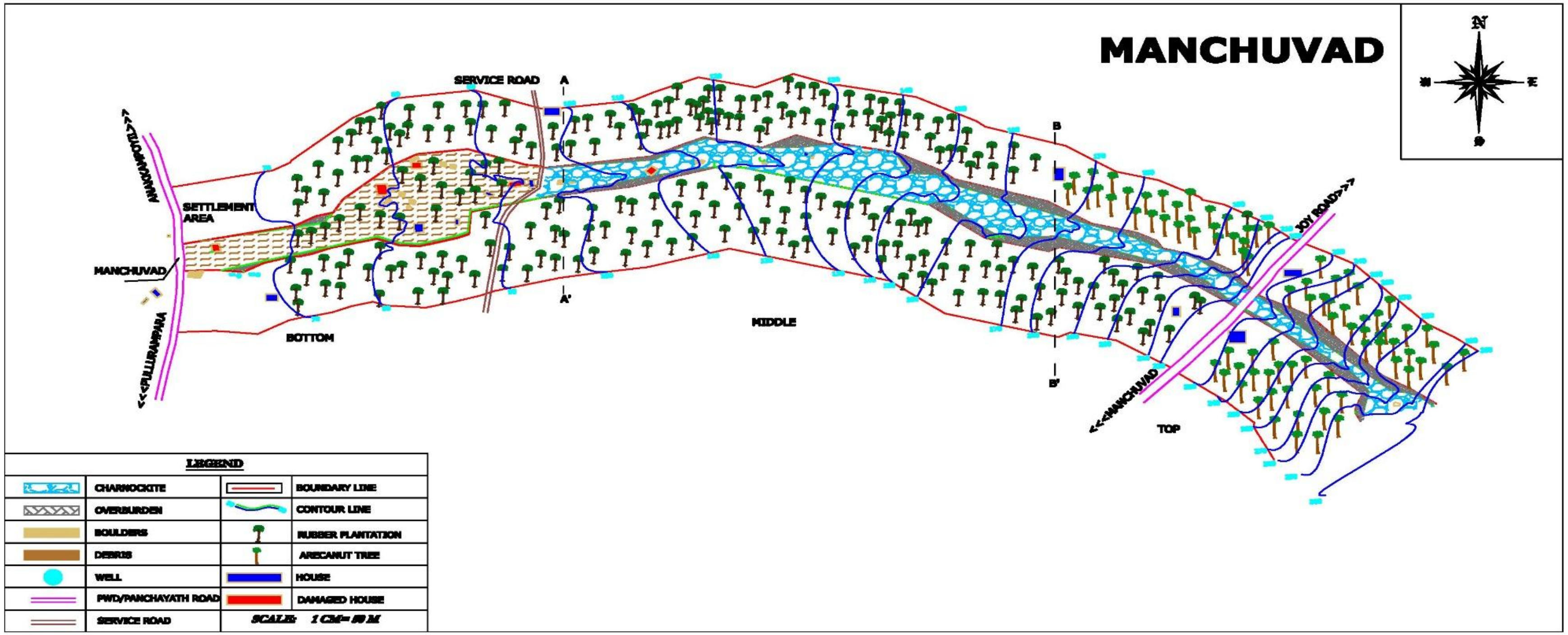

Fig 5.2 TSS MANCHUVAD

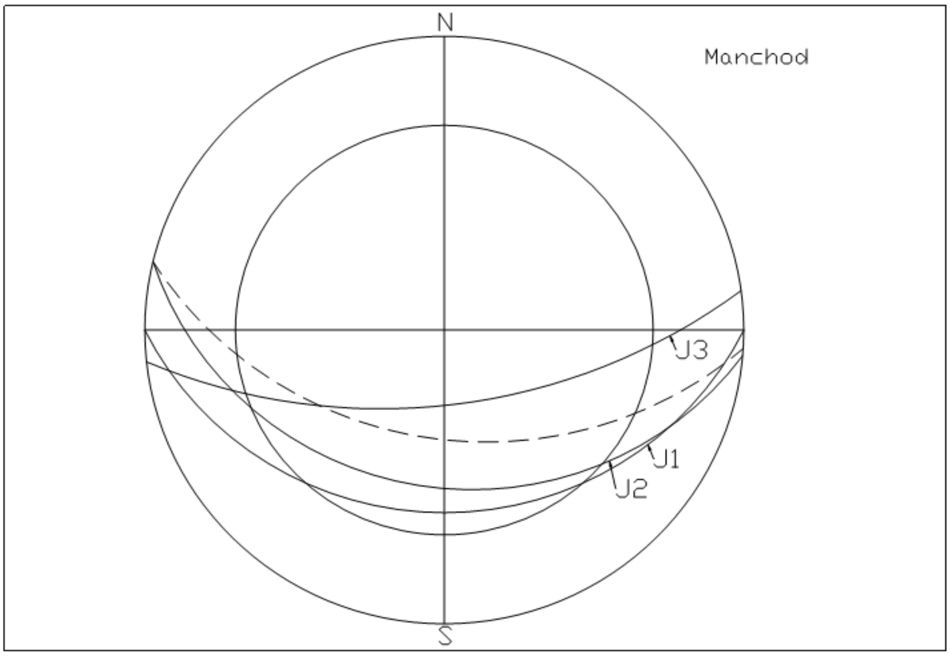

Fig.5.3. β diagram of joint planes. Complete circle represents the friction angle. Dotted arc represents hill slope and continuous arc represents joint plane.

5.6 JOY ROAD

It is situated above the Manchuvad where the slide initiated. General slope is 40° N 95. The thickness of the overburden is 4.5 m. Debris flow is associated with a perennial stream. Natural factors like slope, overburden thickness are the chief causative factors for the debris flow. Flow of the natural drainage is controlled by joints of the rock and slope of the terrain. It is considered as a rainfall triggered landslide. Naturally it can be considered as a profile falling under Highly hazardous zone. Charnockite and hornblende gne5.6 iss are the major rock types. Relative relief is very high. Friction angle determined as 28^0 with cohesion 7 kN/m2. Total silt clay percentage is 28. Soil is non plastic soil with liquid limit 36. Four joint planes are observed (35° N 120, 40° N 130, 50° N 70 and N 200). The joint plane J2 parallel to the hill slope is identified as surface for plane failure. The intersection of joint planes J2 and J4 falls just outside the crescent shaped area, which is the potential surface along which wedge failure can take place during wet condition (Fig 5.4). Factor of safety less than in 1 in both dry and wet conditions. However, the slope is found safe in dry condition because of irregular nature of joints and presence of vegitation**.**

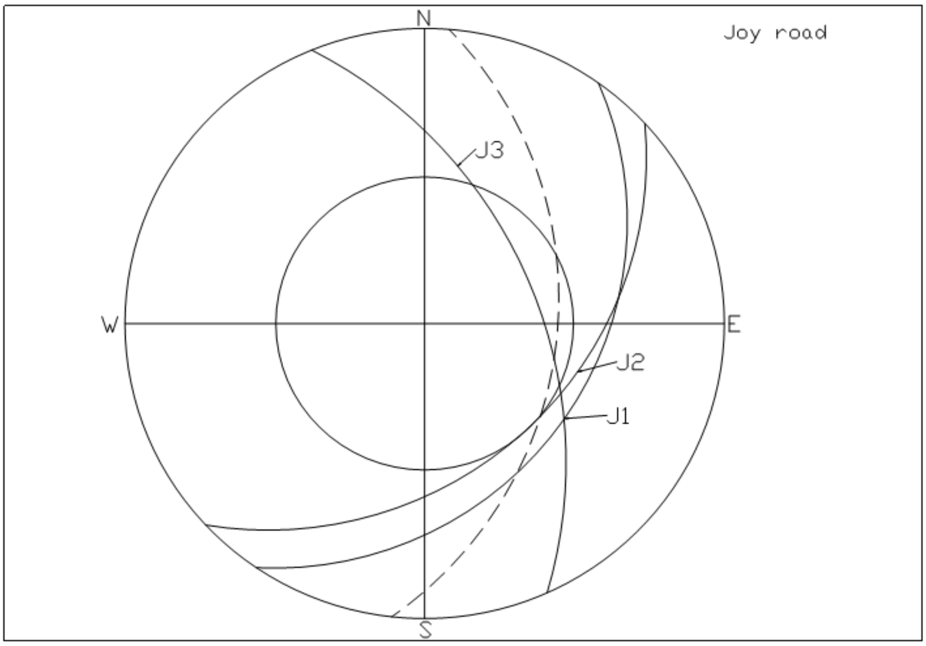

Fig.5.4. β diagram of joint planes. Complete circle represents the friction angle. Dotted arc represents hill slope and continuous arc represents joint plane.

5.6 KARIMB (POOMARATHINKOLLI)

It is located on N 11^{O} 25’51.63” E 076^{O} 05’ 6.63”. General hill slope of the area is 40. The debris flow occured in private land which was cultivated by cocco, jathi and arecanut. The debris run off distance of debris is 500 meters (Plate 7). Loss of 300 arecanut trees were reported. the road was damaged due to the debris flow. The width of the scar varied, 5 m at the top,18m at the middle part and toe portion 30 m. Isolated rock espousers are observed in scar face. The detailed geological map was prepared for the location (Fig. 5.5). Charnockite is the basic rock type of the area. Lateratisation at different degrees are observed. The soil is light brown with clay content slightly plastic when wet. Highly weathered charnockite was observed on scar face. Large rock boulders are also seen resting on the scar face. The total volume of debris flowed through the scar is calculated as 6340 m^3.

Plate 7. Debrisflow at Karimb

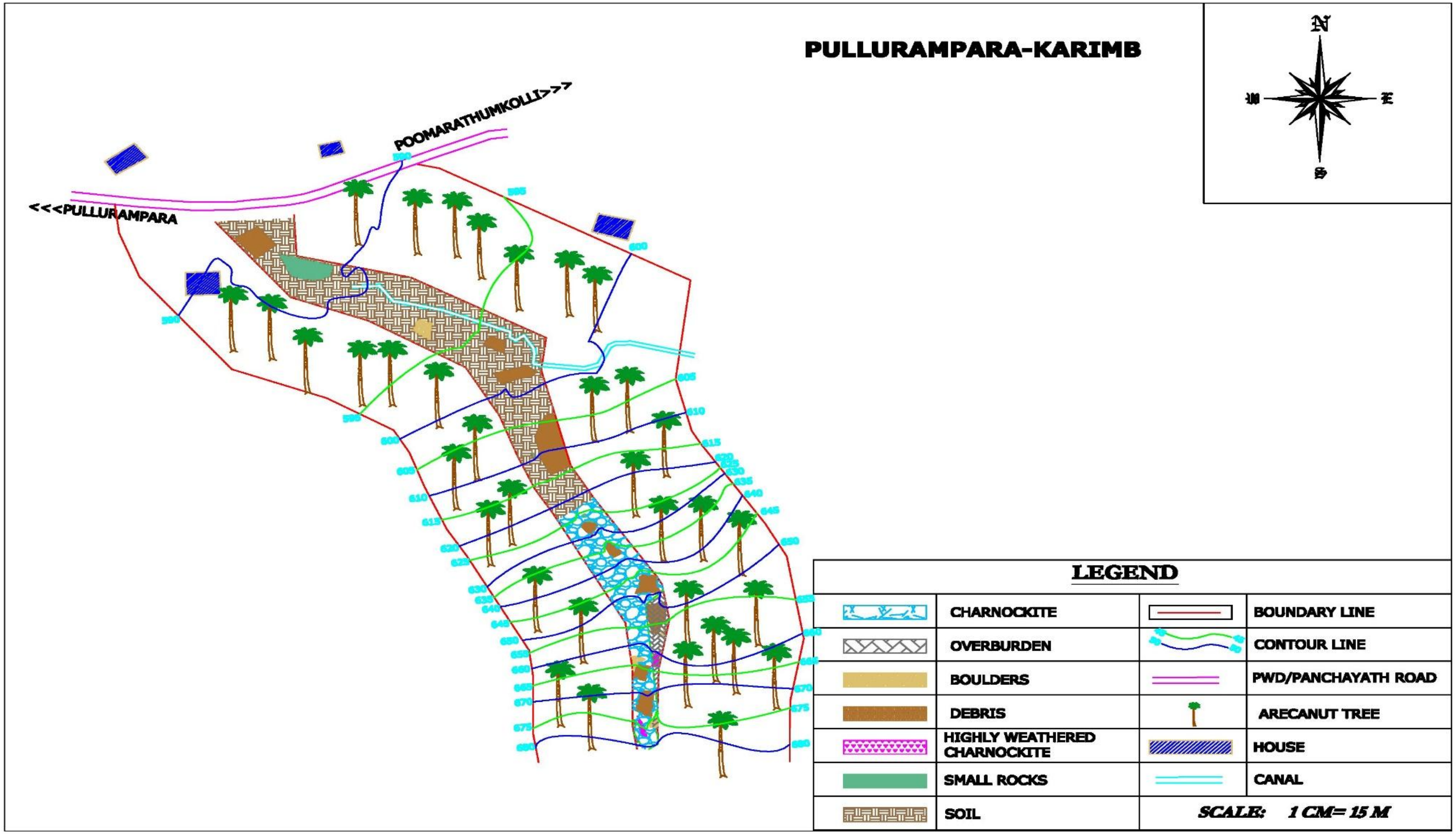

FIG 5.5 TTS KARIMB

CHAPTER 6
MONSOON FURY AND ITS IMPACTS 2018

According to the Indian Meteorological Department (IMD), from June 1 to Aug 2018 the state received 2394.4 mm rain compared to the normal 1701.4 mm. While 11 districts in the state were effected badly, a large portion of the population has been displaced or rendered homeless in the floods and landslides. Infrastructure has to rebuilt across the state. There are several locations that are presently inaccessible because of damaged or destroyed roads and bridges. Population currently in vulnerable region need to be relocated to safer zones. These are areas where ground fissures parallel and across the contours have developed because of premature landslides. They may get reactivated in the event of a prolonged rainfall. Identification of safe areas for settlements in high land areas is urgently needed to mitigate the landslide hazards.

Normally Kerala gets and 2039.6 mm from June to September in 120 days, but rainfall along south west monsoon season 2018 (1^{st} July to 28^{th} August, 2018) has been exceptionally high. Kozhikode district received 2941.7 mm (Actual rainfall) against normal rainfall of 2324.7 mm percentage of departure is 26.5 (1^{st} June to 28^{th} August, 2018).

Many research and academic institutions have identified many areas prone to landslide on the Western Ghats and had made recommendations. Anthropogenic activities such as disturbing the sensitive slopes and the natural flow of streams, indiscriminate quarrying, hydel projects and other developmental activities in the ecologically sensitive areas would have caused the disaster. A common cause of slope failures is by toe cutting of steep slopes. Indiscriminate construction of houses by cutting and leveling the slopes are very common in high lands and incidences of slab slides and subsidence due to soil piping (Tunnel erosion) has increased in the past two to three years. Slope failures reported in Kozhikode during 2018 flood is tabulated in Table 6.1

Table 6.1 Slope failures in Kozhikode district during 2018 monsoon

Location Name	Panchayath	Ward	Latt	Long	Type
Maripuzha (Muthappanpuzha)	Thiruvambadi	1	11 26 56.16	76 06 4.2	Debris slide
Vellarimala	Thiruvambadi	1	11 27 12.58	76 6 14.56	Debris flow
Maripuzha (Muthappanpuzha)	Thiruvambadi	1	11 27 9.0	76 6 4.97	Slump
Maripuzha (Muthappanpuzha)	Thiruvambadi	1	11 26 59.28	76 6 4.98	Slump
Maripuzha (Muthappanpuzha)	Thiruvambadi	1	11 26 51.14	76 5 44.93	Slump
Karimb (Poomarathukolli)	Thiruvambadi	2	11 2 51.63	76 05 6.63	Debris flow
Kodukkatupaara	Thiruvambadi	4	11 24 34.25	76 03 9.48	slump
Nayadampoyil	Koodaranji	4	11 21 48.49	76 05 43	Debris flow
Valaamthod	Koodaranji	1	11 20 31.52	76 6 28.02	Debris flow
Thazhe Kakkad	Koodaranji	5	11 19 52.77	76 6 3.27	Slump
Peedikapaara	Koodaranji	6	11 19 15.29	76 5 28.76	Slump
Kurishumala (Koombara)	Koodaranji	7	11 19 39.19	076 4 49.32	Debris flow
Thanikunnu Mala	Koodaranji	6	11 19 9.46	76 4 49.32	Debris flow
Mullampori	Koodaranji	1	11 21 31.16	76 2 47.30	Slump
Kuliraammutti	Koodaranji	10	11 21 30.94	76 03 25.02	Cracks
Kalpeeni	Koodaranji	9	11 20 39.66	76 3 40.40	Debris flow
Kakkayam dam site	Koorachundu	4	11 33 26.54	75 54 58.98	Slump
Kakkayam dam site	Koorachundu	4	11 3331.53	75 54 50.82	Slump
Kakkayam dam site	Koorachundu	4	11 33 28.40	75 54 56.29	Slump
Kakkayam dam site	Koorachundu	4	11 33 5.7	75 54 57.54	Slump
Near KSEB Surge	Koorachundu	4	11 33 4.3	75 54 56.18	Debris flow
Near KSEB Surge	Koorachundu	4	11 32 57.81	75 5451.73	Debris flow
Kakkayam dam site	Koorachundu	4	11 32 59.95	75 54 50.14	Slump
Kakkayam dam site	Koorachundu	4	11 33 21.80	75 54 53.89	Rockfall
Kakkayam dam site	Koorachundu	4	11 33 26.07	75 54 46.77	Rockfall
Kakkayam dam site	Koorachundu	4	11 33 26.20	75 54 45.59	Rockfall
Kakkayam dam site	Koorachundu	4	11 33 26.07	75 54 44.30	Debris flow
Kakkayam dam site	Koorachundu	4	11 33 28.72	75 54 36.16	Slump
Kakkayam dam site	Koorachundu	4	11 33 42.17	75 54 20.03	Slump
Kakkayam dam site	Koorachundu	4	11 34 3.03	75 53 55.09	Slump
Kakkayam dam site	Koorachundu	4	11 34 2.83	75 53 55.73	Slump
Kakkayam dam site	Koorachundu	4	11 33 21.31	75 54 18.29	Slump
Kakkayam dam site	Koorachundu	4	11 33 4.47	75 54 10.84	Debris flow
Illipillayi mala	Koorachundu	7	11 31 37.01	75 51 49.26	Debris flow
Poovathumchola (Thaniyaamkunnu)	Koorachundu	8	11 31 41.79	075 5124.93	Debris flow
Vattachira	Koorachundu	10,11, 12	11 31 26.99	75 50 38.39	Debris flow
Kallanodu	Koorachundu	6	11 31 21.93	75 53 17.86	Slump
26th Mile	Panangad	5	11 30 59.37	75 53 34.28	Slump

Thalayad	Panangad	5	11 30 8.78	75 53 34.11	Slump
25th Mile	Panangad	4	11 30 41.92	75 53 19.58	Slump
26th Mile	Panangad	4	11 30 45.43	75 53 18.23	Slump
Karinjolamala	Kattipara	14	11 28 0.07	75 55 13.21	Debris flow
Kuttiyadi Hairpin 10	Kaavilumpaara	4	11 43 45.64	75 48 47.34	Slump
Pakrathalam	Kaavilumpaara	4	11 43 46.08	75 48 50.91	Slump
Pakrathalam	Kaavilumpaara		11 43 46.17	75 48 50.92	Slump
Pannyeri	Vaanimel	9	11 48 `10.29	75 45 55.45	Debris flow
Pannyeri	Vaanimel	9	11 48 8.11	75 45 37.78	Slump
Koothadikunnu	Vaanimel	9	11 46 46.63	75 45 21.42	Slump
Aalummoola	Vaanimel	10	11 46 23.28	75 15 34.08	Slump
Valiyapaanam	Vaanimel	10	11 47 22.72	75 47 2.85	Debris flow
Valiyapaanam	Vaanimel		11 47 31.59	75 47 20.80	Debris flow
Vendekkampoyil	Kodenchery	3	11 27 35.37	76 2 18.03	Debris flow
Kodenchery (Bus stand)	Kodenchery	10	11 25 50.48	76 0 26.35	Slump
Chembattamel	koduvalli	15	11 21 11.23	75 55 15.81	Slump
Thamarassery Churam	Puthupaadi		11 30 48.11	76 01 17.04	Slump
Thamarassery Churam	Puthupaadi		11 30 41. 72	76 01 6.53	Slump
Thamarassery Churam	Puthupaadi		11 30 41	76 01 15	Slump
Thamarassery Churam	Puthupaadi		11 30 44.07	76 01 0.7	Slump
Thamarassery Churam	Puthupaadi		11 30 44.70	76 00 59.34	Slump
Thamarassery Churam	Puthupaadi		11 30 47.74	76 00 57.84	Slump
Thamarassery Churam	Puthupaadi		11 30 50.91	76 00 56.97	Slump
Thamarassery Churam	Puthupaadi		11 30 53.48	76 00 56.41	Slump
Thamarassery Churam	Puthupaadi		11 30 54.74	76 00 55.02	Slump
Thamarassery Churam	Puthupaadi		11 30 58.21	76 00 51.12	Slump
Thamarassery Churam	Puthupaadi		11 30 50.73	76 00 54.08	Slump
Thamarassery Churam	Puthupaadi		11 30 39.09	76 01 16.27	Slump
Thamarassery Churam	Puthupaadi		11 30 37.20	76 01 23	Slump
Thamarassery Churam	Puthupaadi		11 29 20.15	76 01 25.01	Slump
Kanappankund (Mattikunnu)	Puthupaadi	2	11 31 20.15	75 59 20.72	Debris flow
Eduthuvechakallu	Puthupaadi	2	11 30 21.47	75 59 29.03	Slump

During the year 2018, several landslides occurred in Thiruvambadi panchayath of which incessant and heavy rainfall events were the dominant reasons. Landslides in this area can be classified into slumps mostly in Maripuzha and Kodukkatupaara area. Debris flow and subsidence have occurred in Vellarimala and Maripuzha respectively (Plate 8). Several houses and buildings were damaged as a result of the slumping events. Loss of cultivated land including arecanut plantations was noted in Ward 2.

Plate 8. Debris slide at Maripuzha

In 2018, multiple debris flows and slumps occurred in Koodaranji panchayath especially in Nayadampoyil (Plate 9), Valaamthod, Kurishumala, Kalpeeni and Mullampori areas. Some houses and farm lands were completely destroyed in Ward 4 & 1. A large crack had developed in Ward 4 and 10. In Koombara (Kurishumala) area 1 house was completely and another was partially destroyed (Plate 10). Many houses developed cracks and suffered structural damages in Ward 1, 4, 9 and 10. Soil pipping was observed in Ward 10 of this panchayath. In Kalpeeni area, the total death toll of human casualties amounts up to 2 and a total of 13 houses were destroyed. Excessive rainfall and land use changes to monocrop plantations could have acted as major factors inducing landslides.

Plate 9: Slump at Nayadampoyil

Plate 10: Debrisflow at Kurishumala

slump and debris flow and rockfall events occurred in different parts of Kurachundu panchayath. The worst effected areas are Kakkayam dam site, Illpillayi mala and Kallanodu areas. Three houses were totally destroyed by landslide near Peruvennamuzhi reservoir and access roads to the dam site was completely destroyed as a result of the landslide (Plate 11).

Plate 11: A view of series of slope failures in near Kakkayam Dam site.

In Panangad panchayath, most of the slumps occurred in the 5th and 4th Wards namely 26th mile, Thalayad and 25th mile areas. In Kattipara panchayath, a major debris flow event occurred destroying 7 houses with a total death toll of 14. There are several houses which are partially damaged in the vicinity of the affected area and are at the risk of future landslide events. Quarrying and an artificial water tank were noted in the summit area of the scar.

Prolonged rainfall was the triggering factor for debris flow. The impoundment of water and its percolation increase the weight of the overburden and eventually led to the disaster.

Damages have occurred in the Kuttiyadi hairpin due to the slump in 2018. Roads and side walls damaged extensively have been destroyed as well (Plate 12). Heavy rains and land use change from existing wild vegetated to cultivated farm lands may be sited as the reason for such slump events.

Plate 12: The scar of the failure starting towards valley from the road edge.

In Vaanimel panchayath, slumps and debris flow occurred in Pannyeri, Koothadikunnu, Valiyapaanam and Aalummoola areas in 2018 (Plate 13). In Pannyeri area cultivated areas including plantations of arec anut, coffee, banana and coconut trees were uprooted and dumped into the stream below and a check dam was destroyed as well. Excessive rainfall and change of natural vegetation to farm lands have created instability to the region. Road cut cliffs had failed and destroyed the village roads and agricultural land along the valleys, particularly in Ward 10.

Plate 13: Debris flow at hill slope Valiyapaanam.

In Kodenchery panchayath a debris flow and slump event occurred in Vendekkampoyil and Kodenchery (Bus stand) area. Two houses were destroyed and nearly an acre of agricultural land was destroyed and a crack was developed in the ground in Ward 3. Water can infiltrate these cracks and develop pore pressure if heavy rainfall take place. This area is prone to further failure in future. In Ward 10 near to Kodenchery bus stand, a house was partially damaged due to slumping. Excessive rainfall is supposed to be a triggering factor for such events in these areas. In Koduvalli, slump occurred in Chembattamel. Evidences of soil piping is observed in the area (Plate 14).

Plate 14: Slump due to soil piping in Chembattamel

Puthupadi panchayath experienced number of disastrous slope failures. Multiple slumps occurred along Thamarassery churam and Eduthuvechakallu. A major debris flow event occurred in Mattikunnu (Ward 2) with a death toll of 1. A bridge was fully damaged and 3 were partially destroyed. 20 houses were partially damaged near Mattikunnu bridge (Plate 15). Excessive rainfall and change in agricultural practices are considered as the major reason for landslide events.

Plate 15: Accumulation of debris at Mattikunnu.

6.1 VALIDATION HAZARD ZONATION MAP

GPS location of all the slope failures are incorporated in the hazard zonation map inorder to examine the validity of the map (Fig. 6.1and Table 6.1). Different types of failures and their distribution in different zones are presented in table 6.2. It is found that majority of the slope failures are falling in highly unstable zones . 70.15 % of total events comes under the highly ustable and critical zones. 22.39 % of the total events was falls under moderately unstable category. The GPS location of the past events are incorporated in the map prepared by NCESS, 2010 (Fig. 6.2.). it is found that 62% of the locations fall under the high hazard and medium hazard zone.

Table 6.2: Distribution landslide events in different zones

	Stable	Moderately Stable	Moderately Unstsble	Highly Unstable	Critical
Cracks	0	0	1	0	0
Debris flow	0	1	10	5	2
Rockfall	0	2	0	0	1
Slump	0	2	4	21	17
Subsidence	0	0	0	1	0
Total	0	5	15	27	20

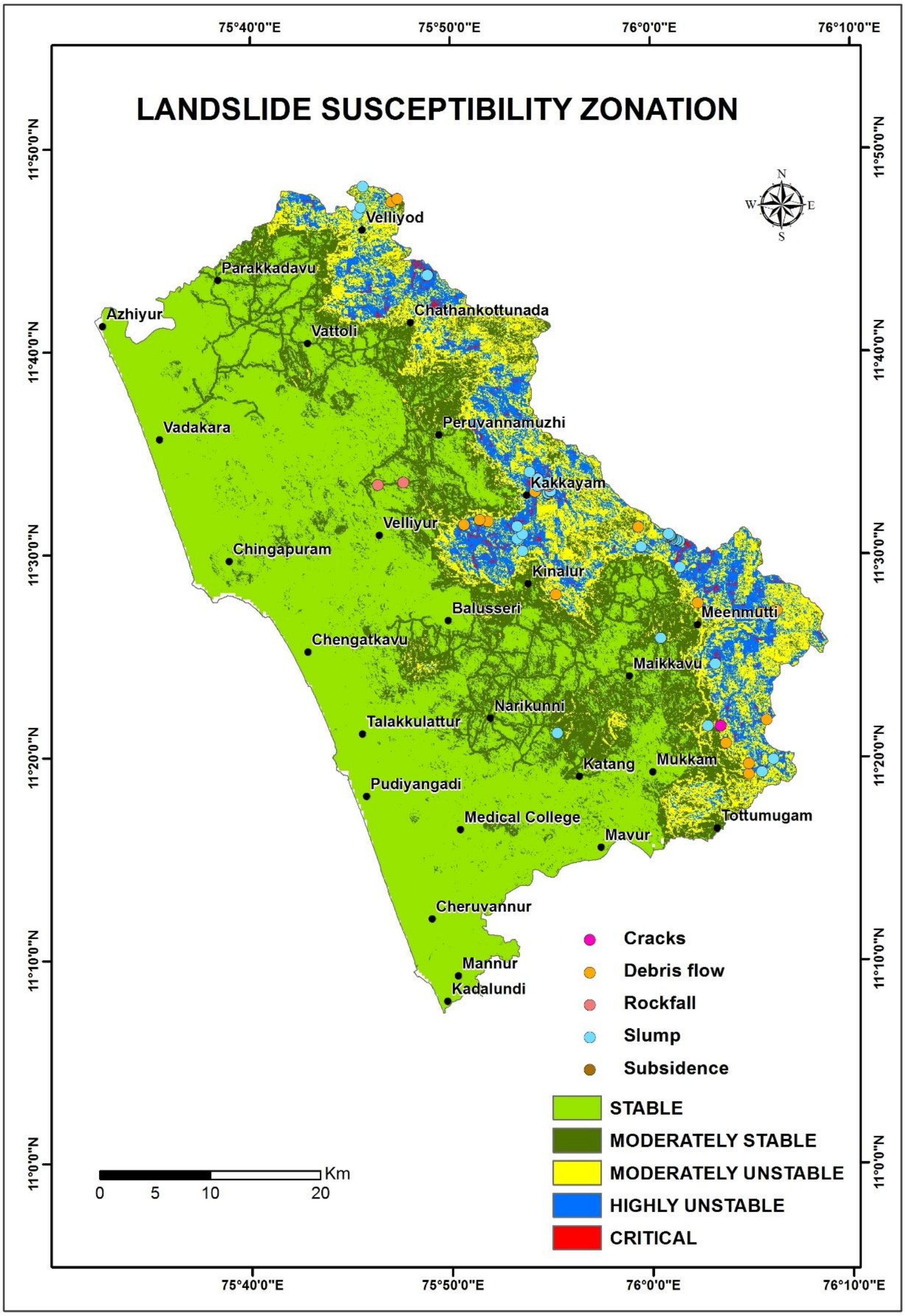

Fig. 6.1. Validation hazard zonation map (Kozhikode district)

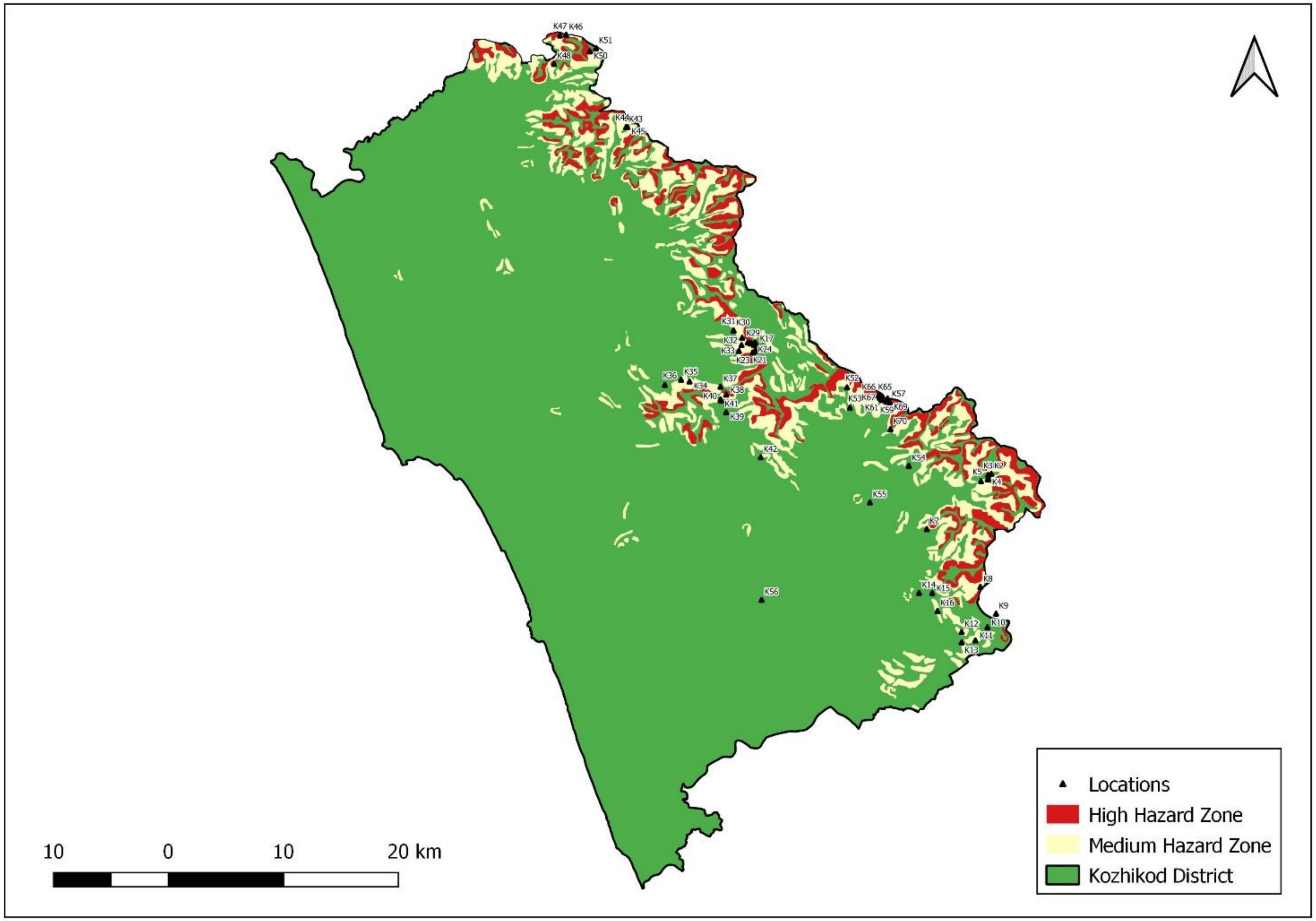

Fig. 6.2. GPS location of landslide events in hazard zonation map by NCESS

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

7.1 CONCLUSIONS

The landslide hazard zonation map prepared for Kozhikode district shows that Chakittapara, Kavvilumpara, Kodencheri, Koodaranji, Koorachundu, Puthupaadi and Thiruvambadi are the major panchayaths with high percentage of highly unstable and critical areas. Detailed study of Thiruvambadi GP was carried out to demarcate the areas sensitive to slope failures. The areas experienced 35 minor and major landslides on august 7, 2012 with a death toll of 8. The multiple debris flows occurred in Pullurampara. A landslide hazard zonation map was prepared for the Grama Panchayath based on the paleo slides. In Thiruvambadi GP, 35.67 % of the total area falls under moderately unstable areas and 26.54 % of the area falls under highly unstable area. 0.96 % of the area is identified as critical. Landslide Susceptibility of 17 wards were calculated. In this panchayath, 23.69 % of the total area falls under moderately unstable areas and 23.79 % of the area falls under highly unstable area. 1.04 % of the area is identified as critical. Ward 1 and & 2 have maximum area under highly unstable and critical category.

Detailed geotechnical and geological studies were carried out for Tharippapoyil, Manchuvad, Joy Road and Karimb. The liquid limit of the soil ranges from 30-39. The soil nature ranges from semi plastic to non-plastic. Friction angle ranges from 21.04 to 40.3. silt +cay content varies from 28 to 39%. Cohesion ranges from 3.1 to 7 Kn/m2. The stability analysis shows that chances of failure exist in all these areas. The attitude joints play an important role in slope failures in the area. The thickness of the overburden ranges 2 to 3m. The overburden slide or flow down at the interface of overburden and underlaying rock. Impoundment of water and wrong landuse practices on these slopes can induce landslides. Chances of failure exists along road cut cliffs. The need for a detailed geotechnical study is required to asses the stability of cut cliffs along the roads. An inventory of landslides, slump, debris flow and soil piping happened in Kozhikode district during South West Monsoon 2018 is also prepared.

Anthropogenic activities such as disturbing the sensitive slopes and the natural flow of streams, indiscriminate quarrying, hydel projects and other developmental activities in the ecologically sensitive areas have contributed to the disaster. A common cause of slope failures is by toe cutting of steep slopes. Indiscriminate construction of houses by cutting and leveling the slopes are very common in the area. Slabslides and subsidences due to soil piping (Tunnel erosion) has increased in the area.

GPS location of all the slope failures happened during 2018 South West Monsoon period were incorporated in the hazard zonation map inorder to examine the validity of the map. It is found that majority of the slope failures are falling in highly unstable zones. 70.15 % of total events comes under the highly unstable and critical zones. 22.39 % of the total events was falls under moderately unstable category. The GPS location of the past events are incorporated in the map prepared by NCESS, 2010. It is found that 62% of the locations fall under the high hazard and medium hazard zone. LSGs and local people must be aware of the landslide hazard zonation map and they must take care when slope modification is carried out construction and quarrying cannot be permitted in high hazardous zones.

7.2 RECOMMENDATIONS

- Total avoidance of settlement and developmental activities, quarrying in critical and high-risk zones should be made mandatory.

- Chances of slope failure exist in already failed areas. Therefore, at most care to be taken in these localities if you are planning for the new settlement.

- From the highly unstable areas peoples should evacuated if rain persist for 2 or 3 days. Rainguage must be installed in such critical zones and people must be warned when threshold values exceed.

- Rain pits, blockage of natural drainage must be discouraged in the risky zones. Only after the geotechnical studies such structures may be constructed.

- All failures have taken place at the close proximity to pre existing natural drainages and therefore one must be cautious when collecting water during continuous rainfall spells in monsoon period. A buffer zone adjoining to natural drainage channels (minimum 200m) should be kept free without settlement.

- Proper drainage must be provided before the onset of monsoon in critical areas and blockage if any, must be cleared.

- Afforestation must be practiced in already failed forest areas.

- Ward level awareness programme and first aid training must be carried out in critical areas.

- A disaster management team should be formed in Panchayath and Ward level to respond to the post disaster situation. (First aid, Rescue and Relief).

- Proper fund must be assigned to local government bodies for disaster preparedness which has critical slopes. Local bodies must have budgetary provisions to handle the situation.

- Suitable areas for rehabilitation of affected people must be found out by experts.

- Retrofitting needed for many partially damaged houses. Geotechnical experts have to visit the area and make evaluation regarding the safety of these houses.

- Proper measures have to be taken to overcome the water shortage situation likely to arise during summer season.

- The livelihood of the people should be protected for a short period.

- A microlevel landslide hazard zonation study based on geological and geotechnical characters should be carried out based on inventory of slope failures prepared by various agencies. Risky areas must be delineated and people must be taught do’s and don’ts in these zones.

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