LANDSLIDE HAZARD ZONATION OF NILAMBUR TALUK USING REMOTE SENSING

By

ASLA K

(2011-20-114)

THESIS

Submitted in partial fulfillment of the requirement for the degree

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DECLARATION

I, hereby declare that the thesis entitled **"LANDSLIDE HAZARD ZONATION OF NILAMBUR TALUK USING REMOTE SENSING"** is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, fellowship or other similar title, of any other University or Society.

Vellanikkara,
Date: 10/3/17

ASLA K
(2011-20-114)

CERTIFICATE

Certified that this thesis entitled **"LANDSLIDE HAZARD ZONATION OF NILAMBUR TALUK USING REMOTE SENSING"** is a record of research work done independently by Ms. Asla K. under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

Place: Tavanur
Date: 10/3/17

Er. Vishnu B.
(Major Advisor, Advisory Committee)
Associate Professor
Department of Irrigation and Drainage
Engineering, KCAET, Tavanur

CERTIFICATE

We, the undersigned members of the advisory committee of Mrs. Asla K. (2011-20-114), a candidate for the degree of **B.Sc.-M.Sc. (Integrated) Climate Change Adaptation**, agree that the thesis entitled **"LANDSLIDE HAZARD ZONATION OF NILAMBUR TALUK USING REMOTE SENSING"** may be submitted by Mrs. Asla K., in partial fulfillment of the requirement for the degree.

Er. Vishnu B.
(Chairman, Advisory Committee)
Associate Professor
Department of Irrigation and Drainage Engineering
KCAET, Tavanur

Dr. E. K. Kurien
(Member, Advisory Committee)
Special Officer
ACCER, K.A.U. ,
Vellanikkara

Er. Shivaji K.P.
(Member, Advisory Committee)
Assistant Professor
Department of FPME
KCAET, Tavanur

Dr. Shyla Joseph
(Member, Advisory Committee)
Associate Professor
ARS, Mannuthy

EXTERNAL EXAMINER
BABU MATHEW
SENIOR PRINCIPAL SCIENTIST
CWRDM, KUNNAMANGALAM
KOZHIKODE

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Asla K.

Dedicated to my parents

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SYMBOLS AND ABBREVIATIONS

AHP	Arithmetic Hierarchy Process
BIS	Bureau of Indian Standards
CRRI	Central Road Research Institute
DEM	Digital Elevation Model
E	East
FR	Frequency Ratio
GIS	Geographic Information System
GRASS	Geographic Resources Analysis Support System
GSI	Geological Survey of India
IAEG	International Association for Engineering Geology and the Environment
ILWIS	Integrated Land and Water Information System
InfoVal	Information Value
ISG	Indian Society of Geomatics
ISRO	Indian Space Research Organisation
Km^2	Square Kilometer
KSLUB	Kerala State Land Use Board
LHZ	Landslide Hazard Zonation
LSI	Landslide Susceptibility Index
LSZ	Landslide Susceptibility Zones
MCA	Multi-Criteria Analysis
MLR	Multiple Logistic Regression
Mt.	Mount
N	North

NDVI	Normalised Difference Vegetation Index
NE	North East
NRSC	National Remote Sensing Centre
NW	North West
ROC	Receiver Operating Characteristics
RS	Remote Sensing
S	South
SE	South East
SMCE	Spatial Multi Criteria Evaluation
SPSS	Statistical Packages for the Social Sciences
Sq.Km.	Square Kilometer
SW	South West
USGS	United States Geological Survey
W	West

CHAPTER 1

INTRODUCTION

The term landslide includes a broad range of different types of motion whereby earth material is dislodged by falling, sliding and flowing under the influence of gravity. In fact, mass movements such as landslides are natural phenomenon that causes landscape changes, threat to life, destruction of property, damage to natural resources, developmental projects and essential commodities. Landslides tend to dislocate objects that they come in contact with its way by uprooting trees, destroy utility lines, such as telephone, electricity and sewages and destruction of road, railway and bridges. In recent times the occurrence of landslides has increased in both frequency and intensity resulting from a combination of several attributes including geological, geomorphological, morphometric, climatic, and anthropogenic that directly or indirectly cause slope instability. This trend is expected to continue in future also due to increased unplanned urbanisation and development, continued deforestation and increased regional precipitation as a result of changing climatic conditions in landslide prone areas. In earlier periods too little considerations were given to the potential problems in land use planning and slope stability analysis. Nowadays, greater awareness of landslide problems had led to significant changes in the control of development on unstable land.

In India, the Himalayas and Western Ghats are the most vulnerable areas to landslides. Annual recurring landslides of Himalayas and hill ranges of North-East belongs to the very high magnitude/frequency types whereas those of Western Ghats and Nilgiris are of moderate intensity and that of Eastern Ghats and Vindhyan areas are of low intensity types. As compared to the Himalayas, landslides are less in number in Western Ghats areas, but they are frequent enough to warrant deep and systematic research and control in these areas. Majority of the landslides in India falls under the category of rainfall induced landslides. The influencing factors are rainfall, runoff, percolation rate, seasonal changes in moisture content, degree of saturation with depth etc.

In Kerala, landslides commonly occur in localised areas of the Western Ghats region where the slope is steep and the soil is over saturated as a result of prolonged rainfall along with unscientific land use, drainage and construction practices. In Kerala landslides are a recurring phenomenon during monsoon periods, especially in hilly tracts of Idukki, Malappuram, Palakkad and Wayanad districts. The study by Kerala State Disaster Management Authority reveals that 1848 km^2 or 4.71% of the state is under high hazard category and 3759 km^2 or 9.77% is under low hazard category. It is estimated that landslides had resulted about 100 fatalities and rendered about 600 families homeless along the Western Ghats (Kuriakose *et al.*, 2009) whilst floods and landslides together have caused an estimated damage of 12 billion euros in Kerala in 2007 alone (Murali Kumar, 2007). One of the prime causes of landslide occurrences in Kerala is conversion of natural forests to agricultural lands. Earlier studies report that rise in landslide frequency in Kerala is seen since 1940s by the onset of deforestation by migrant farmers to hilly areas. Land-use practices related to rubber (*Hevea brasiliensis*) plantations may have aggravated the situation. Stability studies on certain hill slopes in Western Ghats show a concentration of landslides in areas where developmental activities have been intensive. Population pressures and urbanisation leading to the conversion of natural forests to agricultural fields results in severe slope instability.

Area selected for this study is Nilambur Taluk of Malappuram District and its majority falls under Western Ghats region. Nilambur Taluk is one among the five most landslide prone taluks of the state. The most common type of landslides in Kerala is debris flows.

Hence, identification of landslide-prone areas is essential for safer strategic planning of future developmental activities. Therefore, Landslide Hazard Zonation (LHZ) becomes important. Landslide Hazard Zonation map divides the land surface into zones of varying degree of instability based on landslides inducing causative factors. A landslide hazards map depicts an area prone to landslide by integrating the cause and triggering factors of the landslide with data concerning the past distribution of slope failure. In general terms, it is used to describe a wide range of land forms and process involving the movement of the soil and rock down the slope under the influence of gravity. Such maps help to identify the geo-environmentally favourable sites for future developmental activity, particularly in the hilly regions. Landslide hazard map is very useful in estimating, managing and mitigating landslide hazard for a region. The relative importance of factors (weights) and their categories (ratings) plays a vital role in LHZ studies.

Remote sensing is gaining importance in landslide studies due to its wide coverage and increasing spatial and temporal resolution. Remote sensing has been widely adopted in landslide mapping for rapid response and recovery after hazard occurrence by government agencies as well as research community. Recently, landslide hazard mapping has been made possible due to the accessibility and availability of variety of remote sensing data and thematic layers as causative factors data using GIS.

Thus, remote sensing can play a role in the production of a landslide hazard zonation map and in the generation of thematic maps related to landslide occurrences. Several previous works have showed the potential of remote sensing data both in the extraction of causal factors which are linked to landslide occurrences and finding of landslide areas. According to Brabb (1993) at least 90 % of landslide losses can be avoidable if the problem is recognized before the development or deforestation begins. Hence, there is a dire need for identification of existing and potential unstable slopes.

In this context, the study was undertaken with the following objectives:

- Preparation of landslide hazard zonation map for Nilambur Taluk using remote sensing.
- To suggest mitigation measures for controlling landslides.

CHAPTER 2

REVIEW OF LITERATURE

2.1 DEFINITION

The most popular definition of landslides is “the movement of a mass of rock, debris, or earth down a slope” (Cruden, 1991) which includes different types of slope failure processes observed in nature. Thornbury (1954), defined landslide as a “gravitative transfer producing immediate and perceptible modification of earth’s surface”. Geological survey of India defines landslide as a process involving downward and outward movement of a part of slope forming material along a definite plane i.e. plane of failure. It is caused due to shear failure along this plane. According to United States Geological Survey (USGS) the term "landslide" describes a wide variety of processes that result in the downward and outward movement of slope-forming materials including rock, soil, artificial fill, or a combination of these. According to Varnes and IAEG Commission on Landslides and other Mass-Movements (1984) landslide hazard can be defined as the probability of occurrence of a potentially damaging landslide event within a given area in a given period.

Landslides are disastrous which can cause massive destruction to life and property and may lead to large-scale landscape transformations (Chandel *et al.*, 2011). They are one of the complex natural phenomena that are hard to model and simulate. For forecasting occurrence of landslides in near future in an area, comprehensive knowledge on causative factors, history, expected frequency of land sliding character and magnitude in an area is necessary (Rai *et al.*, 2014). Landslides are a part of the earth surface processes, while considered as one of the most dangerous natural hazards that may follow triggering events (e.g., extreme rainfall and earthquakes) in mountainous areas, causing loss of human life and damage to property (Tien Bui *et al.*, 2012).

2.2 TYPES OF LANDSLIDES

The term "landslide" describes a wide variety of processes that result in the downward and outward movement of slope-forming materials including rock, soil, artificial fill, or a combination of these. The materials may move by falling, toppling, sliding, spreading, or flowing. Figure.1 shows an illustration of a landslide, with the commonly accepted terminology describing its features.

2.2.1 Falls

Abrupt detachment of soil, rock, or both from a steep slope along a surface by means of falling, bouncing or rolling (Highland and Bobrowsky, 2008). A collection of landslide material is found at the base of the slope because of a fall. Gravity mechanical weathering and presence of interstitial water are some influencing factors of falls (Wahono, 2009).

2.2.2 Flows

Flows involve movement of material downward a slope in the form a fluid. Sub types of flows are earth flow, mudflow, debris flow and debris avalanche (Anbalagan, 1992). The flow of material along its way can pick up trees cars and even houses.

2.2.2.1 Debris flow

When the materials on a slope become saturated with water, soil along with rock, organic matter combined with water flow downslope. They are often called as mudslides due to the presence of fine materials (Anbalagan, 1992) Debris flows can even cause death

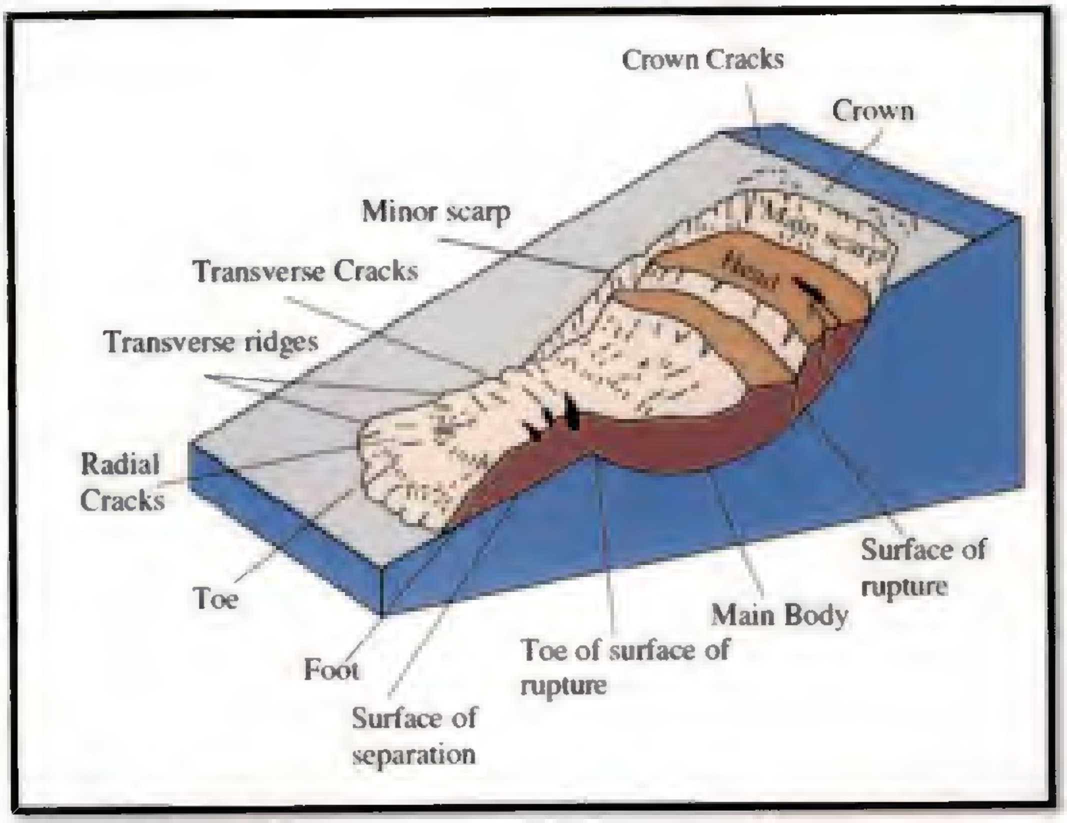


Fig 1. A simple illustration showing commonly used labels for the parts of a landslide

2.2.2.2 Mud flow

When slopes are covered by water saturated soils or fine grained sedimentary deposits, an intense rainfall or melting of large amount of snow or ice can result in a mud flow.80% of solid material involved are of less than silt size (0.06 mm) (Girty, 2014). They are faster than earth flows and contain finer particles than debris flows.

2.2.2.3 Earth flow

Saturated soil moves down the slope leaving a bowl shaped depression on the sloping land surface. The speed of earth flow varies from 0.17 to20 km/hr depending upon the water content (Cruden and Varnes, 1996). The greater the water content, the faster they travel. Earth flows are generally slower than mudflows

2.2.2.4 Debris avalanche

Debris avalanche is formed when an unstable slope is collapsed and the resulting debris is moved far away from the slope. In some cases, snow and ice contributes to the movement (Davies, 2014).

2.2.2.5 Creeps

According to Cruden and Varnes (1996), creeps are marked by slow and steady downward movement of slope-forming soil or rock. Creeps are indicated by curved or bent segments of tree trunks, restraining walls, fences, roads, or railroad tracks along with the down slope tilting of layered rocks and tilted telephone poles. Moves usually less than 1 meter (0.3 foot) per decade.

2.2.2.6 Lahar

Mudflow or debris flow that originates on the slope of a volcano, usually triggered by heavy rainfall eroding volcanic deposits, sudden melting of snow and ice due to heat from volcanic vents or the breakout of water from glaciers, crater lakes, or lakes dammed by volcanic eruptions.

2.2.3 Lateral spreads

Lateral spreads commonly occur on very gentle or flat slopes and result in nearly horizontal movement of earth materials. Failure occurs because of liquefaction, the process by which saturated, loose, cohesion less sediment is transformed from a solid into a liquid state. Such changes are induced by ground shaking during earthquakes (Schuster and Highland, 2003).

2.2.4 Slides

Slides are either called as slumps. Slides are movements of masses on failure surfaces or on the zone of shear strain. Failure surfaces are either (a) curved in concave upward sense (rotational slides) or (b) nearly planar (translational slides).

2.2.4.1 Rotational slides

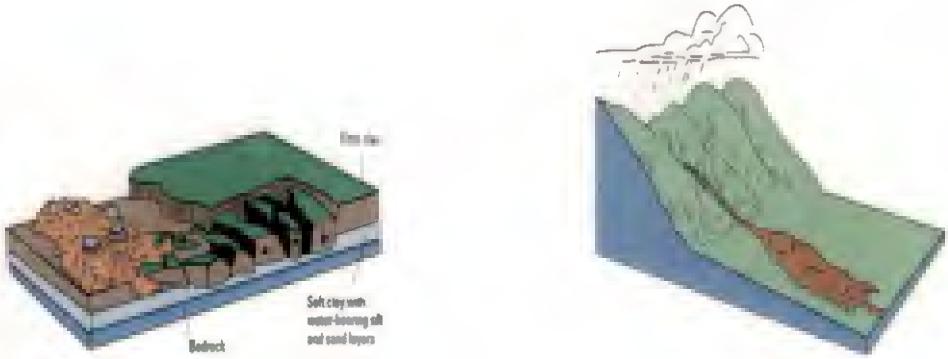
According to Cruden and Varnes (1996) in rotational slides, the surface of rupture is curved concavely upward (spoon shaped) and the slide movement is more or less rotational. Rotational slides occur most frequently in homogeneous materials.

2.2.4.2 Translational slides

If the detached landmass slides along a relatively planar surface with little rotational movement or backward tilting, then the resulting slide is called translational. Relatively common planar surfaces of failure are joints or bedding planes.

2.2.5 Topples

A topple is distinguished by the forward rotation of a mass of soil or rock about some pivotal point, below the centre of gravity of the displaced soil or rock. Sometimes toppling occurs due to the actions of gravity or due to fluids/ice in the cracks (Prabu, 2013). Topples consist of debris, rock or earth materials.

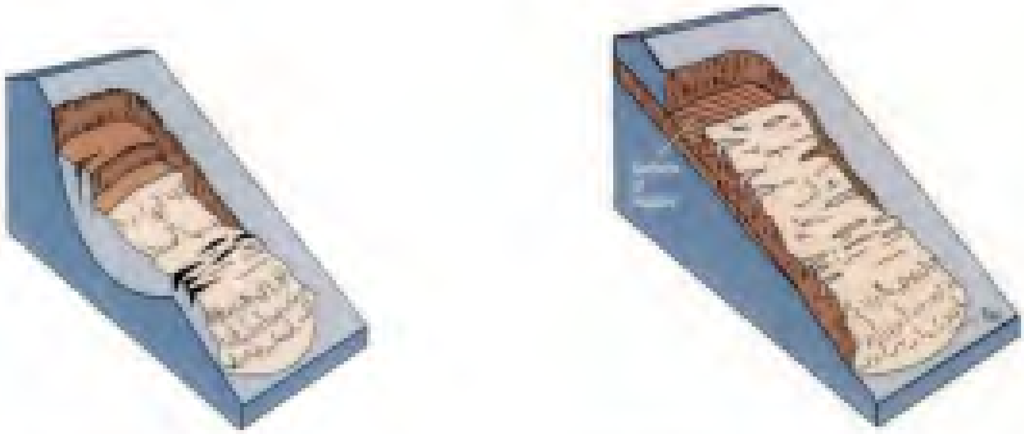


Lateral spread

Debris flow

Rock fall

Topple



Rotational slide

Translational slide

Fig 2. Figures showing different types of landslides

2.3 CAUSES OF LANDSLIDES

Many factors contribute to slides, including geology, gravity, weather, groundwater, wave action and human actions. There are two primary categories of causes of landslides: natural and anthropogenic. Sometimes, landslides are made worse, by a combination of the two factors (Highland, 2004).

2.3.1 Natural factors

2.3.1.1 Gravity

According to Kusky, (2008), gravity is the main driving force behind the mass wasting processes. Gravity will pull on material and force to downhill. Gravity works more effectively on steeper slopes, but slopes that are more gradual are also vulnerable.

2.3.1.2 Geological factors

Many slides occur in a geologic setting that places permeable sands and gravels above impermeable layers of silts and clay, or bedrocks (Cruden, 1993). Water seeps downward through the upper materials and accumulates on the top of the underlying units, forming a zone of weakness.

2.3.1.3 Heavy and prolonged rainfall

Slope saturation by water is a primary cause of landslides. Saturation can occur in the form of intense rainfall and snowmelt leading to changes in groundwater levels, surface-water level changes along coastlines, earth dams, and in the banks of lakes, reservoirs, canals, and rivers. Rise in water table can cause unstable slopes (Jishnu, 2015).

2.3.1.4 Earthquakes

Seismic activities are always a main cause of landslides all over the world. When earthquakes occur on areas with steep slopes, most times the soil slips causing landslides. Furthermore, ashen debris flows caused by earthquakes can also trigger mass movement of soil (Highland and Bobrowsky, 2008).

2.3.1.5 Forest fire

Heavy loss of vegetation due to forest fires can trigger landslides (Jishnu, 2015).

2.3.1.6 Volcanoes

Some of the most devastating types of landslides are due to volcanic activity. Volcanic edifices are young, unconsolidated, and geologically weak structures that in many cases can collapse and cause rockslides, landslides, and debris avalanches (USGS, 2004).

2.3.1.7 Waves

Wave action erodes the beach or bank and cut into slopes, and this sets the stage for future slides.

2.3.2 Anthropogenic factors

Population increase and expansion of neighbourhood lands to cities and commercial spaces are the primary contribution of humans to the occurrence of landslides. Landslides are initiated by unscientific or changing drainage patterns, destabilization of slopes, deforestation, over steepening of slopes by undercutting the bottom and loading the top of a slope by soil or other component material that may exceed the shear strength to withhold the material. However, landslides may also occur in once-stable areas due to other human activities such as irrigation, lawn watering, draining of reservoirs (or creating them), leaking pipes, and improper excavating or grading on slopes (Ventura, *et al.*, 2013).

Cruden and Varnes (1996) classified landslide causal factors into two: preparatory and triggering factors. They also classified causal factors into geological, morphological, physical and human induced changes. This is the widely used classification.

Table 1. Causal factors for landslides

Geological factors	**Morphological factors**
Weak materials	Tectonic or volcanic uplift
Sensitive materials	Glacial rebound
Sheared materials	Fluvial erosion of slope toe
Jointed or fissured materials	Wave erosion of slope toe
Adversely oriented mass discontinuity	Glacial erosion of slope toe
Adversely oriented structural discontinuity	Erosion of lateral margins
Contrast in permeability	Sub terrain erosion
Weathered materials	Deposition loading slope or it's crest
	Vegetation loss
Physical factors	**Human induced factors**
Intense rainfall	Excavation of slope and toe
rapid snow melt	Loading of slope or it's crest
Prolonged exceptional precipitation	Draw down of reservoir
Rapid draw down of floods and tides	Deforestation
Earthquake	Irrigation
Volcanic eruption	Mining
Freeze and thaw weathering	Artificial vibration
Shrink and swell weathering	Water leakage from utilities

Source: Cruden and Varnes, 1996

2.3.3 Preparatory factors

Without actually initiating the landslides, preparatory factors makes the slope more susceptible to failure. Examples include long-term effect of erosion at the base of a slope, weathering, land use drainage pattern, lithology, geological structure etc.

2.3.4 Triggering factors

Triggering factors are those factors that actually initiate landslide events such as rainfall events, earthquake and volcanic eruptions. Rainfall is the most common triggering factor (Lee and Jones, 2004).

2.4 GLOBAL AND NATIONAL SCENARIO

Landslide is an important natural disaster that affects most of the hilly region around the globe. Recent studies identified certain countries as high landslide prone countries including Colombia, Tajikistan, India, China and Nepal. In these countries, number of people killed per year per 100 sq.km is estimated to be more than one. Single landslide with highest number of fatalities is reported in Kansu province of China in 1920 and was an earthquake-induced landslide. An earthquake-triggered debris avalanche was reported in 1970 on the slopes of Mt. Huascara, Peru, with fatality of 18,000 people. About 30,000 people were killed in a landslide caused by a heavy storm that deposited 911 mm of rain in a few days in Venezuela, called as Vargas tragedy (Yadav, 2009).

Geological Survey of India (2012) reported that about 12.6% of land area/0.42 million sq.km of our country, excluding snow covered area, is prone to landslide hazard. Out of this, 0.18 million sq. km contributes North East Himalaya, including Darjeeling and Sikkim Himalaya; 0.14 million sq. contributes North West Himalaya (Uttarakhand, Himachal Pradesh and Jammu & Kashmir); 0.09 million sq. km in Western Ghats and Konkan hills (Tamil Nadu, Kerala, Karnataka, Goa and Maharashtra) and 0.01 million sq. km in Eastern Ghats of Aruku area in Andhra Pradesh. According to National Disaster Management Authority (2009), Landslides of different types occur frequently in the geo–dynamically active domains in the Himalayan and north-eastern parts of the country as well as relatively stable domains in the Western Ghats and Nilgiri hills in the southern part of the country. During monsoon season, 22 states and parts of union territory of Puducherry and Andaman and Nicobar Islands are affected by this hazard.

Due to immature and rugged topography, fragile rock conditions, high seismicity and high rainfall, the Himalayan mountain ranges and hilly tracts of the north-eastern region are highly susceptible to slope instability. Increased anthropogenic interference due to developmental activities adds to this. Therefore, probability of reoccurrence of landslides is high in Himalayan and north-eastern regions. Both Western Ghats and Nilgiri hills are sensitive to overburden due to high rainfall and over saturation.

In most of the landslide prone areas vegetal cover has been reduced to less than 30%, which is less than recommended. Due to population expansion more human settlements, roads dams, tunnels, water reservoirs, towers and other public utilities came up in vulnerable areas. In Himalayan regions, the road network is more than 50,000 km. Large number of dams have been constructed across Himalayan regions. Landslides with severe impacts and losses include the Varunavat landslide of Uttarkashi, the Malpa landslide along the Rishikesh-Badrinath pilgrimage route, the Zubza and Mao Seng Song landslides along the Dimapur-Imphal National Highway, the Sonapur landslide along the Shillong-Silchar National Highway, the Sakinaka landslide in Mumbai, the Konkan landslides 0of 2005 and the Ghanvi village landslide in Himachal Pradesh in 2007. Table.2 shows some of the important landslide events in the country.

Table 2. Landslides in India (1968-2014)

Date	Location	Remarks
October 4, 1968.	Darjeeling landslide, West Bengal	The landslide was triggered by floods and the 60 km long highway was cut in 91 parts and thousands of people died
1984	Kalisur	
October 1990	Nilgiris	36 people killed and several injured. Several buildings and communication network damaged
July 1991	Nilgiris	300 people killed, road and buildings damaged, Millions of rupees
November 1992	Assam	300 people killed, road and buildings damaged, Millions of rupees loss
June 1993	Nilgiris	Road network and buildings damaged, Rs.5 million damage estimate
July 1993	Aizawal	4 persons were buried
August 1993	Itanagar	25 people buried alive, 2 km road Damaged
August 1993	Kalimpong, West Bengal	40 people killed, heavy loss of property
November 1993	Kohima, Nagaland	200 houses destroyed, 500 people died, about 5km road stretch was damaged
January 1994	Nilgris	40 people killed, property worth several lakhs damaged
June 1994	Kashmir	National Highway 1A severely damaged
May 1995	Varundh Ghats, Konkan Coast	20 people killed, breaching of Ghats road damaged to the extent of 1km.
June 1995	Aizwal Mizoram	25 people killed, road severely damaged
14,August 1998	Kullu, HP	22 persons killed and several injured about 1 km road destroyed
18,August 1998	Okhimath	69 people killed

July 2000.	Mumbai landslide, Maharashtra	Around 67 people died and the local trains were also stricken
2001	Malpa, Kali river	205 people killed, road network to Mansarovar disrupted
November 9, 2001	Amboori landslide, Kerala:	40 people died. The landslide was known as the worst landslide in Kerala's history
August 2003	Budha Kedar	
July 2004	Uttarkashi	Heavy loss of infrastructures
August 03, 2004	Joshimath -Badrinath	Heavy landslides hit Lambagarh area washed away nearly 300 meter long road between Joshimath and Badrinath, 17killed
2005	Landslide at Tehri dam project;	9 killed
2005	Konkan	
2007	Sakinaka, Mumbai	
2009	Ghanvi village	
2009	Karvar Landslide	
2009	La- Jhekla debris flow	
2010	Nilgiri	
2010	Leh Debris Flow	
2010	Kapkot landslide	
June 16, 2013	Kedarnath landslide, Uttarakhand:	Occurred because of Uttarakhand floods. 5700 people were dead.
July 30, 2014	Malin landslide, Maharashtra:	Due to heavy rainfall and around 151 people died and 100 missing

2.5 KERALA SCENARIO

In Kerala, landslides are a recurring phenomenon during monsoon periods, especially in hilly tracts of Idukki, Malappuram, Palakkad and Wayanad districts. One of the prime causes of landslide occurrence in Kerala is conversion of natural forest into agricultural fields. The study by Kerala State Disaster Management Authority reveals that 1848 km^2 or 4.71% of the state is under high hazard category and 3759 km^2 or 9.77% is under low hazard category. According to Thampi *et al.* (1995), the major areas affected by slope movements are Wayanad (Kappikalam), Palakkad (Palakkayam), Idukki (Kandalur and Bison valley), Kottayam (Adivaram, Kodunga), Quilon (Ottakal) etc. Devikulam, Vythiri, Nilambur, Mannarkad and Ranni are the most landslide prone taluks in the state. All 14 districts in the state except Alappuzha are prone to landslides. Wayanad and Kozhikode districts are prone to deep-seated landslides, while Idukki and Kottayam are prone to shallow landslides. The Western Ghats occupies 47% of this state and the annual rainfall is as high as 3000 mm, obtained during two monsoon seasons. This favours slope failures often resulting in debris flows. Influence of slopes on landslides has been emphasised by many researchers. Most of the mass movements in western ghat area are reported to occur on slopes of 20 degree. Muraleedharan (1995) reported that Mananthavady, Mundakkayi, Mappadi and Vythiri areas of Wayanad district experienced frequent landslides where the slope class is 30°-35° or more and in Neyyar catchment area slope class is 20°-40°.

Table 3. Extent of landslide prone area in each district

District	Area km^2	Area %	Area km^2	Area %
	high		low	
Thiruvananthapuram	45.59	2.08	114.90	5.24
Kollam	75.61	3.04	191.07	7.69
Pathanamthitta	170.28	6.41	426.25	16.04
Alappuzha	0.00	0.00	0.00	0.00
Kottayam	61.78	2.81	190.50	8.65
Idukki	388.32	8.90	873.71	20.02
Ernakulam	61.42	2.01	229.05	7.49
Thrissur	108.15	3.56	217.40	7.15
Palakkad	324.62	7.25	366.88	8.19
Malappuram	198.34	5.58	267.56	7.53
Kozhikode	109.00	4.64	206.71	8.80
Wayanad	102.56	4.82	196.57	9.23
Kannur	168.64	5.69	272.55	9.20
Kasaragod	33.67	1.69	205.90	10.35
Total for the state	1847.98	4.75	3759.07	9.67

2.6 LANDSLIDE HAZARD ZONATION

According to Varnes (1984), zonation is referred as "the division of land into homogenous areas or domains and their ranking according to degree of actual /potential hazard caused by mass movement". Landslide hazard zonation is defined as the mapping of areas with an equal probability of occurrence of landslides of a given type and magnitude within a specified of time (Guzzetti *et al.,* 1999 and Varnes 1984). Landslide hazard classes are displayed through LHZ maps.

2.6.1 Landslide hazard:

When considering the probability of landslide occurrence within a given area and within a specified period, identification of the causes for the slope failure and the processes that triggered the movement are of primary importance. (Radbruch-Hall and Varnes (1976), Varnes (1984)) reported that many factors play vital roles in slope failures and associated processes. The thematic inputs, which determine the probability of land sliding for a particular slope or an area, may be grouped into two categories, called the preparatory factors and the triggered factors.

Without actually initiating the landslides, preparatory factors makes the slope more susceptible to failure, such as geology, structures, slope and aspect, relative relief, geomorphology, soil, drainage pattern, landuse/landcover (Dai and Lee, 2002).

The triggering factors shift the slope from a marginally stable to an unstable state and thereby initiate failure in an area of given susceptibility, such as heavy rainfall and earthquake (Wu and Siddle, 1995).

2.6.1.1 Geology

Geological and topographical parameters play a crucial role in the prognosis of landslide. Geological structures had been used by Saha *et al.* (2005) as a landslide causal factor. The chance of landslide occurrence rises with proximity to geological structures.

2.6.1.2 Slope

The topographical parameters like slope, aspect and relative relief play a significant role in landslide studies. As the slope increases the probability of the occurrence of landslide increases because as the slope angle increases the shear stress of the soil increases. Slope maps define slope categories based on the frequency of particular angles of slope. It is observed that slope greater than 25° is significant for the landslide occurrences. Increase in the slope gradient due to undermining of the foot of the slopes by streams waves or due to previous rockfall or slide, contributes to slope failures (Nithya and Prasanna, 2010).

2.6.1.3 Aspect

Aspect identifies the down-slope direction of the maximum rate of change in value from each cell to its neighbours. Aspect can be thought of as the slope direction.

2.6.1.4 Landuse/Landcover

The present day landuse has great importance in LHZ and mitigation measures. Land cover is an indirect indication of the stability of hill slopes. The Land use map shows the different types of land cover pattern present in the study area. Vegetation cover is an important factor, which influences the occurrence and movement of the rainfall, which triggers the landslide. Barren and sparsely vegetated areas show faster erosion and greater instability as compared to reserve or protected forests, which are thickly vegetated and generally less prone to mass wasting processes. Forest cover, in general, smothers the action of climatic agents on the climatic agents on the slopes and protects them from the effects of weathering and erosion. A well-spread root system increases the shearing resistance of slope material. Agriculture, in general, is practiced on low to very low slopes, though moderately steep slopes are not spared at places. However, the agricultural lands represent areas of repeated water charging for cultivation purposes and as such may be considered stable. Satellite data has the capability to directly record these features from the ground.

2.6.1.5 Soil

The occurrence of landslide is mainly due to the presence of huge thickness of loose soils. When mixed with rainwater, it triggers the landslide.

2.6.2 Uses of Landslide Hazard Zonation

Depending upon the adopted methodology and the comprehensiveness of the input data, a landslide hazard zonation map be able to provide certain information on location of occurrence, time of occurrence, type of landslide, extent of the slope area likely to be affected etc. Intensive and sustained efforts are required for preparation of a hazard zonation map. A large amount of data including many variables, covering large areas needs to be collected stored and evaluated. This include data on regional geology, geomorphic setting, slope conditions, landuse/land cover information etc. Finally, the risk of occurrence of landslide is evaluated and the hazard zonation map is prepared (Ghosh, 2012). Now a days adoption of remote sensing techniques made the data collection much easier. Different GIS software are available for storage, retrieval and analysis of collected data. Landslide hazard zonation maps have different uses.

The LHZ maps have wide variety of uses, some of which are listed below.

- The LHZ maps identify and delineate unstable hazard-prone areas, so that environmental regeneration programmes can be initiated adopting suitable mitigation measures.
- They are used in preparation of developmental plans for townships, dams roads transport network, land use plans, choice of alignment of new roads, for keeping the existing roads free of landslide hazard.
- General purpose master plans and landuse plans.
- Discouraging new development in hazard prone areas.

- Choice of optimum activity pattern based on risk zones.
- Quick decision making in rescue and relief operations.

Landslide hazard zonation maps have a large number of users, including several government departments, private agencies and individuals.

2.6.3 Assumptions for LHZ

Landslide Hazard Zonation has been actively pursued for the last two decades and various methodologies are still being refined. Varnes (1984) has outlined three assumptions that form the basis of landslide hazard zonation.

1. It is considered that future slope failures are most likely to occur in geologic, geomorphologic and hydrologic situations that have led to past failures.
2. In a given study area the factors that cause landslides can be rated or weighted.
3. If conditions that promote instability can be identified, it is often possible to estimate their relative contribution and assign them some spatial quantitative index.

2.7 REMOTE SENSING *Vs* GIS

Literally, Remote Sensing means obtaining information about an object, area or phenomenon without coming in direct contact with it. From the following definitions, we can have a better understanding about Remote Sensing:

Remote sensing is defined as "the science and art of obtaining information about an object, area or phenomenon through the analysis of data acquired by a device that is not in contact with the object, area or phenomenon under investigation" (Lillesand *et al.*, 2004).

According to White (1977), Remote Sensing includes all methods of obtaining pictures or other forms of electromagnetic records of Earth's surface from a distance, and the treatment and processing of the picture data. Remote Sensing then in the widest sense is concerned with detecting and recording electromagnetic radiation from the target areas in the field of view of the sensor instrument. This radiation may have originated directly from separate components of the target area, it may be solar energy reflected from them; or it may be reflections of energy transmitted to the target area from the sensor itself.

According to American Society of Photogrammetry, Remote sensing is defined as the process of gathering and processing information about an object without direct physical contact.

According to the United Nations, (1986), Remote Sensing means sensing of earth's surface from space by making use of the properties of electromagnetic wave emitted, reflected or diffracted by the sensed objects, for the purpose of improving natural resource management, land use and the protection of the environment.

According to Campell (1996), Remote Sensing is the practice of deriving information about the earth's land and water surfaces using images acquired from an overhead perspective, using electromagnetic radiation in one or more regions of the electromagnetic spectrum, reflected or emitted from the earth's surface.

GIS (Geographic Information System) is a kind of software that enables the collection of spatial data from different sources (Remote Sensing being one of them), perform tabular and spatial analysis and design the layout of a map. Indian Society of Geomatics (ISG) and Indian Space Research Organisation (ISRO) defined GIS as a system, which provides a computerised mechanism for integrating various geo-information data sets and analysing them in order to generate information relevant to planning needs in a context.

GIS draws concepts and ideas from different disciplines, such as cartography, cognitive science, computer science, engineering, environmental sciences, landscape architecture, law, photogrammetry, public policy, remote sensing, statistics and surveying. GIS also examines the impacts of GIS on individuals and society and the influences of society on GIS, along with the study of the fundamental issues arising from the creation, handling, storage and use of geographic information. A GIS software can handle both vector and raster data (some handle only one of them). GIS primarily deals with geographic data to be analysed, manipulated and managed in an organized manner through computers to solve real world problems. Therefore, GIS operation requires two things – computer system and geographic data (Patra, 2010).

The number of recent publications on various methods for GIS based landslide hazard assessment is overwhelming, especially when compared with those that also deal with landslide vulnerability and risk assessment, which are still very few. Overviews and classification of GIS based landslide hazard assessment methods can be found in Soeters and Westen (1996), Carrara *et al.,* (1991, 2000, and 2008), Guzzetti *et al.,* (1999) Aleotti and Chowdhury, (1999) and Westen *et al*, (2000). In terms of software used, GIS systems such as Arc Info, ArcView, ArcGIS, SPANS, IDRISI, GRASS and ILWIS are mostly used and statistical packages such as Statgraph or SPSS. Most GIS systems are good in data entry, conversion, management, overlaying and visualization, but not very suitable for implementing complex dynamic simulation models. Some GIS systems are specifically designed for implementing such dynamic models (Prabu, 2013).

Using Remote Sensing and Geological Information System, qualitative and quantitative natures of landslides are studied and by applying several statistical and computational models.

2.8 ANALYTICAL HIERARCHIAL PROCESS (AHP)

The method employed in this study is Analytical Hierarchical Process (AHP). AHP is developed by Saaty (1980). Ghafoori *et al.* (2011) claims that the analytical hierarchy method is precise method for evaluation of landslide potential due to the use of binary comparison affecting factors and considering numerous factors for landslide evaluation at the same time in comparison to the other prevalent method.

It was developed as a reaction to the finding that there is a miserable lack of easy-to-implement, common and easily understood methodology to enable the complex decision-making. Ever since, the power and simplicity of the AHP has led to its extensive use across multiple spheres in every part of the world. The AHP has found use in business, research and development, government, defence, social studies and other domains involving decisions in which choice, prioritization or forecasting is needed. Due to its ease of use and simplicity, the AHP has found ready recognition and acceptance by decision-makers. It helps in structuring the decision-maker's thoughts and organizes the problem in an easy manner that is simple to track and analyse. Broad areas in which the AHP has been applied include alternative selection, resource allocation, forecasting, business process re-engineering, quality function deployment, balanced scorecard, benchmarking, public policy decisions, healthcare, and many more. The AHP helps in structuring the complexity, measurement and synthesis of rankings. These qualities make it suitable for a wide variety of applications. The AHP is a proved theoretically sound, market tested and accepted methodology .It is a methodology capable of producing results that agree with perceptions and expectations. In AHP, a problem is decomposed into a hierarchy of sub-problems that can more easily comprehend and instinctively evaluated. The subjective evaluations are converted into numerical values and processed to rank each alternative on a numerical scale. Usually a 10-point scale is used.

Landslide susceptibility mapping using AHP method was done by Ghafoori *et al.* (2011) in Yadak-Tevil watershed, NE Iran. In the present study, seven thematic maps were created namely, lithology, drainage, and distance from slope, distance from fault, slope aspect, land use and distance from road. The study area was classified into five classes of relative landslide susceptibility, namely, very low, low; moderate, high, and very high. Results showed that 67% of the area is under high zone.

Pourghasemi *et al.* (2012) prepared landslide susceptibility map for a landslide-prone area (Haraz) in Iran using a spatial multi criteria evaluation approach (SMCE). In the first stage, landslide locations were identified in the study area from interpretation of aerial photographs, and field surveys. In the second stage, twelve data layers were used as landslide conditioning factors for susceptibility mapping. Next, landslide-susceptible areas were analysed using the SMCE approach and mapped using landslide conditioning factors. For verification, the results of the analyses were compared with the field-verified landslide locations. Additionally, the receiver operating characteristics (ROC) curves for all landslide susceptibility models were drawn and the area under curve values was calculated. Landslide locations were used to validate results of the landslide susceptibility map generated using the SMCE approach and the verification results showed a 76.84 % accuracy.

2.8 RECENT STUDIES

A brief review of the studies conducted by various authors is highlighted here:

Prasannakumar *et al.* (2012) similarly made an Evaluation and Validation of landslide spatial susceptibility in the Western Ghats of Kerala, through GIS-based weights of evidence model and area under curve technique. The quantitative relationship between landslides and the causative factors were statistically weighted using the ArcSDM extension of ArcGIS. The result was validated using the Area under Curve method and shows a prediction rate of 81.32%.

Landslide hazard zonation using geospatial techniques was carried out by Abraham and Shaji (2013), in and around Thodupuzha — Idukki — Munnar road (TM Road) in Idukki district, Kerala. Hazard zonation was attempted using terrain fragility concept. Thematic maps of various terrain parameters like landuse, slope, drainage pattern, drainage density, relative relief, surface material and landform were prepared and their integration was carried out on a GIS platform and the hazard prone areas were identified.

Vijith *et al.* (2013) prepared a landslide susceptibility zonation (LSZ) map and quantitative validation of the result at a scale of 1:50,000 for the upland catchment of river Meenachil, Kottayam district, Kerala, India by recognizing and mapping the palaeoslide locations and the associated terrain attributes. A weight of evidence modelling which is a bivariate statistical method was used for the analysis. Fourteen terrain parameters namely, flow path length, Normalized Difference Vegetation Index (NDVI), slope, geomorphology, slope length, drainage density, soil type, profile curvature, soil thickness, land use, relative relief, aspect, plan curvature, and topographic wetness index were generated and its weights were determined. 'Omnibus test' was used for determining the conditional independence of the evidential themes and those themes, which found to be conditionally independent were integrated to produce the final LSZ, map. The results shows that areas having slope less than 16° is classified as stable and the very high and high susceptible region is contributed by the slope between 16° and 45°, facing southwest, west and northwest directions, with extended influence from relative relief, slope length, flow path length and compound topographic index. The reliability and accuracy of the LSZ map was assessed by the receiver operating characteristic curve analysis and the model shows a prediction accuracy of 89.2%.

Landslide hazard zonation using Remote Sensing and GIS techniques was conducted recently in Meenachil and Kanjirappally taluk, Kottayam district, Kerala, India by Ajin *et al.* (2014). This study used the application of weighted overlay analysis method based on remote sensing and GIS techniques to produce the landslide hazard zonation map for the study area. The factors influencing the landslide activity were collected and the thematic maps of these factors are reclassified and weighted overlaid using GIS environment. The landslide hazard zonation maps were generated.

Kannan *et al.* (2014) studied landslide hazard zonation in Bodi- Bodimettu Ghat section, Theni district, Tamil Nadu. In this study, three different methods, namely, Bureau of Indian Standard (BIS), Multi- Criteria Analysis (MCA), and

Frequency Ratio (FR) were used to generate landslide hazard zonation maps. The comparisons were done using the parameters such as success rate curve, spatial agreed area, landslide density. The output shows the same variation for all the three methods.

Krishnan *et al.* (2014) determined the susceptibility of two different statistical techniques in shallow landslide (debris flow) initiation susceptibility assessment in the Western Ghats. In this study, Information Value (InfoVal) and the Multiple Logistic Regression (MLR) methods based on bivariate and multivariate statistical analysis have been applied for shallow landslide susceptibility assessment. The factors influencing the landslide activity were used to generate the thematic maps. Landslide Susceptibility Index (LSI) maps were generated by integrating the weighted thematic maps and divided into five landslide susceptibility zones (LSZ). The LZS map produced by InfoVal technique showed higher accuracy and is more realistic compared in the field.

Raveendran *et al.* (2015) attempted to demarcate landslide hazard zones of Devikulam Taluk of Idukki using GIS platform. The study used Geomorphology, Geology, Drainage density, Slope, Soil and Land use layers .These thematic layers were overlaid with appropriate weights to generate landslide hazard zones in Devikulam taluk. The study area was divided into five vulnerable zones namely Class I, Class II, Class III, Class IV, and Class V. Class I is a very low vulnerable zone while Class V is very high vulnerable zone. Study found that most of the landslide Vulnerability locations fall under Class V and Class IV.

CHAPTER 3

MATERIALS AND METHODS

3.1 STUDY AREA

Nilambur in Malappuram district of Kerala is located close to the Nilgiris range of the Western Ghats on the banks of the Chaliyar River at around 11°16′37″N and 76°13′33″E. Nilambur taluk is located in Malappuram district, North of Kerala, South India. It is situated geographically at the eastern end of the district where Tamilnadu state boarder shares the Western Ghats mountain lands with Kerala. The taluk's boundaries are Nilgiri hills of Tamilnadu in east, Eranadu taluk in west, Palakkad district (Mannarkad taluk) and Perinthalmanna taluk in south and Kozhikode (Calicut) district in north. Total population of the study area is around 5, 74,059. Spread over an area of 1323.20 sq. km, Nilambur taluk contains total of 19 villages. Location map is shown in Fig. 3.

3.2 DATASETS

The datasets used for the present study are land use map, geology map, road network, drainage network, soil map, rainfall data, and digital elevation model. The datasets thus obtained are used in the creation of the landslide hazard zonation maps.

Following are the datasets used for the present study.

3.2.1 Landslide Data

Landslide occurrence data was collected from geological survey of India, Trivandrum. Some of the landslide events were identified from Landslide Inventory of Kerala by Muraleedharan and Kumar (2007). Identified landslides are listed and represented below (Table 4 and Fig 4).

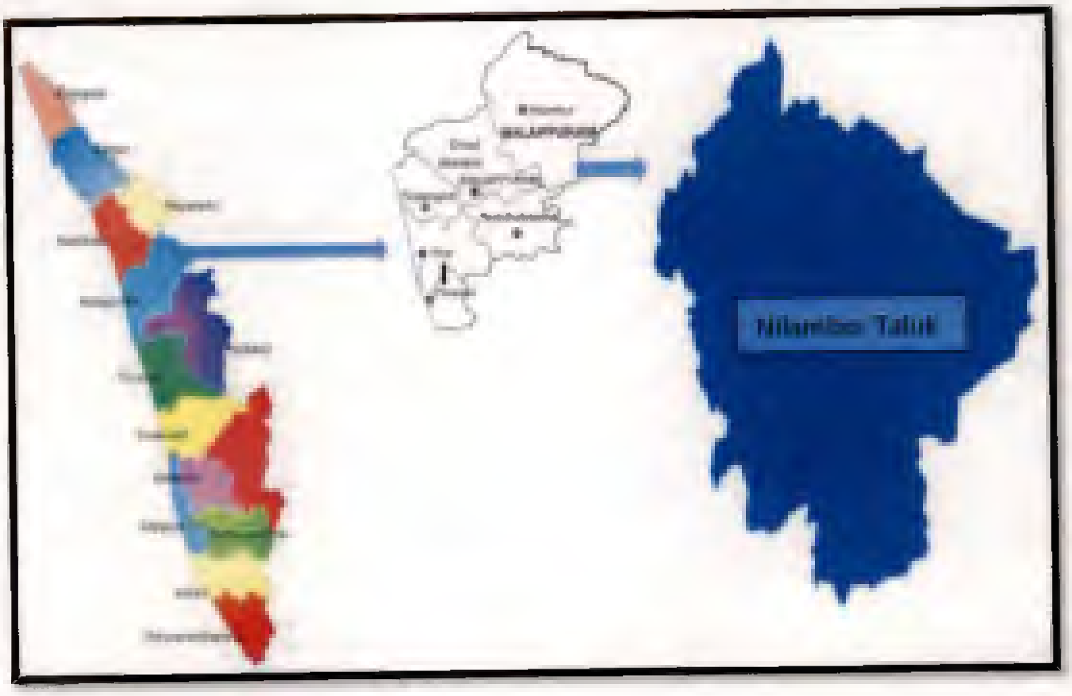


Fig 3. Study Area

Table 4. Previous landslide locations

Sl:No	Longitude E	Latitude N	Sl:No	Longitude E	Latitude N
1	76.39178	11.43631	24	76.36256	11.39496
2	76.39085	11.43526	25	76.35515	11.38903
3	76.38683	11.4313	26	76.35726	11.39011
4	76.38652	11.4311	27	76.35645	11.38982
5	76.38407	11.42764	28	76.36546	11.41588
6	76.38288	11.4228	29	76.36494	11.41471
7	76.38254	11.42167	30	76.37436	11.41495
8	76.38004	11.42021	31	76.23705	11.4199
9	76.37912	11.41984	32	76.22656	11.39626
10	76.37878	11.41939	33	76.14414	11.33546
11	76.37848	11.41841	34	76.13566	11.33726
12	76.37848	11.41888	35	76.16558	11.33043
13	76.37792	11.41708	36	76.14876	11.33796
14	76.37769	11.41656	37	76.14599	11.33843
15	76.37713	11.4164	38	76.15958	11.34309
16	76.37553	11.41587	39	76.13839	11.33536
17	76.37457	11.41584	40	76.10998	11.36974
18	76.37373	11.41306	41	76.22658	11.39822
19	76.37574	11.41256	42	76.12956	11.33839
20	76.37523	11.41065	43	76.3965	11.13889
21	76.37472	11.40931	44	76.22658	11.39822
22	76.36619	11.39871	45	76.35822	11.17817
23	76.38299	11.42684	46	76.35611	11.21319

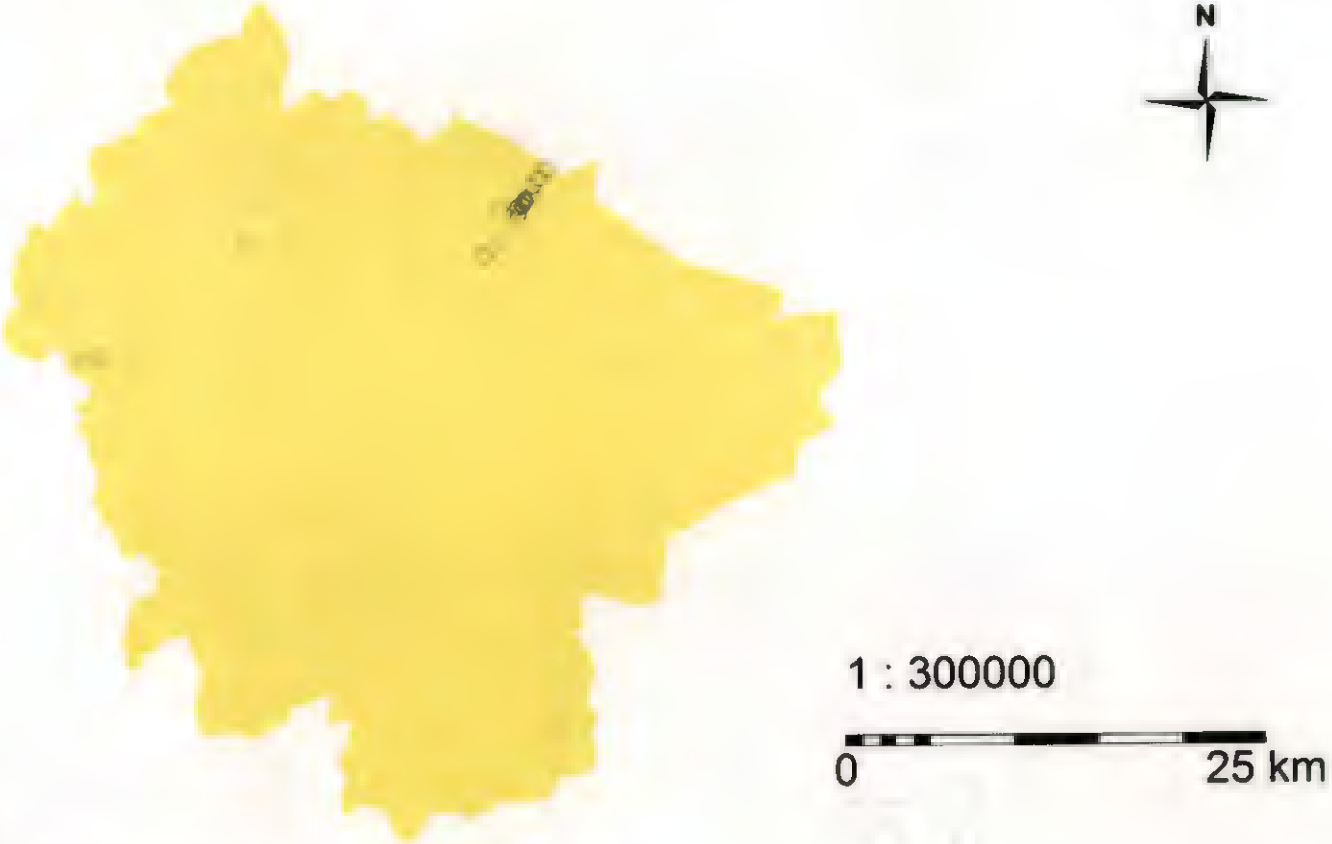


Fig 4. Map indicating previous landslide locations.

3.2.2 Digital Elevation Model (DEM)

For identifying the hazard zones in Nilambur Taluk, good quality Digital Elevation Model (DEM) is required for calculating some parameters such as slope and aspect. The data used in the preparation of aspect map and slope map is of Cartosat-1: DEM - Version-3R1, 1 arc Sec (~ 32 m) resolution. This DEM data was downloaded from ISRO, National Remote Sensing Centre's (NRSC) India Geo-platform - Bhuvan (http://bhuvan.nrsc.gov.in). Figure 25 represents the DEM for Nilambur Taluk.

3.2.3 Soil Map

Soil map and attribute information have been collected from the Kerala State Land Use Board (KSLUB), Trivandrum. Based on depth, texture, slope and drainage characteristics, the soils of the study area fall into 9 soil mapping units namely K10, K18, K19, K20, K22, K24, K26, and K27 & K29 (KSLUB, 1995). The description of the soil mapping units is represented in Table.5.

3.2.4 Geology Map

Geology map and attribute information have been collected from the Kerala State Land Use Board (KSLUB), Trivandrum.

3.2.5 Landuse Map

Landuse map and attribute information have been collected from the Kerala State Land Use Board (KSLUB), Trivandrum.

3.2.6 Rainfall data

Rainfall data for the area is collected from WorldClim-World Climate Data. BIO16 (average of wettest quarter) layer was used for the present study and this layer contain data from 1950 to 2000.

Table 5. Description of Soil Mapping Units of Nilambur Taluk

Soil mapping unit	Description	Texture
K10	Very deep, well drained, gravelly clay soils on gently sloping midland laterites with valleys of northern Kerala, with moderate erosion, associated with deep, well drained, gravelly clay soils with moderate surface gravelliness and ironstone layer at 100- 150 cm on nearly level lands, slightly eroded.	Gravelly clay
K18	Very deep, well drained clayey soils on gently sloping lands of Wayanadu plateau, with moderate erosion; associated with very deep well drained clayey soils	Clayey
K19	Very deep, well drained clayey soils on moderately sloping high hills with thin vegetation, with moderate erosion; associated with rock outcrops	Clayey
K20	Deep, somewhat excessively drained, gravelly clay soils with moderate surface gravelliness on steeply sloping high hills with thick vegetation, with moderate erosion; associated with very deep, well drained, clayey soils on gentle slopes.	Gravelly clay
K22	Very deep, well drained, clayey soils on gently sloping low hills with isolated hillocks, with moderate erosion; associated with deep, well drained, gravelly clayey soils on moderately steep slopes	Clayey
K24	Deep well drained, gravelly loam soils with ironstone layer at 100 to150cm on moderately steeply sloping medium hills with thin vegetation, with moderate erosion; associated with rock crops	Gravelly loam
K26	Very deep well drained clayey soils with loamy soils on gently sloping medium hills with thick vegetation, with moderate erosion, associated with rock outcrops.	Clayey
K27	Very deep, well drained, loamy soils on gently sloping medium hills with thick vegetation, with moderate erosion; associated with rock outcrops	Fine loamy
K29	Very deep, well drained, loamy soils on gently sloping uplands with valleys, with moderate erosion; associated with very deep, well drained, loamy soils on gentle slopes	Loamy

3.2.7 Software used

ILWIS 3.31 software was used for the analysis. ILWIS is an acronym for the Integrated Land and Water Information System. It is a Geographic Information System (GIS) with Image Processing capabilities. ILWIS was developed by the International Institute for Aerospace Survey and Earth Sciences (ITC), Enschede, The Netherlands. ILWIS is a GIS and Remote Sensing package, which allows input, management, analysis and presentation of geo-graphical data. ILWIS is a platform to generate information on the spatial and temporal patterns and processes on the earth surface. ILWIS uses vector and raster data, but most of the analysis is done in raster.

3.3 Methodology

The preparation of Landslide Hazard Zonation Map requires the following parameters:

a) Slope
b) Aspect
c) Soil
d) Geology
e) Land Use/ Land Cover
f) Rainfall
g) Elevation

3.3.1 Preparation of thematic maps

Thematic maps for certain parameters such as slope, aspect, soil, geology, landuse and rainfall were created using ILWIS software. All data layers were projected to the WGS84 Northern Hemisphere Plane coordinate system. The initially processed parameter shape files were used in the preparation of the thematic maps.

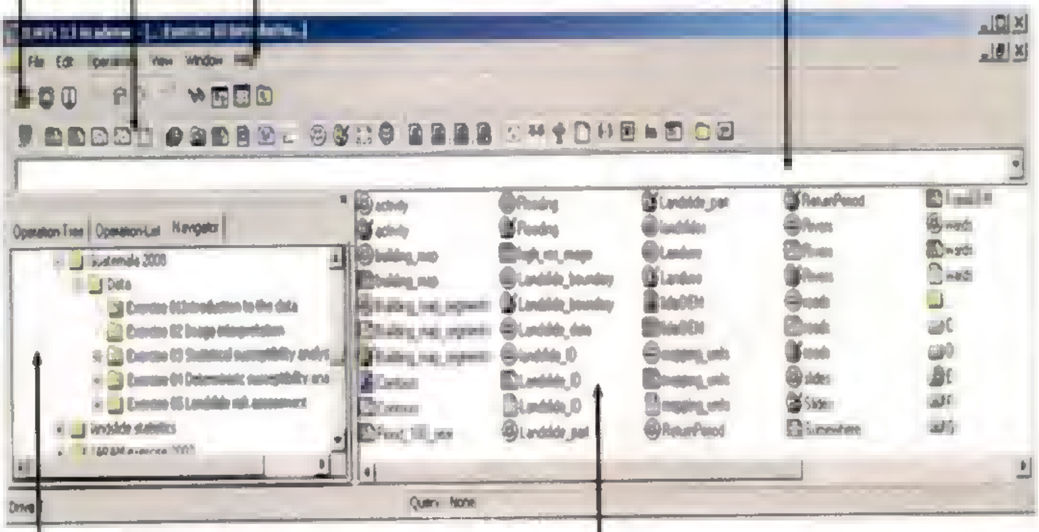
Thematic maps for slope and aspect were derived from DEM using image processing tool of ILWIS 3.31 software. The Land Use, Soil types and Geology of the study area were featured to raster using the conversion tools of ILWIS.

Object selection
Defines which objects are visible in data catalog

Toolbar

Menu bar
Used for executing most operations

Command line:
Used for executing most of the calculations with maps



Navigation pane
You can also change it to operation-tree or operation list

Data catalog
with icons indicating different types of data.
Note: right-clicking on an icon gives the operations that are possible

Fig 5. Figure illustrating different parts of software platform

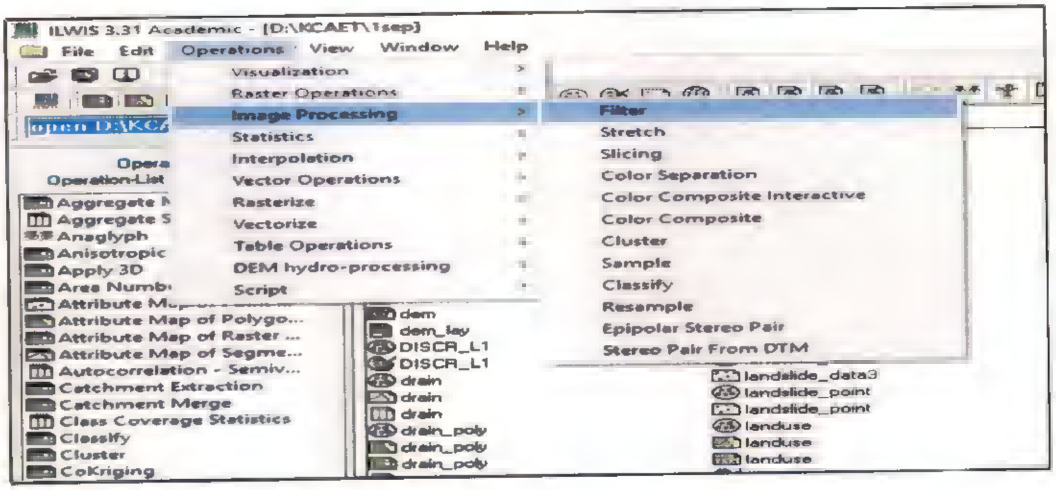
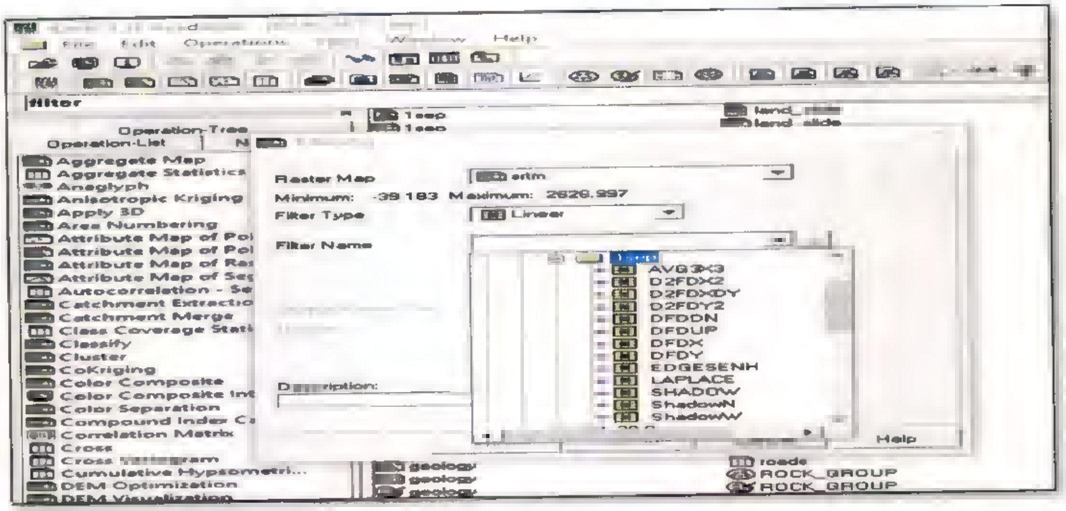


Fig 6. Selection of filter operation



Raster Map: ertm

Minimum: -39.183 Maximum: 2626.997

Filter Type: Linear

Filter Name

Description:

Fig 7. Window showing different types of linear filters

3.3.1.1 DEM to Slope

3.3.1.1.1 Creating DFDX and DFDY

Slope map was derived from Digital Elevation Model using filter function of image processing menu. Opting linear filter-DFDX and DFDY, raster maps DX and DY were produced.

3.3.1.1.2 Creation of Slope

The formula used for the creation of slope map was 100*HYP(DX,DY)/PIXSIZE(DEM), where DX and DY were raster maps created using filter function. This was done using map calculation (Fig 9).

3.3.1.1.3 Creation of domain for slope classification

Domain class is created for slope (Fig 10).

3.3.1.1.4 Combine Slope with Domain

3.3.1.2 DEM to aspect

Aspect map was also derived from DEM. The formula used was Aspect=RADDEG (ATAN2(DX, DY) +PI), where DX and DY were raster maps created using filter function of image processing menu.

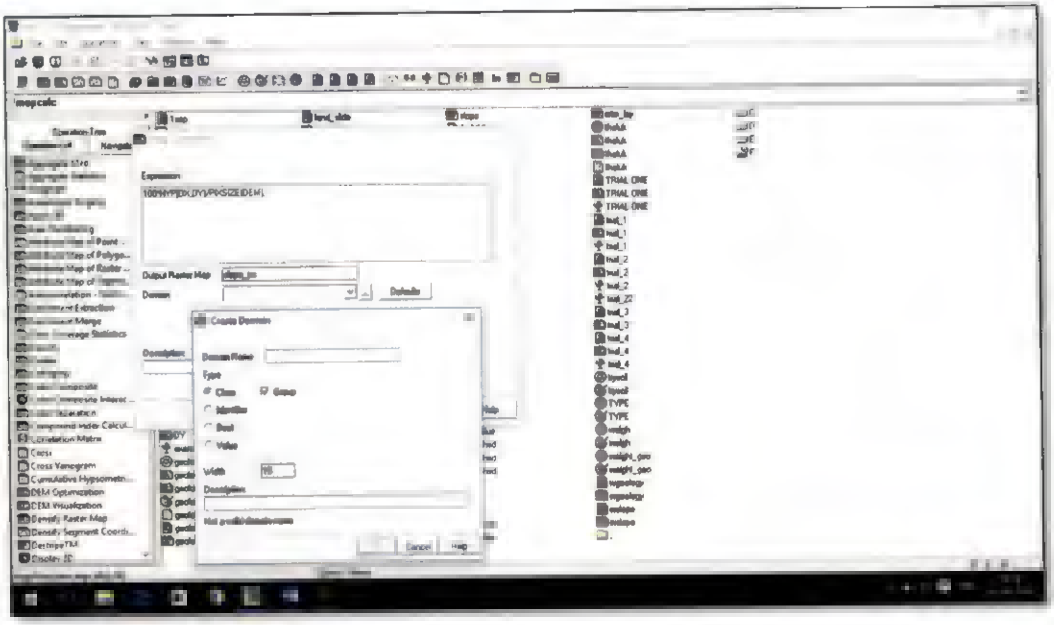
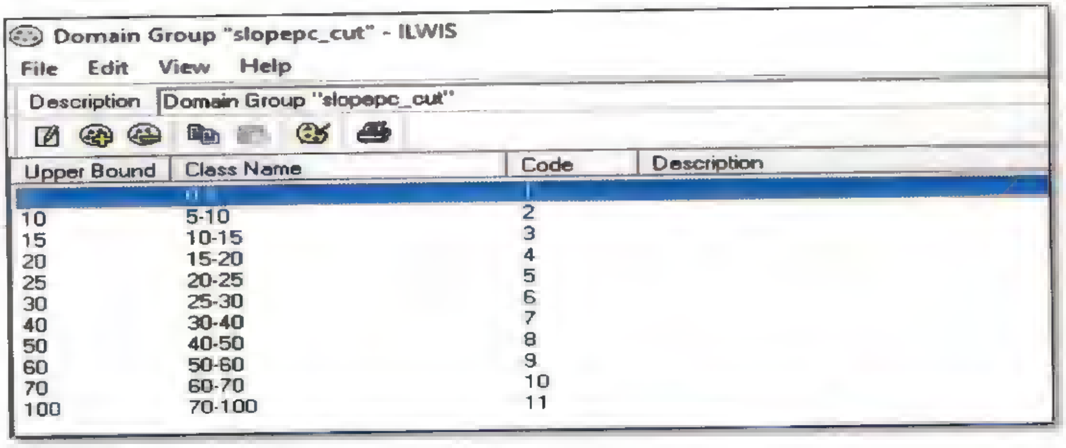

Expression: 100*HYP(DX,DY)/PIXSIZE(DEM)

Fig 8. Figure showing map calculation and create domain window


Domain Group "slopepc_cut" - ILWIS

Description: Domain Group "slopepc_cut"

Upper Bound	Class Name	Code	Description
[illegible]	[illegible]	1	
10	5-10	2	
15	10-15	3	
20	15-20	4	
25	20-25	5	
30	25-30	6	
40	30-40	7	
50	40-50	8	
60	50-60	9	
70	60-70	10	
100	70-100	11	

Fig 9. Domain group created for slope

3.4 SPATIAL MULTI CRITERIA EVALUATION (SMCE)

For executing the model, the SMCE module of ILWIS-GIS was used. SMCE application assists and guides users in doing multi-criteria evaluation in a spatial manner. Spatial Multiple Criteria Evaluation (SMCE) is a method that assists stakeholders in decision making with regard to achieving a particular goal. It is an ideal tool for transparent group decision making, using spatial criteria, which are combined and weighted in line with the overall goal. The input is set of data that are spatial representation of the criteria (used as factors and constraints), which are standardized and weighted in a criteria tree. The theoretical background for the multi-criteria evaluation is based on the Analytical Hierarchical Process (AHP) developed by Saaty (1980). The input is a set of maps that are the spatial representation of the criteria. They are grouped, standardized and weighted in a criteria tree. The output is one or more composite index map, which indicates the realization of the model implemented. The AHP has been extensively applied on decision-making problems (Saaty and Vargas 2001).

3.3.1 Analytical Hierarchical Process (AHP)

AHP is a multi-objective, multi-criteria decision-making approach to reach at a scale of preference among a set of alternatives. AHP gained wide application in site selection, suitability analysis, regional planning, and landslide susceptibility analysis. The landslide hazard zonation is done using SMCE module of ILWIS-GIS and its theoretical background is Analytical Hierarchical Process (AHP). This is a type of expert knowledge driven model. The AHP - LHZ model comprises an expert knowledge and the independent spatial data that are usually stored in a GIS. The structure of the knowledge base largely determines the appropriate inference technique required to generate a conclusion from the model. According to the AHP method, importance of every two parameters is set according to their contribution to landslides.

Table 6. Saaty's rating scale

Intensity of Importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Weak importance of one over another	Experience and judgment slightly favour one activity over another
5	Essential or strong importance	Experience and judgment strongly favour one activity over another
7	Demonstrated importance	Demonstrated importance An activity is strongly favoured and its dominance demonstrated in practice
9	Absolute more importance	The evidence favouring one activity over another is of the highest possible order of affirmation
2,4,6,8	Intermediate values between the two adjacent judgments	When compromise is needed

The scale proposed by Saaty (1977) involves a rating system ranging between 1/9 and 9 where 1/9 is the least important and 9 the most important parametric effect. Saaty's rating scale is explained in Table 6. In our research the rating system ranges from 1 to 9. Generalized procedure for conducting SMCE is shown below:

3.3.2 Spatial Multi Criteria Evaluation Analysis

Spatial Multiple Criteria Evaluation analysis is done using raster data, therefore all input data is converted to raster format. Spatial Multi Criteria Evaluation was opted from the operation tree or from raster operations (Fig 11). Both the Problem Analysis and Decision Making modules can be used for Landslide Hazard Zonation. Here problem analysis module is opted (Fig 12).

3.3.2.1 Addition of factors and constraints data

Click on Insert Spatial Constraint icon or click Edit>Insert>Spatial factor to insert all 'factor' data (Fig 13).

3.3.2.2 Standardization of factors and constraints

For standardizing, switch on multi criteria analysis mode (Fig 14). To make spatial multi-criteria analysis possible, the input layers need to be standardized from their original values to the value range of 0–1. There are different standardization options (Fig 15 and Fig 16) in the SMCE module of ILWIS (ITC 2001). The class maps use an associated table for standardisation where a column must be filled with values ranging between 0 and 1.

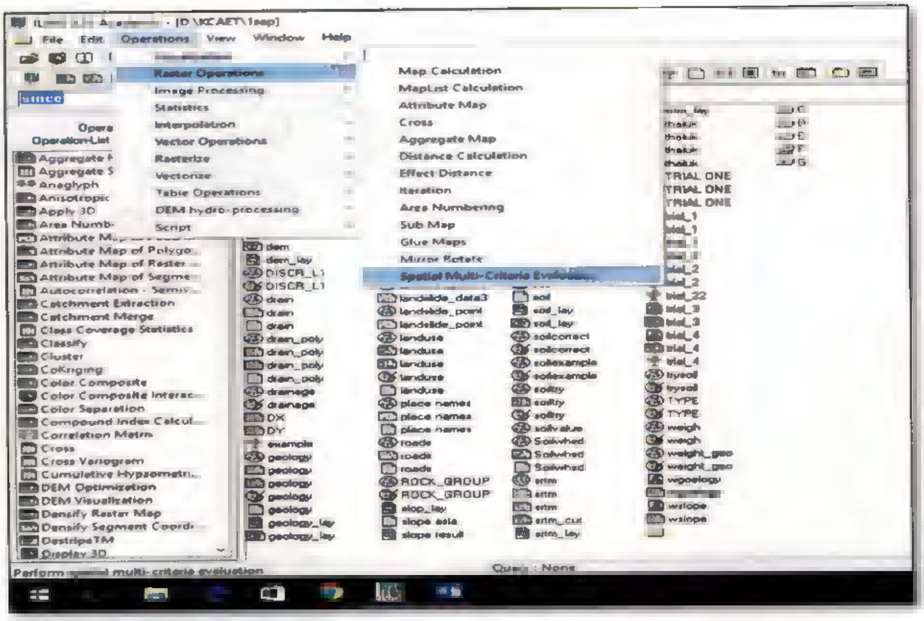
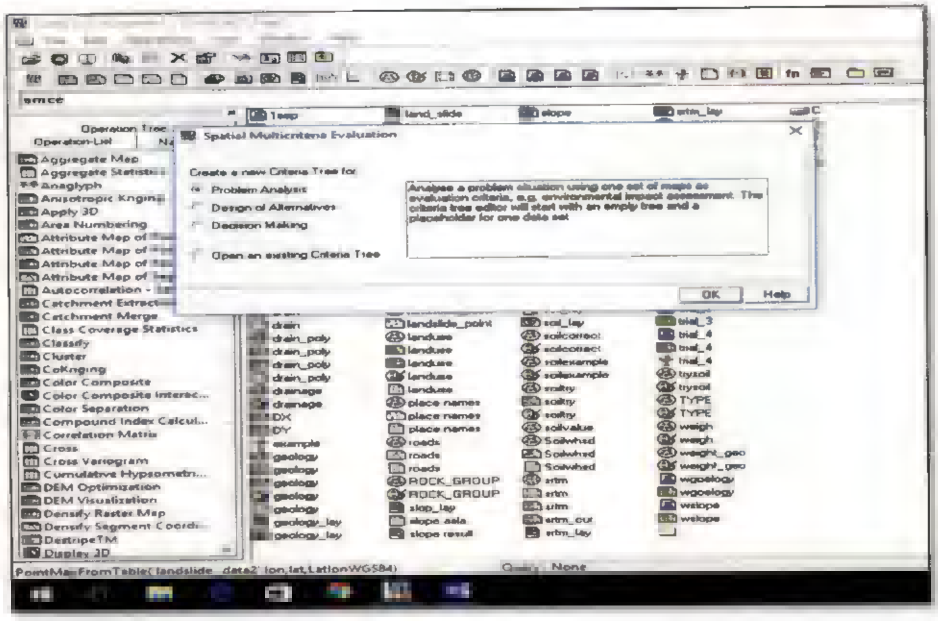


Fig 10. Selection of SMCE module from raster operations



Spatial Multicriteria Evaluation

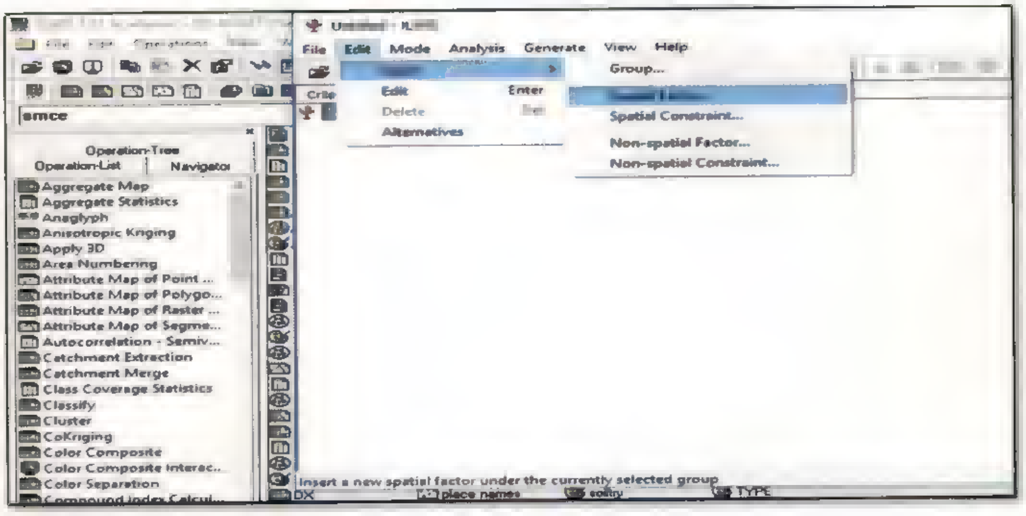
Create a new Criteria Tree for

- ● Problem Analysis
- ○ Design of Alternatives
- ○ Decision Making

○ Open an existing Criteria Tree

Analyse a problem situation using one set of maps as evaluation criteria, e.g. environmental impact assessment. The criteria tree editor will start with an empty tree and a placeholder for one data set

Fig 11. Window showing different SMCE options



Insert a new spatial factor under the currently selected group

Fig 12. Addition of spatial factors

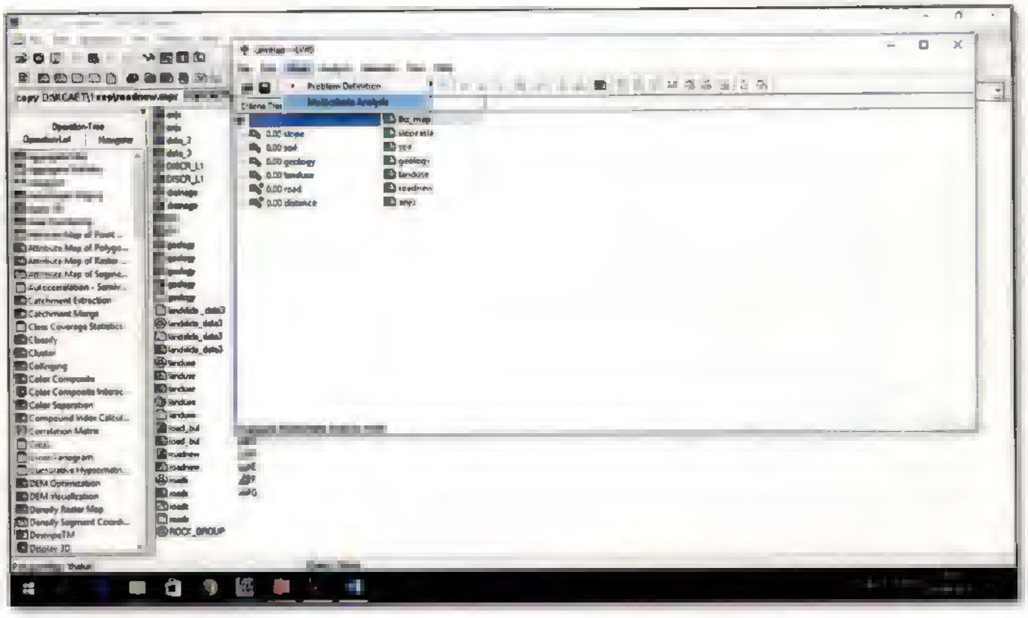


Fig 13. Window showing all input spatial factors

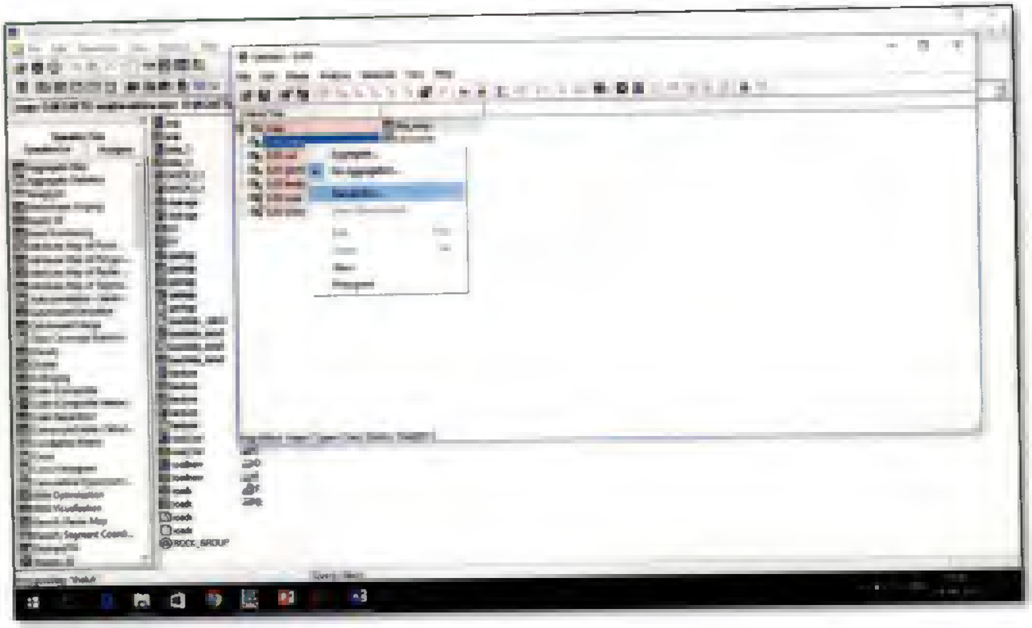


Fig 14. Standardization of input spatial factors

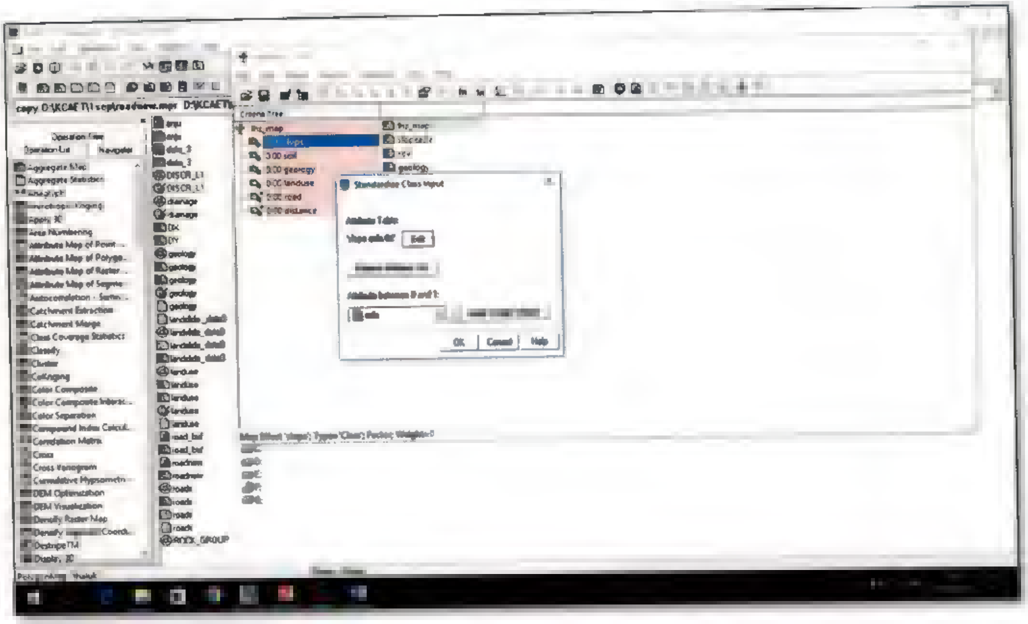


Fig 15. Standardization of input spatial factors

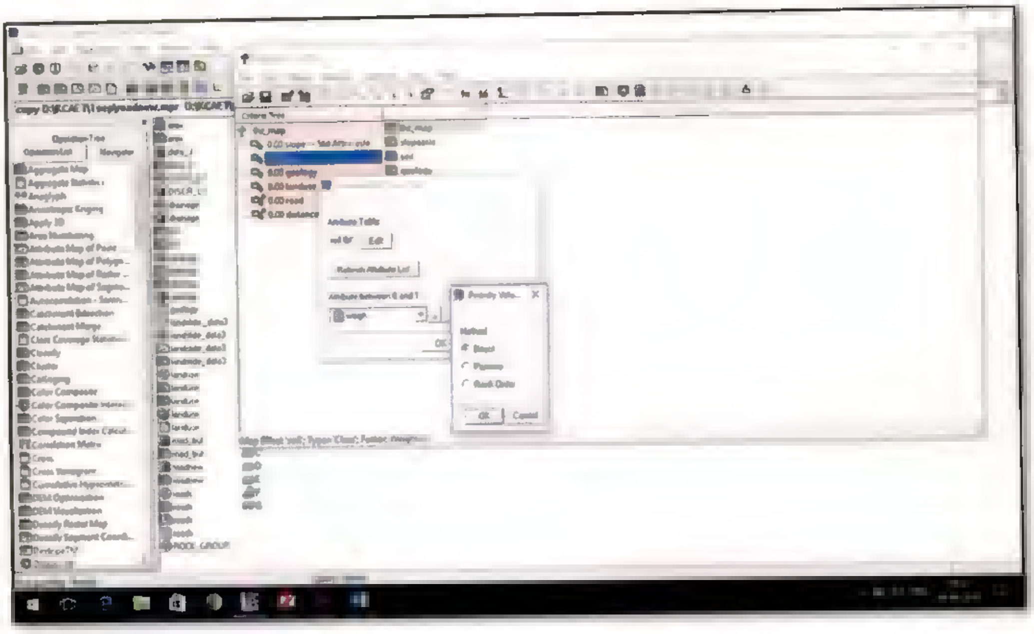


Fig 16. Window showing different options for weight assignment

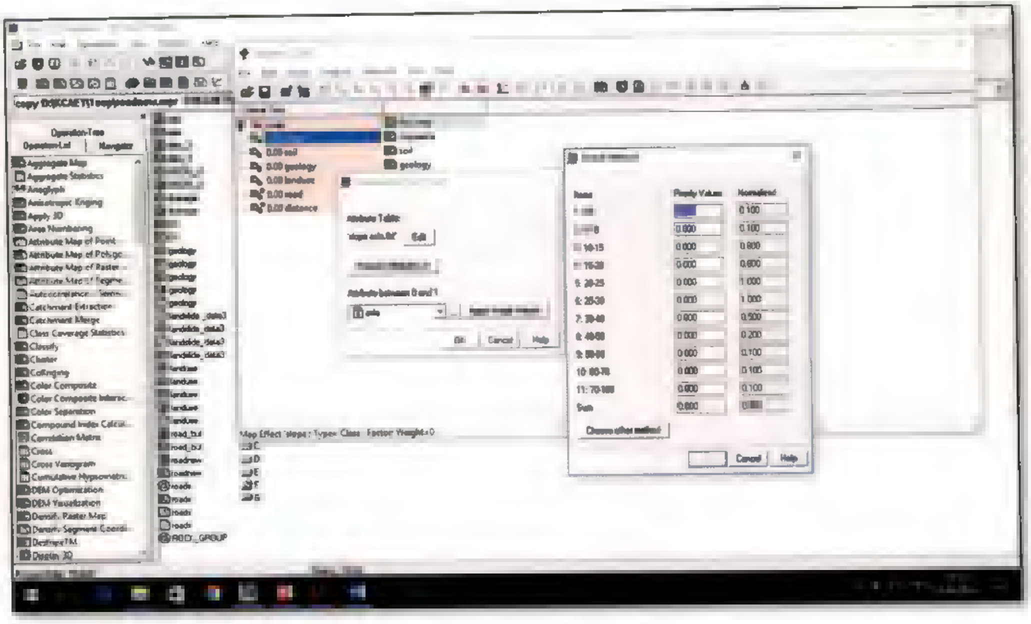


Fig 17. Figure showing direct method window for assignment of weights

3.3.2.4 Assignment of weights

After selecting the suitable indicators and defining their standardisation, in the hierarchical structure, weights were assigned to each criteria and intermediate result. For weighting, 3 main methods are provided in ILWIS-GIS: direct method, pairwise comparison and rank order method (Fig 17). Finally, landslide hazard map was created by direct method (Fig 18).

3.3.2.5 Run Spatial Multi Criteria Evaluation Module

The parameters were combined in SMCE to produce a landslide hazard zonation map.

3.3.2.6 Interpretation of Result

Thematic maps for different parameters were created and are standardised and weighted in a criteria tree. Thematic maps were combined in SMCE to produce a landslide hazard zonation map. Derived results and discussions are explained in next chapter.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1. MAPPED THEMATIC LAYERS

To derive the LHZ map, seven numbers of factors like slope, soil, geology, landuse, aspect, rainfall and elevation were considered. Thematic maps for the mentioned parameters were created using ILWIS 3.31 software (Fig 20, Fig 21, Fig 22, Fig 23, Fig 24, Fig 25, Fig 26, Fig 27).

4.1.1 Slope

Slope map was derived from DEM using ILWIS software. Slope of any terrain is one of the factors that make the landmass more vulnerable to landslide. In gentle slope areas, surface runoff is slow allowing the water to get absorbed to the land, whereas, steep slope area facilitates high runoff and make the landmass vulnerable to the landslide. The slope map of the study area is derived from the Cartosat-1: DEM - Version-3R1 and slope of the study area is classified into nine classes, which is as per figure 20. It was reported that occurrence of landslide increased dramatically in areas where slope is between 6° and 45° (Baldiviezo *et al.,* 2004). Dai and Lee (2002) reported that landslide incidences were maximum when the slope angle is between 35° and 40°.

In literatures, slope length, slope percentage, slope convexity, slope direction (aspect) and slope steepness are all studied, while the slope angle is mostly used (Dai and Lee, 2002). The slope angle is directly related to the landslides; it is frequently used in preparing landslide susceptibility maps. The most important constraint indicator used for the national landslide risk assessment is the slope angle. For the current study slope angle is considered. The slope map of the study area was divided into 9 slope categories. In areas that have very gentle or flat slopes, landslides are not expected or occur only under very specific conditions. Landslides are expected more in areas with a slope angle ranging from 25° – 40° slopes.

Majority of the study area fall under 0^0-15^0 slopes followed by 30°-45° slopes (Fig. 20). Histogram showing the distribution of different slope categories is shown in Fig. 19.

The weights for slope classes were assigned in this analysis based on the literature reviewed (Ajin *et al.,* 2014 and Jishnu, 2015), ranging from 0 to 9, where 9 means high susceptible area for landslide and 0 none susceptible (Table. 7). Later these values were converted to a range 0 to 1.

4.1.2 Aspect

Aspect is defined as the direction of maximum slope of the terrain surface and has an indirect influence on slope instability. According to Sinha *et al.* (1975), as compared to the north facing slopes, the south facing slopes have lesser vegetation density and hence, the erosional activity is found to be relatively more in south facing slopes. The southern slopes are more exposed to sunlight and maximum anthropogenic activities are seen in such slopes. Aspect is measured counter clockwise in degrees from 0 (due north) to 360 (again due north, coming full circle). The derived aspect map represents nine classes, namely, N, NE, E, SE, S, SW, W, NW and flat as per the classification given in other studies (Anbalagan *et al.,* 2015 and Saha *et al.*, 2005). Flat slopes have no direction and are given a value of 0. The aspect of the slope is one of the major contributing factors for a landslide. It affects pore water pressure fluctuations and alternation of weathering environment brought on by wet/dry cycles. Degree of saturation of the slope-forming material is another major factor controlling the occurrence of landslides. Moisture retention and vegetation is reflected by slope aspect. It has been reported that in north facing slopes the landslide frequency is relatively low, and it increases with the orientation angle, reaching the maximum on south facing slopes and then declines (Dai and Lee, 2002).

Various studies and the Geological Survey of India report by Seshagiri *et al.* (1982), reveal that most of the landslides incidences in south facing aspect were caused by a higher amount of solar insolation in these slopes. It is also reported that slope with higher insolation and associated higher temperatures have increased erosion. Areas with removed vegetation will receive direct sunlight, forming drier soil conditions, thus increasing the possibility of landslide incidences. In the present study, aspect map is generated through GIS analysis and ranking is assigned to directions (Kanungo *et al.,* 2006) and formed as a thematic layer for subsequent overlay analysis (Table.8 and Fig. 21).

4.1.3 Soil

The occurrence of landslide is mainly due to the presence of huge thickness of loose soils. When mixed with rainwater, it triggers the landslide. Soil map and associated attribute information has been collected from KSLUB, Trivandrum. The mostly seen soil type in the study area is clay. Clay is a fine- grained natural rock or soil material that combines one or more clay minerals with traces of metal oxides and organic matter. Gravelly clay, gravelly loam and loam soil are other kinds of soil seen in the area. Thematic map for soil is generated for the study area (Fig. 22) and weights were assigned (Table. 9) based on reviewed literature (Ajin *et al.,* 2014 and Jishnu, 2015).

4.1.4 Geology

Different rock types (or lithology) have diverse composition and structure, which contribute to the strength of the material. The stronger rocks give more resistance to the driving forces as compared to the weaker rocks, and hence are less prone to landslides and vice versa.The three rock types present in this data layer are metamorphic, plutonic and residual cappings. Metamorphic rocks occupy majority of the study area followed by plutonic rocks.

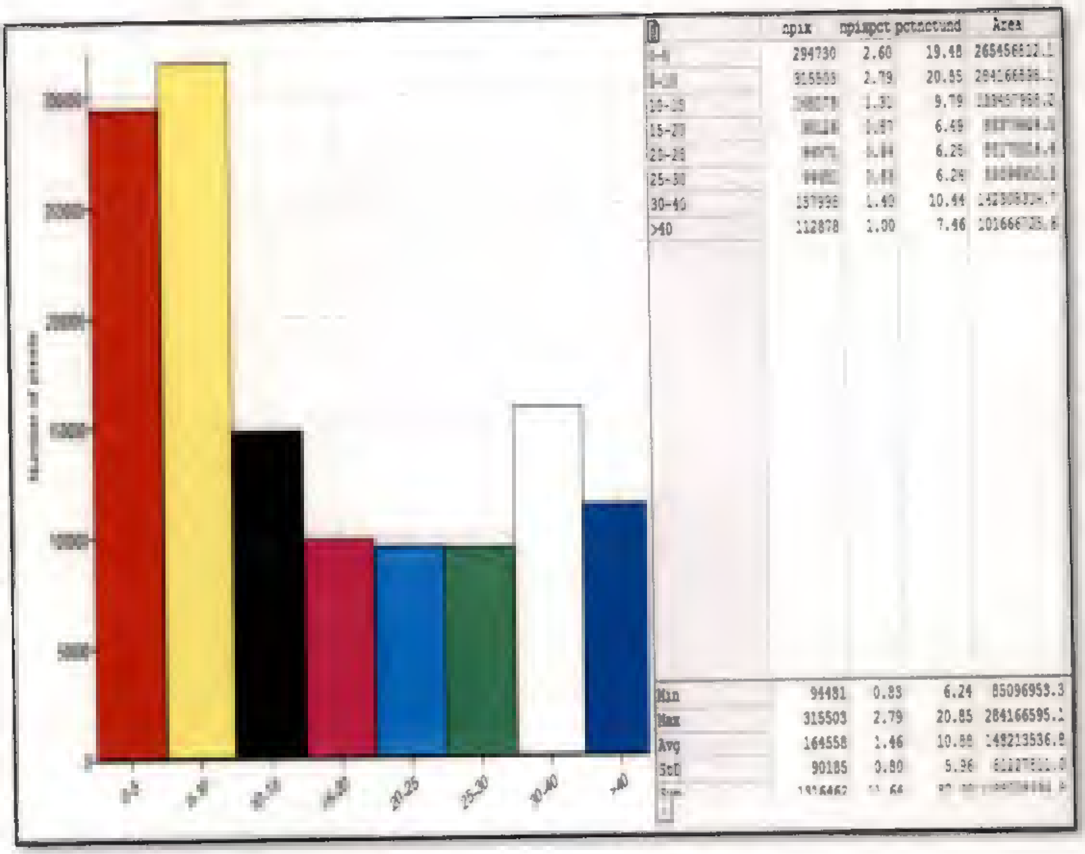
Slopes composed of metamorphic rocks, eventhough the the rock types are hard ones, the strata as a whole may exhibit weakness due to the presence of joint planes that have formed due to the influence of tectonic forces during the process of metamorphism.The soils occupying western ghats have low cohesion and rainfall is heavy and slopes are also steep which are favouring factors for landslides. Thematic map for geology (Fig. 23) was derived and weights were assigned (Table 10) based on lietrature study (Ajin *et al.,* 2014 and Jishnu, 2015).

Table 7. Weight assigned for slope

Sl.No	Slope (degree)	Weight
1	0-5	1
2	5-10	3
3	10-15	5
4	15-20	7
5	20-25	7
6	25-30	9
7	30-40	9
8	>40	9

Table 8. Weight assigned for aspect

Sl:No	Direction	Weight
1	Flat	0
2	North	1
3	North-East	4
4	East	7
5	South-East	8
6	South	9
7	South-West	6
8	West	3
9	North-West	2



	npix	npixpct	pctnotund	Area
[illegible]	294730	2.60	19.48	[illegible]
[illegible]	315503	2.79	20.85	[illegible]
10-15	[illegible]	[illegible]	9.79	[illegible]
15-20	[illegible]	[illegible]	6.49	[illegible]
20-25	[illegible]	[illegible]	6.25	[illegible]
25-30	[illegible]	[illegible]	6.24	[illegible]
30-40	157998	1.40	10.44	[illegible]
>40	112878	1.00	7.46	[illegible]
Min	94481	0.83	6.24	85096953.3
Max	315503	2.79	20.85	[illegible]
Avg	164558	1.46	[illegible]	[illegible]
StD	90185	0.80	5.36	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Fig 18. Histogram showing the distribution of different slope categories

Table 9. Weight assigned for soil

Sl.No	Index	Soil Type	Weight
1	K10	Gravelly clay	4
2	K18	Clayey	2
3	K19	Clayey	2
4	K20	Gravelly clay	4
5	K22	Clayey	2
6	K24	Gravelly loam	8
7	K26	Clayey	2
8	K27	Loamy	6
9	K29	Loamy	6

Table 10. Weight assigned for geology

Sl:No	Type	Weight
1	Metamorphic rocks	6
2	Plutonic rocks	4
3	Residual cappings	4

4.1.5 Landuse

Land use is another key factor responsible for landslide occurrences. The incidence of landslide is inversely related to the vegetation density. Hence, barren slopes are more prone to landslide activity as compared to the forest area. Changes in vegetation cover often results in modified landslide behaviour (Glade 2003). Twelve land use classes namely agriculture, built-up cities, cropland (Kharif), double crop (Kharif + Rabi), fallow land, forest deciduous, forest evergreen(dense), forest evergreen (open), forest plantations, grassland, waste land and water bodies have been considered for the current study.

Landuse is the human aspect which affects the degree of landslides susceptibility in some places. This is due to human activities conducted in steep areas which can reduce the stability of slopes. Many studies have been conducted that the landuse such as construction of roads in hilly areas will increase landslides susceptibility. As a result, several landslides have occurred on the road networks and nearby areas, whether they are on the upper or lower road slopes. Earlier studies report that rise in landslide frequency in Kerala are seen since 1940s by the onset of deforestation by migrant farmers to hilly areas. Land-use practices related to rubber (*Hevea brasiliensis*) plantations may have aggravated the situation. In our study area there are 12 types of land uses. Table 11 shows weighted values that were used based on the literature and weighting by several experts. (Ajin *et al.*, 2014 and Jishnu, 2015). Thematic map for the study area was created (Fig. 24).

4.1.6 Rainfall

The precipitous terrain causes rapid runoff and does not store water easily. Rainfall is considered as the triggering mechanism for landslides. High intensity rainfall causes heavy water discharge. With suitable terrain (high slope and elevation) the debris flow can be occurred (Kuriakose *et al.*, 2009).

Changes in the moisture regime, produces hydrostatic pressure. The increase in the pore water pressure in the soils cause a decrease in the mobilized shear resistance, which is likely to cause shear instability. Harmful effect of rainwater is more in areas cracking clay soils are present particularly after drought condition. Magnitude of the problem depends on the climatic conditions, topography of the area, geological structure, slope permeability and other properties of rocks and soils associated with intensity and frequency of rainfall. Weights were assigned for different rainfall ranges (Table 12) and rainfall map for the study area was developed using Thiessen polygon method in ILWIS 3.31 software (Fig. 25).

4.1.7 Elevation

Elevation is another important factor that causes landslides. As the height of the terrain increases, the possibility of the land mass movement also increases and vice versa. The Elevation map for the study is prepared from Cartosat-1: DEM - Version-3R1 and is classified into nine classes, as shown in figure 26. The weights were assigned (Ajin *et al.*, 2014 and Jishnu, 2015), to the individual heights as per the influence of the landslide phenomenon (Table 13).

Table 11. Weight assigned for landuse

Sl:No	Type	Weight
1	agriculture	8
2	Built-up cities	9
3	Cropland (Kharif)	7
4	Double crop (Kharif + Rabi)	7
5	Fallow land	9
6	Forest deciduous	2
7	Forest evergreen(dense)	2
8	Forest evergreen (open)	3
9	Forest plantations	2
10	grassland	9
11	Waste land	9
12	Water bodies	0

Table 12. Weight assigned for rainfall

Sl:No	Rainfall(mm)	Weight
1	1200-1400	4
2	1400-1600	4
3	1600-1800	4
4	1800-2000	6
5	2000-2200	8
6	2200-2400	8
7	2400-2600	8
8	2600-2800	9

Table 13. Weight assigned for elevation

Sl:No	Elevation(m)	Weight
1	0-250	2
2	250-500	2
3	500-750	2
4	750-1000	5
5	1000-1500	7
6	1500-1750	8
7	1750-2000	8
8	2000-2500	9
9	>2500	9

Table 14. Weight assigned for different factors

Factors	Weight
Slope	20
Soil	15
Geology	7
Landuse	18
Rainfall	10
Elevation	10
Aspect	3

4.2 LHZ MAP

This study aims to derive the landslide hazard zonation for the Nilambur Taluk of Malappuram District, Kerala, India using remote sensing and to suggest mitigation measures for controlling landslides. Landslide Hazard Zonation is achieved using spatial multi criteria evaluation (SMCE) module of ILWIS 3.31 RS-GIS software. The spatial multi criteria evaluation (SMCE) is based on the Analytical Hierarchical Process (AHP) developed by Saaty (1980). This is a technique for applying a common scale values to diverse and dissimilar input in order to create an integrated analysis. Landslide hazard zonation has been derived using the above model by integrating the eight preparatory factors. The hazard zonation is classified into three zones namely, low, moderate, and high hazard to landslides. The thematic layers of slope, aspect, soil, land-use, geology, elevation and rainfall were prepared. These thematic layers were assigned proper weightage (Table 14) through knowledge based weight assessment and then integrated in the GIS environment to prepare the landslide hazard zone map of the study area.

Integration of thematic maps for carrying out multi-criteria or overlay analysis in GIS environment was done using ILWIS software and the LHZ map for Nilambur Taluk has been created and is shown in Fig. 27. According to the LHZ map, 12.38 sq.km (0.94%) is located in the low hazard zone, 1080.79 sq.km (81.68%) in the moderate hazard zone and 230.03 (17.38%) in high hazard zone (Fig 29 and Table 15). Western regions of the study area including Akampadam, Kalikavu and Karuvarakundu and areas along Kozhikode - Nilambur - Gudallur Highway have highly unstable zones. The probability of occurrence of debris flow in this region is high during an intensified rain. These regions have steeply sloping topography and with heavy rainfall during the monsoon season it can cause heavy landmass movement. Some of the tourist spots are concentrated around Akampadam and Karuvarakundu regions like Adyanpara waterfalls and Keralakund waterfalls. Mampad rubber estate, Ariyani rubber estate and areas along Kanjirappuza fall under high hazard zone. Some of the reserved forest area is also coming under high hazard zone. LHZ map was validated with previous landslide points by overlaying landslide points on final map and a majority of landslide points fall under high hazard zone (Fig 28).

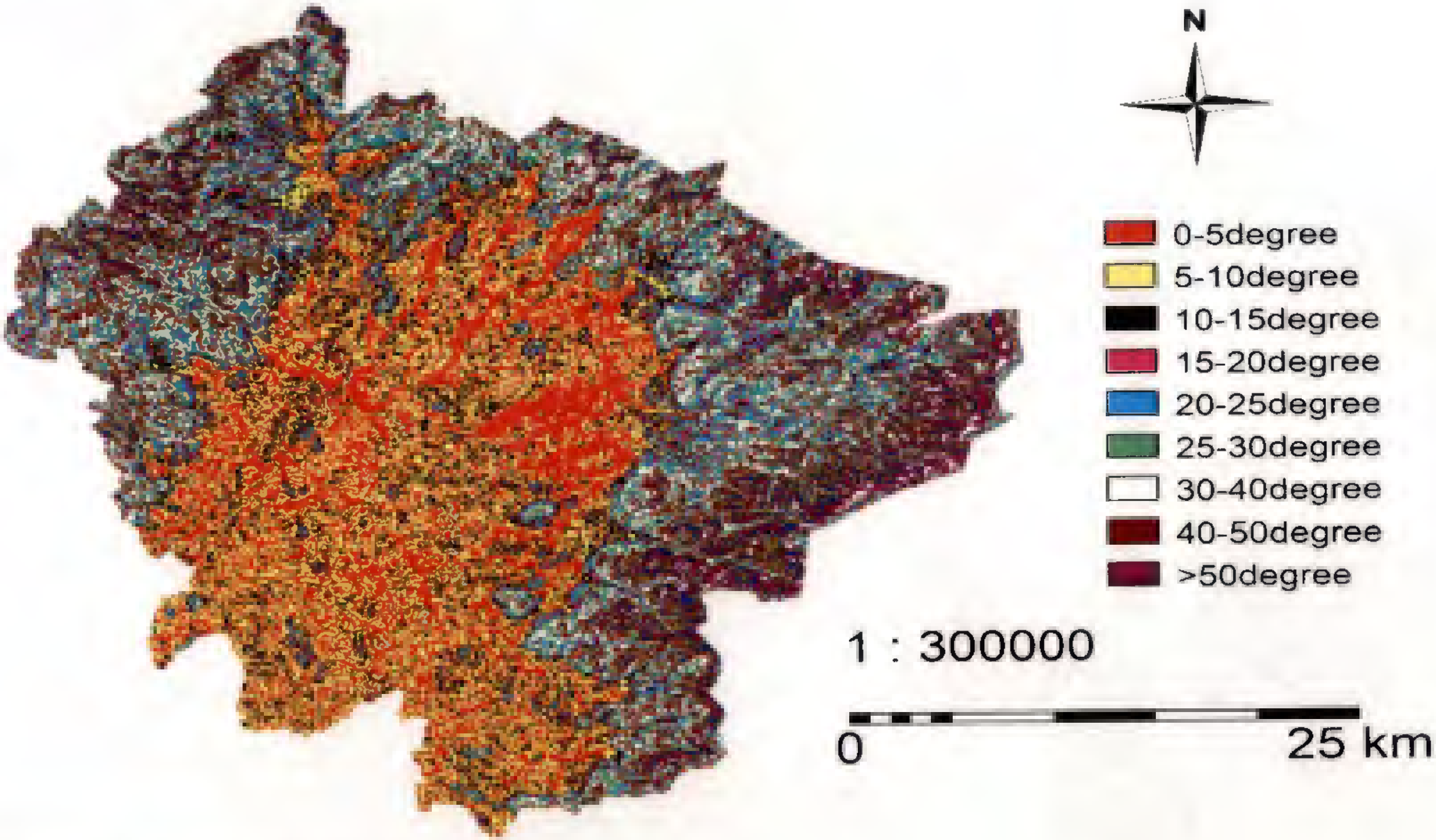


Fig 19. Map showing slope ranges of Nilambur Taluk

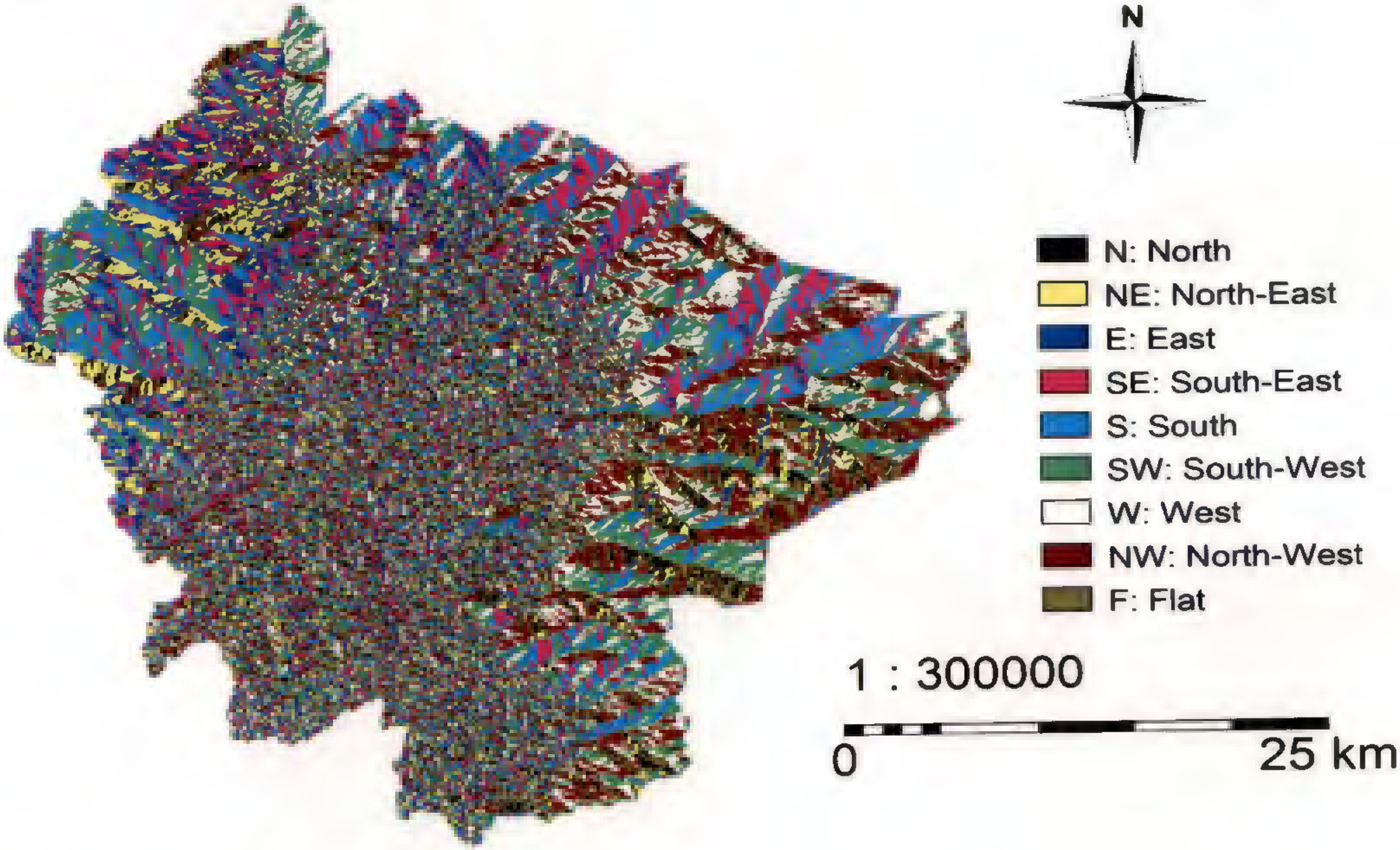


Fig 20. Aspect Map of Nilambur Taluk

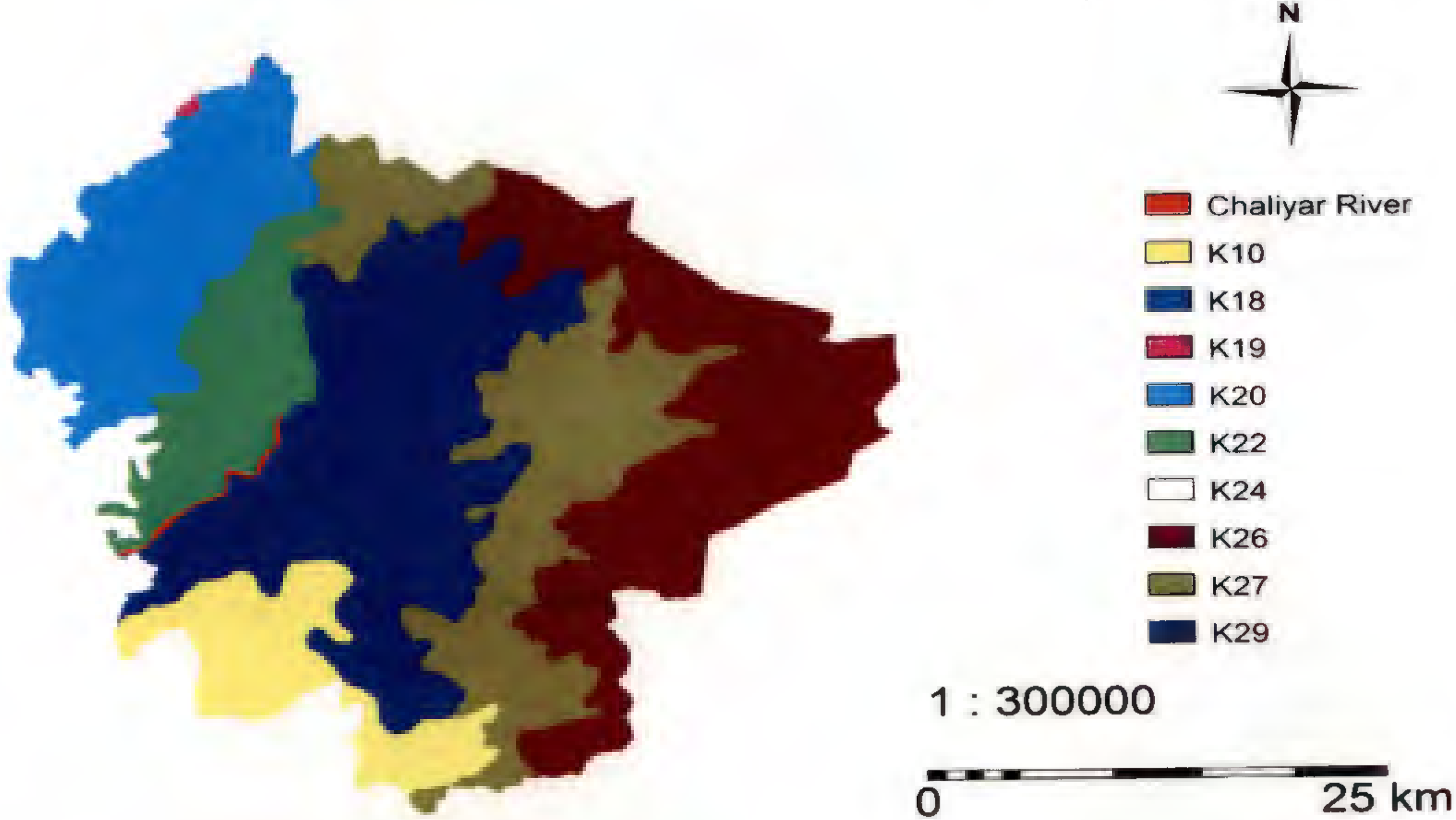


Fig 21. Soil Map of Nilambur Taluk

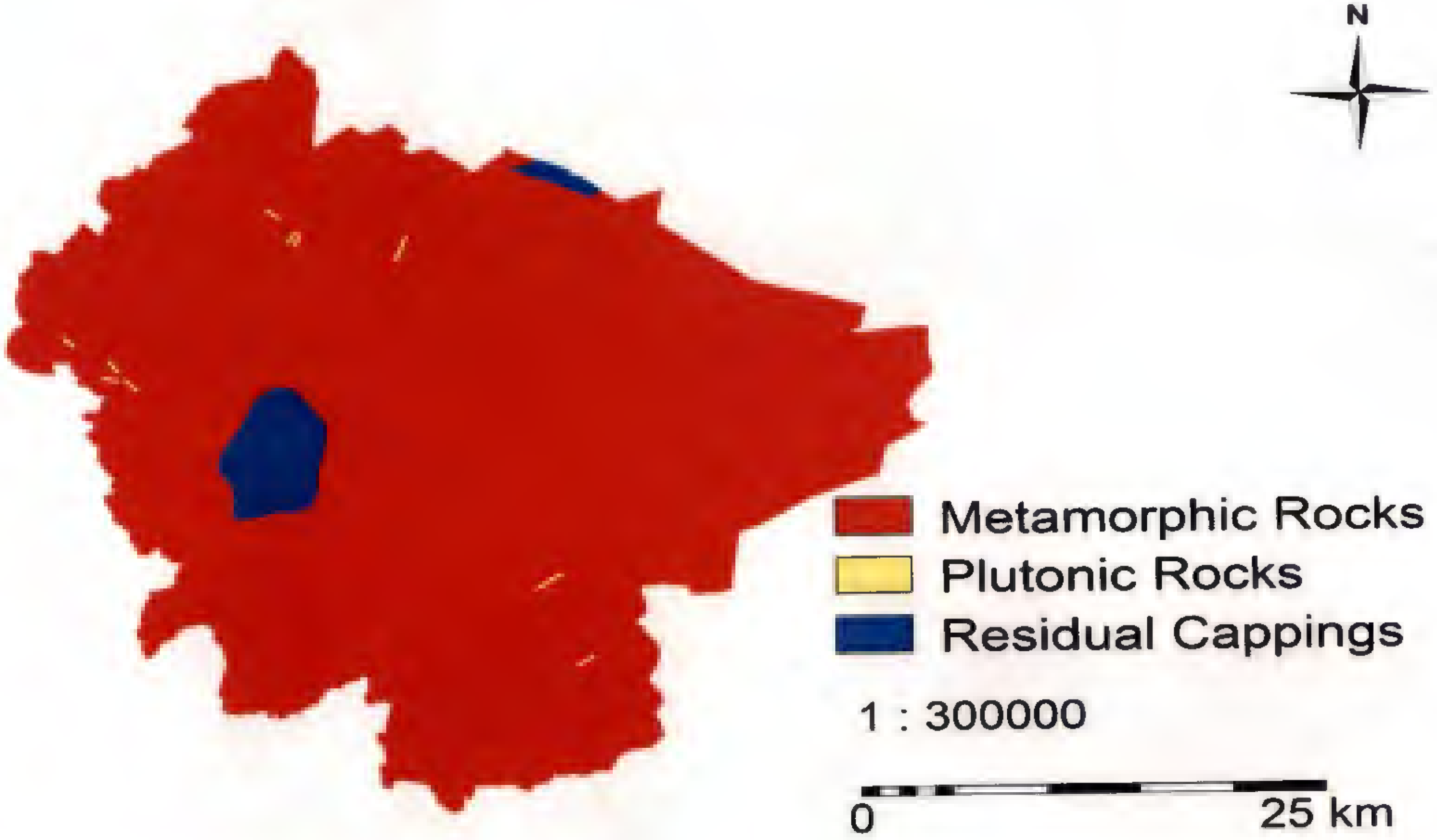


Fig 22. Geology Map of Nilambur Taluk

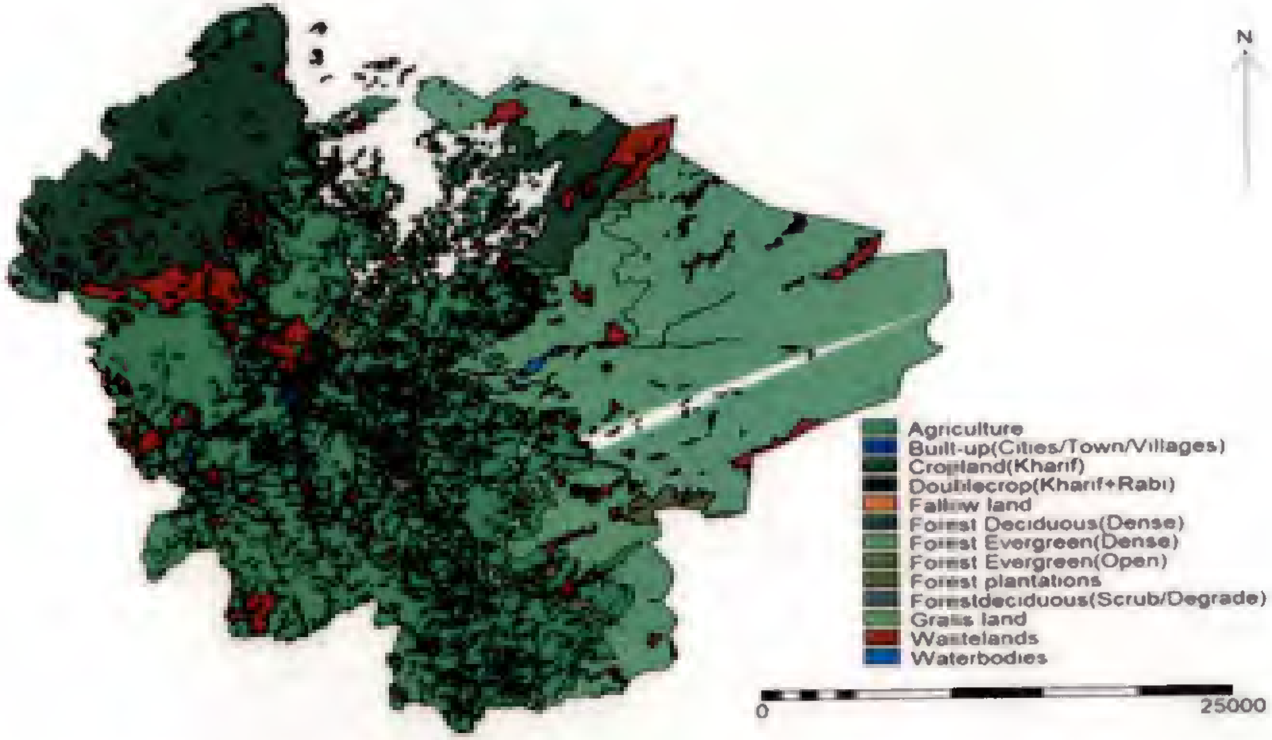


Fig 23. Landuse Map of Nilambur Taluk

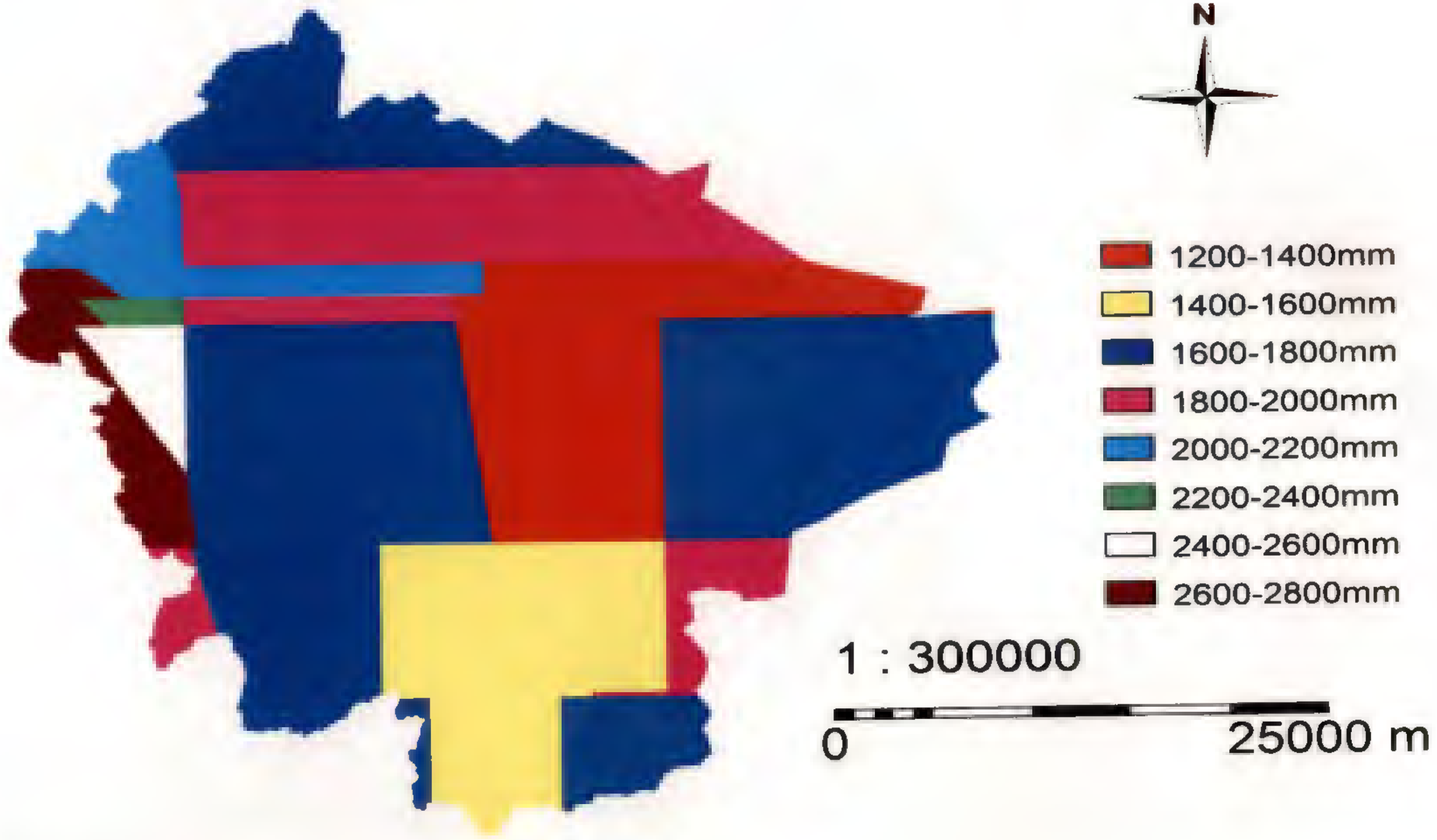


Fig 24. Rainfall Map of Nilambur Taluk

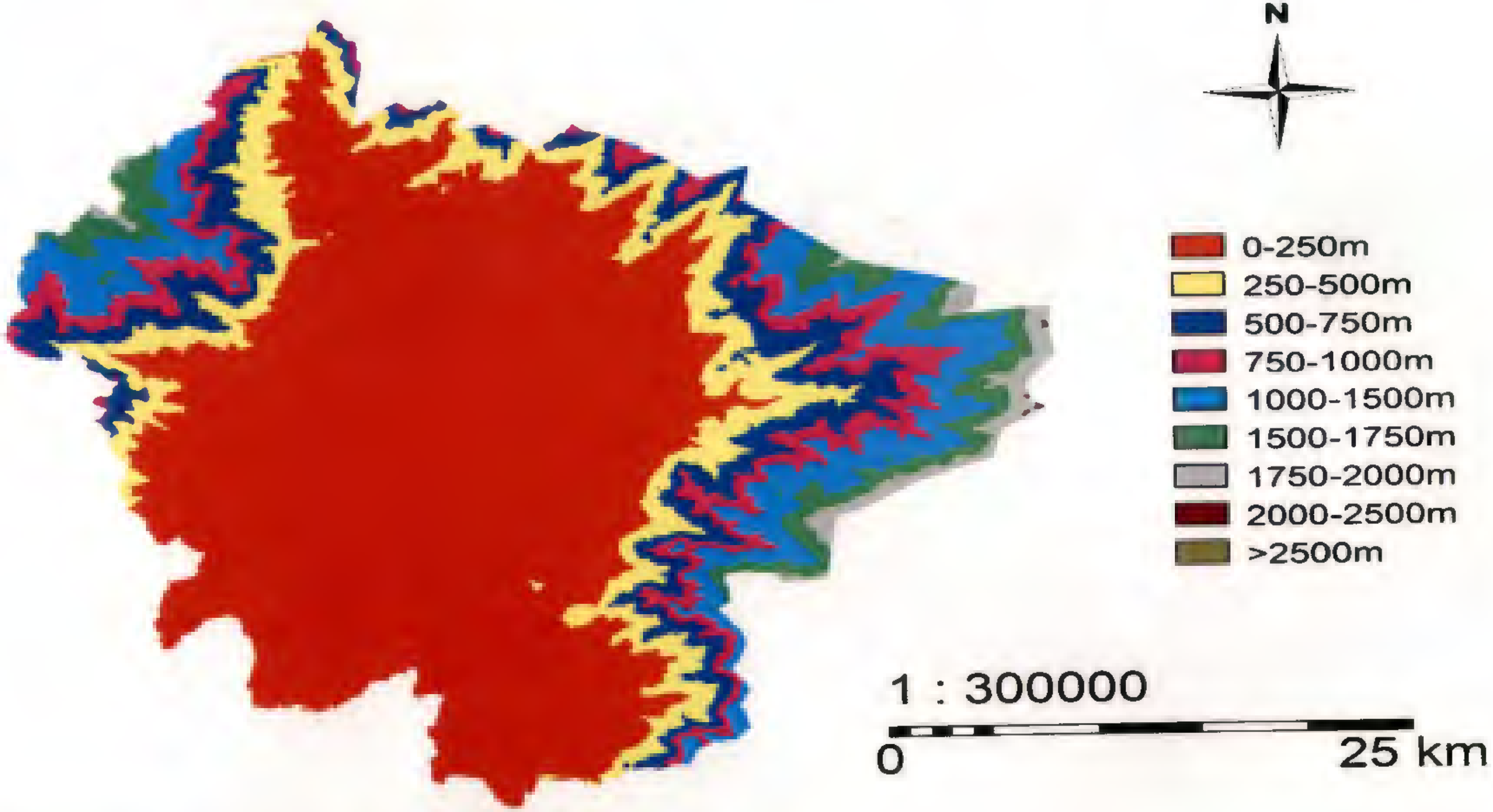


Fig 25. Digital Elevation Model (DEM) map of Nilambur Taluk

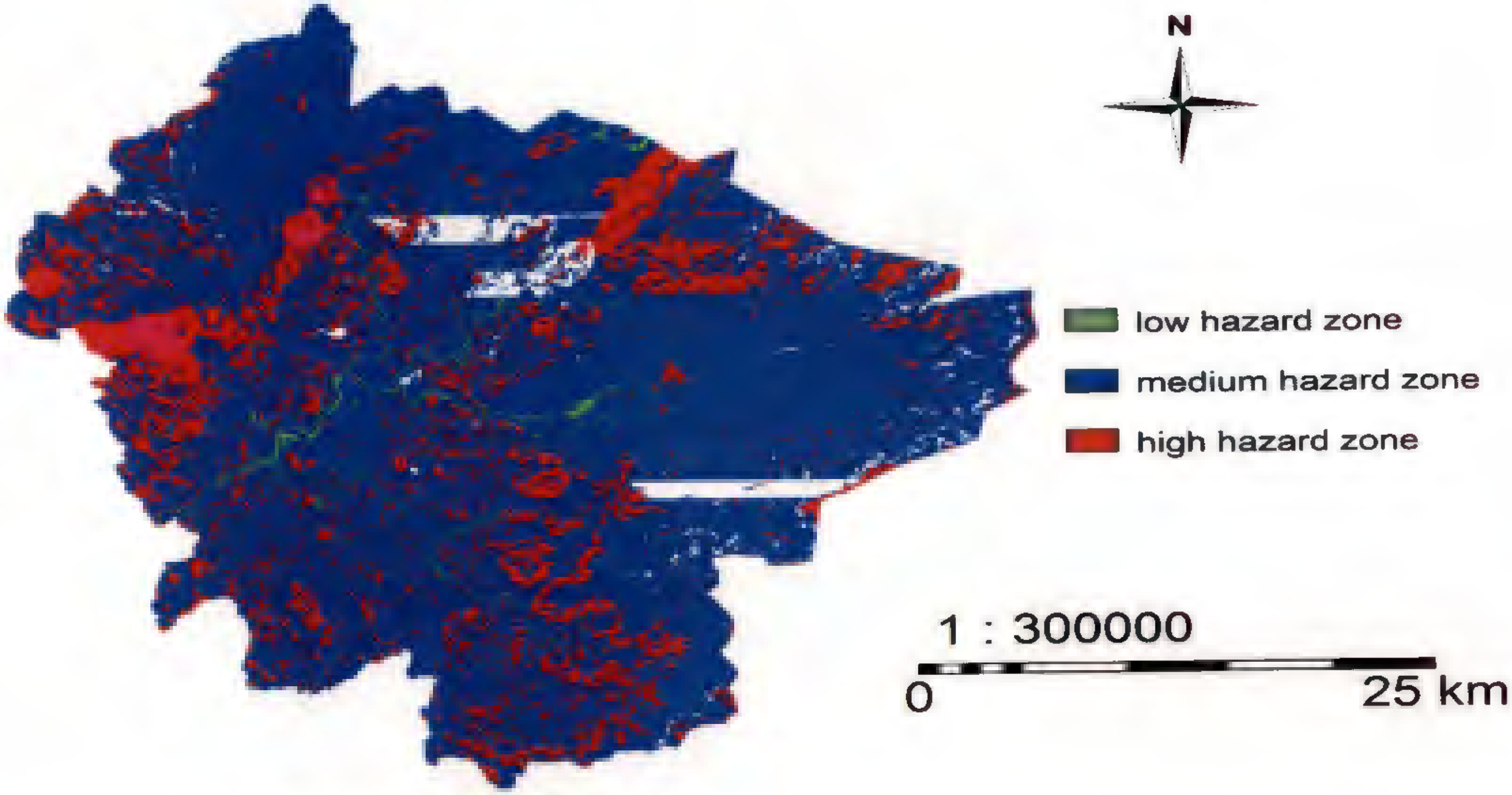


Fig 26. LHZ map of Nilambur Taluk

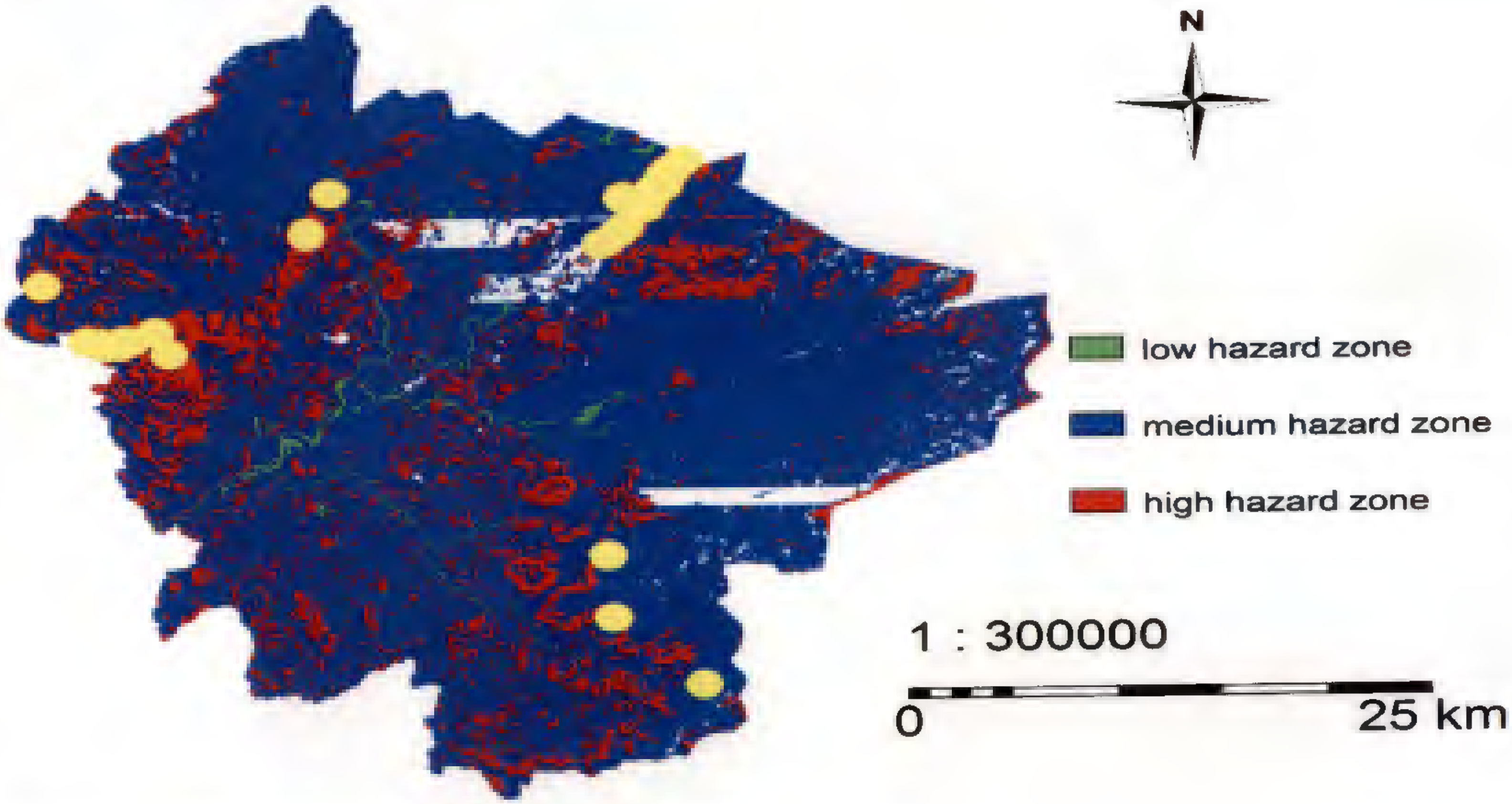
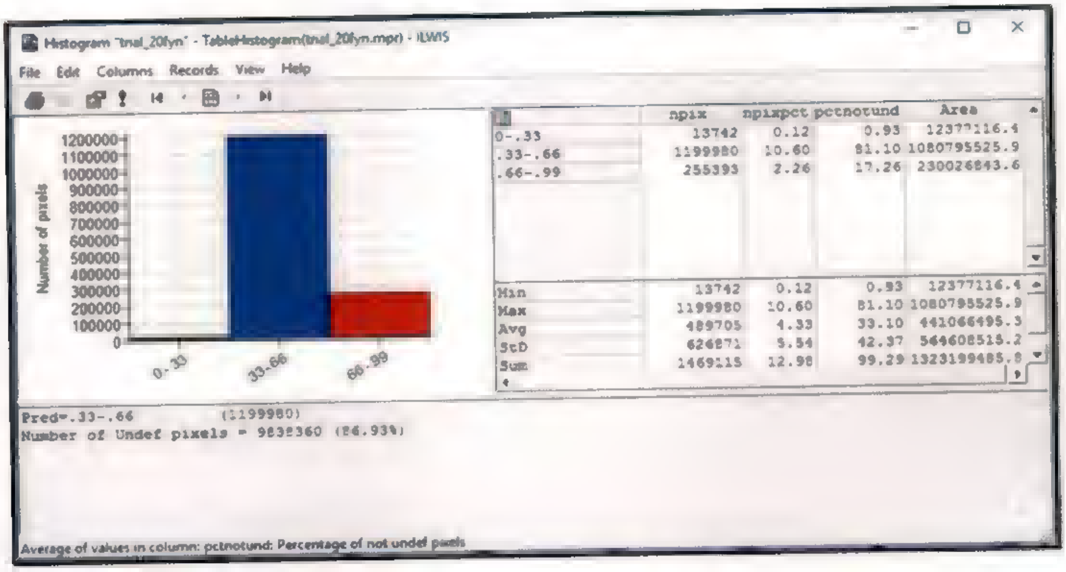


Fig 27. LHZ map overlaid with previous landslide points



```
                 npix  npixpct pctnotund        Area
0-.33           13742     0.12      0.93  12377116.4
.33-.66       1199980    10.60     81.10 1080795525.9
.66-.99        255393     2.26     17.26  230026843.6

Min             13742     0.12      0.93  12377116.4
Max           1199980    10.60     81.10 1080795525.9
Avg            489705     4.33     33.10  441066495.3
StD            626871     5.54     42.37  564608515.2
Sum           1469115    12.98     99.29 1323199485.8
```

```
Pred=.33-.66          (1199980)
Number of Undef pixels = 9832360 (86.93%)
```

Average of values in column: pctnotund: Percentage of not undef pixels

Fig 28. Histogram showing area under each hazard category

Table 15. Area and percentage of landslide hazard zones

Hazard	Area(sq.km)	Area (%)
Low hazard	12.38	0.94
Medium hazard	1080.79	81.68
High hazard	230.03	17.38
Total	1323.20	100

4.3 MITIGATION MEASURES

The following suggestions have been derived from the control and preventive measures of Central Road Research Institute (CRRI). This may be employed in order to reduce risk of landslide and to improve the mitigation measures.

4.3.1 Stabilization of slopes

Typical landslide stabilization measures include grading the unstable portion of the slope to a lower gradient, construction of retaining walls and drainage improvements. A stabilization measure provides a long-term solution but requires long-term maintenance costs. Controlling adverse human activities by diverting storm water away from steep slopes, maintaining appropriate native vegetation, and proper disposal of debris flow are measures that would improve stability.

Areas along Kozhikode - Nilambur - Gudallur Highway are found to be under high hazard zone. Stabilization of roads can be made along these hilly tracts and avoid further unscientific developmental activities along roadways. Cut slope failures are also reported from these areas. Proper drainage lines can be provided along roads and can be periodically maintained to prevent seepage of water on the cut face area of the road. Biotechnical and soil bioengineering stabilization are two widely adopted techniques nowadays and offer a cost-effective and attractive approach for stabilizing slopes against erosion and shallow mass movement. Modification of slope can be carried out prior to construction. This may include reduction of the slope angle but also improvement of soil type. When applying slope modification and cut and fill procedures strict analysis of the environmental impact is necessary. Changes in groundwater movement need to be evaluated and monitored.

Improper or poorly designed drainage systems can contribute to slope instability. To stabilize slopes, drainage should be brought down to the bottom of the slope. Subsurface drainage may be provided at the valley point to protect nearby agricultural lands. Proper drainage ensures surface erosion control.

For reducing landslide risks, the major measure is the regulation of landuse. Afforestation and forest conservation can be practiced in the area of dense and medium vegetation. Slope modification and afforestation can be practiced in the area of Degraded Vegetation / Forest blank with 25° – 45° slope.

4.3.2 Protection

Protection measures for landslides primarily focus on control or diversion of the moving debris. Protective measures to stop the slide, or steer away the debris flow from a settlement involves engineering measures such as concrete retaining walls, ditches and catchment basin. However, considerable long-term maintenance costs are often associated with these measures to clean out and dispose of accumulated debris. Destruction of natural forest in anticipation of new tree plantation may be abolished

4.3.3 Avoidance

Avoidance measures are considered as a permanent solution to a landslide hazard. Measures include repositioning away from the slope, relocation of the facilities and associated infrastructures to safer areas, which is quite a difficult method to adopt in our condition. Planned development activity can be made in the area of built-up area falling in moderate hazard zone and can avoid further constructional activity in the area of high hazard with 20° – 40° slopes. Landuse limitations also aim a reduction of probability of landslide activation.

4.3.4 Maintenance and monitoring

Maintenance and monitoring measures may involve active cleanout of available catchment areas, regular observation and assessment of slope conditions, landslide-warning, monitoring slope and weather instrumentation. Generally, these measures are relatively low cost and can be highly effective in reducing public exposure to landslide risk. There is a need of instrumental monitoring of landslide, collection of relevant field data, preparation of hazard maps and development of suitable models to forecast the behaviour of landslide prone area.

There are a number of different actions adopted and attempted to control problems with full, partial and no success for different cases all over the world. It is very rare that a major problem could be controlled by one particular technique, since the parameters involved in instability are numerous in most of the cases. One technique may be very successful at one site and on the other hand may fail at another spot.

CHAPTER 5

SUMMARY AND CONCLUSIONS

Landslide is a natural disaster that causes severe damage to life and properties. Many areas of Western Ghats of Kerala are highly prone to landslide activity. Thus the landslide mapping of Nilambur Taluk, which is one among the five most landslide prone taluks of Kerala, is taken up.

This study aims to derive the landslide hazard zonation for the Nilambur Taluk of Malappuram District, Kerala, India using remote sensing and to suggest mitigation measures for controlling landslides. Landslide Hazard Zonation is achieved using spatial multi criteria evaluation (SMCE) module of ILWIS 3.31 RS-GIS software. The spatial multi criteria evaluation (SMCE) is based on the Analytical Hierarchical Process (AHP) developed by Saaty (1980). This is a technique for applying a common scale values to diverse and dissimilar input in order to create an integrated analysis. Landslide hazard zonation has been derived using the above model by integrating the eight preparatory factors. The hazard zonation is classified into three zones namely, low, moderate, and high hazard to landslides. The thematic layers of slope, aspect, soil, land-use, geology, elevation and rainfall were prepared. These thematic layers were assigned proper weightage through knowledge based weight assessment and then integrated in the GIS environment to prepare the landslide hazard zone map of the study area.

Integration of thematic maps for carrying out multi-criteria or overlay analysis in GIS environment was done using ILWIS 3.31 software and the LHZ map for Nilambur Taluk has been created and is shown in Fig 27. According to the LHZ map, 12.38 sq.km (0.94%) is located in the low hazard zone, 1080.79 sq.km (81.68) % in the moderate hazard zone and 230.03 (17.38%) in high hazard zone. Western regions of the study area including Akampadam, Kalikavu and Karuvarakundu and areas along Kozhikode - Nilambur - Gudallur Highway have highly unstable zones. Some of the tourist spots are concentrated around Akampadam and Karuvarakundu regions like Adyanpara waterfalls and

Keralakund waterfalls. Mampad rubber estate, Ariyani rubber estate and areas along Kanjirappuza fall under high hazard zone. Some of the reserved forest area is also coming under high hazard zone.

Mitigation measures for controlling landslides have been suggested. These include stabilization of slopes, ensure proper drainage, control of plantations along hilly areas, afforestation, stabilization of roads along hilly areas and avoidance of further constructional activity in the area of high hazard with 20° – 40° slopes. LHZ map was validated with previous landslide points by overlaying landslide points on final map and a majority of landslide points fall under high hazard zone.

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LANDSLIDE HAZARD ZONATION OF NILAMBUR TALUK USING REMOTE SENSING

By

ASLA K

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ABSTRACT OF THE THESIS

Faculty of Agriculture

Kerala Agricultural University

ACADEMY OF CLIMATE CHANGE EDUCATION AND RESEARCH

KERALA AGRICULTURAL UNIVERSITY

VELLANIKKARA, THRISSUR – 680656

KERALA, INDIA

2016

ABSTRACT

Present study aims at the preparation of a landslide hazard zonation map for Nilambur Thaluk of Malappuram district, Kerala and to suggest mitigation measures for controlling landslides. Landslide Hazard zonation is achieved using spatial multi criteria evaluation (SMCE) module of ILWIS 3.31 RS-GIS software. SMCE is based on the Analytical Hierarchical Process (AHP) developed by Saaty (1980). Different parameters contributing to landslides were identified. Thematic maps of various parameters like slope, aspect, soil, geology, landuse, rainfall and elevation were prepared. These thematic layers were standardised and overlaid with appropriate weights to generate landslide hazard zones of Nilambur Taluk. The study area was divided into three zones namely low, medium and high hazard zones.

Landslide Hazard Zonation (LHZ) map of the Nilambur Thaluk was prepared using the SMCE module of ILWIS software. According to the LHZ map, 12.4 km^2 (0.94%) is located in the low hazard zone, 1080.8 km^2 (81.68) % in the medium hazard zone and 230 km^2 (17.38%) in high hazard zone. Study found that most of the areas fall under medium hazard zone followed by high hazard zone. Analysis of the LHZ map, revealed that the Western regions of the study area including Akampadam, Kalikavu and Karuvarakundu and areas along the Kozhikode - Nilambur - Gudallur Highway are highly unstable. The probability of occurrence of debris flow in this region is high. These regions have steeply sloping topography and with heavy rainfall during the monsoon season it can cause heavy landmass movement. Some of the tourist spots are concentrated around Akampadam and Karuvarakundu regions like Adyanpara waterfalls and Keralakund waterfalls. Mampad rubber estate, Ariyani rubber estate and areas along Kanjirappuza fall under high hazard zone. Some of the reserved forest area is also coming under high hazard zone. Landslide mitigation measures like slope stabilization, drainage, control of plantations, afforestation, stabilization of roads and avoiding constructional activity in high hazard area have been suggested. The LHZ map was validated by overlaying with previous landslide points.