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GEOSPATIAL APPROACH FOR LANDSLIDE DISASTER MANAGEMENT: A CASE STUDY FROM INDIA

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Abstract:

Landslides of shallow nature but disastrous are very common in the hill ranges of Kerala, the southernmost state of India. The increased frequency of slope failures have been associated with unscientific land use practices and developmental activities in naturally existing landslide hazard area. An assessment of landslide hazards is therefore, a prerequisite for sustainable development of the region. The present study uses Remote Sensing and GIS for finding susceptible zones of landslide hazards in Malappuram District which has an arealextented of 3555 Km^2. Nine factor layers responsible for landslide occurrence, such as, relative relief, slope, aspect, curvature, drainage density, drainage frequency, landuse, road buffer and drainage buffer are assigned numerical rating as per earlier workers and used for the purpose of landslide hazard zonation. Map delineates critical risk, high risk, moderate risk, low risk and no risk zones. 11.5% of the district is identified as critical and high risk zones. For the ready use in disaster management a hazard zonation map at the level of lowest administrative unit (Panchayth level) is prepared. Accordingly the Karulaigramapanchayath has maximum area under critical risk zone (17.27 Km^2) followed by Chungathara (12.84 Km^2) and Karuvarakund (8.21 Km^2). The landslide susceptibility assessment will be useful to planners and engineers to know the zones which are more vulnerable to landslide disaster and can evolve strategies for disaster risk reduction.

Key Words: Landslide Hazard Zonation, Charnockite Group, Geo Factors & Geospatial Analysis

1. Introduction:

The Western Ghats of Kerala experiences widespread occurrences of landslide from time immemorial. However, in the last decade frequency of slope failures and the amount of damage and casualties has increased considerably. Five major slope failures in a series occurred on 17 th July 2007 within an area of 5 Km^2 in the Malapuram district. An assessment of potential hazardous zones is, therefore necessary to delineate the area into various landslide hazard zones for sustainable planning and implementation of other developmental schemes in the district. For this purpose, a macro zonation of the landslide hazard was carried out on 1:50000 scale (Fig 1). Macro zonation mapping involves the special assessment of the terrain to delineate areas of potential landslide zones of various magnitudes. Various workers have used different methodologies and different parameters for landslide hazard zonation (Sharma 2008; Vijith and Madhu 2007; Talaei2014). The aim of these methods is to identify the hill slope that are susceptible to future slope failure based on the knowledge of paleoslide, geological aspect, terrain parameters and other environmental conditions that are associated with the event.

2. Study Area:

The area of the study is located in between North longitude 10°40' and 11°30' East longitudes 75°50' and 76°36' with an aerial extend of 3555 Km^2 (Fig 1). District is a higher administrative unit in each state and gramapanchayaths form the lowest administrative unit in each district. Malappuram District consists of hundred and two gramapanchayaths altogether. The climate is tropical humid characterised by moderate temperature and heavy rainfall occurs during the monsoon season and the average annual rainfall is 2793 mm.

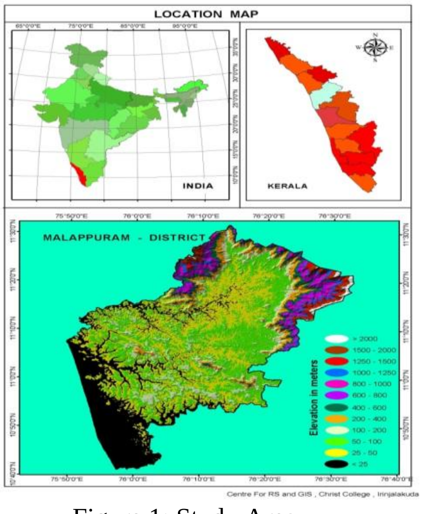

Figure 1: Study Area

3. Geology of the Area:

Two major geological belts can be observed in Malappuram District. The majority of the area is covered by charnockite group of rocks. The eastern parts comprisesmigmatite. Charnockite group includes charnockite, charnockite gneiss, granitic gneiss and hornblende boitite gneiss. Decreasing order of abundance in areal distribution are banded magnetite quartzite, pyroxene granulite, amphibolites, hornblende granulite and pyroxenite. Migmatitic complex is represented by biotite hornblende gneiss and quartzofeldspathic gneiss. Pegmatite and quartz veins constitute acid intrusive where as dolerite and gabbro are the basic intrusives. Lateritisation is wide spread, at places attaining a thickness of morethan 10 m near the coast, isolated cappings of Neogene Warakali sediments noticed. Quartenary unconsolidated sediments are restricted to the coastal planes.

4. Methodology:

The data sources for the present study are the GPS location of landslides, Survey of India toposheets, geological map prepared by GSI and remote sensing data. The Survey of India Toposheets provided the, drainage network, land use and road net work of the area. The SRTM data was used to derive the elevation of the area. For spatial analysis Arc GIS and ERIDAS have been used. Geo spatial analysis is attempted using various thematic maps prepared on a GIS platform (Scale 1:50000) using toposheets, remote sensing and field data. The methodology involves the preparation of various thematic/factor maps using GIS software. Nine landslide inducing factors were considered in the present study for calculating the probability of the landslides. The susceptibility study was based on the previous occurrence landslides locations which were collected using GPS. The locations were then digitized as point layer. Then created a database to assess the surface area and number of landslides in the study area. The thematic maps of geo factors such as slope, relative relief, aspect, curvature, drainage density, drainage frequency, landuse, road buffer and drainage buffer were generated in a GIS after extensive image interpretation and field work.

The ground survey conducted during south west monsoon period from 2009 to 2010, provides a first evaluation of the usefulness of SRTM data for this purpose inorder to validate physically, the landslide susceptibility map prepared in GIS, the maps compared and verified with field information on later slope failures in critical and highly unstable zones.

5. Terrain evaluation using Geospatial Analysis:

A numerical rating called LSR (Landslide SusceptibilityRating) is assigned to each of the parameters based on their relative importance depending upon the terrain conditions, field data methodology adopted by many workers (Thampi 2006; John Mathai 2009; Sreekumar and Arish Aslam 2013). The terrain factors selected for hazard zonation and their respective landslide susceptibility values assigned are tabulated in the Table 1.

Table 1: Different factors and LSR values

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

After assigning landslide susceptibility ratings, a LSIis computed for each factor with a correlation of landslide percentage per Km^2 of that category and the LSR assigned to it. The LSI, Eq. (1), is calculated by summation of each factor's ratio value using the raster calculator option of the software.

$$LSI= Dl+ Ds+ Da+ Dr+ Dd+ Df+ Dm+ Db+ Dc \quad \text{Equation (1)}$$

Where, Dlis frequency ratio of land use; Dsis frequency ratio of slope; Dais frequency ratio of aspect; Dris frequency ratio of relative relief; Ddis frequency ratio of drainage density; Dfis frequency ratio of drainage frequency; Dm is frequency ratio of distance from road; Db is frequency ratio of distance from drainage and Dcis curvature respectively.Thus, LSI maps corresponding to the quantitative zonation model has been prepared.

6. Result and Discussion:

6.1 Hazard Zonation Using GIS: The DEM (Digital Elevation Model) was created by scanning and digitizing all the contours and converted them into the vector form from the raster layer.

6.2 Slope: Hill slope is a very important parameter in the preparation of Landslide Hazard Zonation Map of an area. The map defines various slope categories of the study area and has been prepared by transforming the SRTM data into slope angles at any given point. Thampi et al 1988 reported that the maximum slide population is observed in slope category 25°- 35°. In Malappuram the slope ranging from 10-15° shows maximum number of slides in all, 10 slope categories are identified and areas falling under category in Malappuram district have been worked out (Table 2, Fig 2). The distribution pattern of slopes indicates that in Malappuram 11.50 % lies above 30°.

Table 2: Slope

S.No	Class	Area	LS% / km^2	LSI
1	0 - 5	1968.98	0.00	0.00
2	5 - 10	714.46	3.05	0.91
3	10 - 15	298.88	16.99	5.10
4	15 - 20	206.67	10.53	3.16
5	20 - 25	141.79	20.47	6.14
6	25 - 30	96.87	37.45	11.24
7	30 - 35	63.09	11.50	3.45
8	35 - 45	53.59	0.00	0.00
9	45 - 65	10.41	0.00	0.00
10	>65	7.47	0.00	0.00
	Total		100.00	30.00

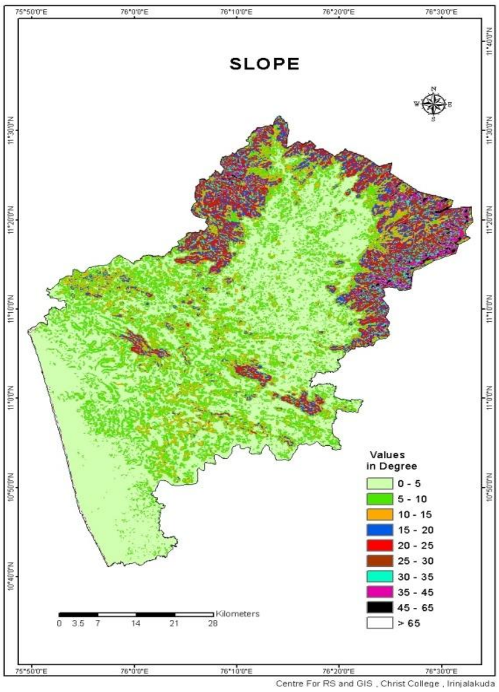

Figure 2: Slope Map

6.3 Relative Relief:

It is the difference in height between the highest and lowest point per unit area. Thampi et al 1988 reported that the maximum slide is associated with a relief of 200-400m range (Table 3). In Malappuram district, 64.27% of this area comes underthis category. In Malappuram district landslides are more often seen in slopes with relief 200-400 m.

Table 3: Relative Relief

S.No	Class	Area	LS% / km^2	LSI
1	<50	1424.80	0.00	0.00
2	50 – 100	1051.04	1.69	0.17
3	100 – 200	365.37	4.86	0.49
4	200 – 300	262.03	23.72	2.37
5	300 – 400	197.08	40.55	4.05
6	400 – 500	115.73	15.34	1.53
7	500 – 600	64.15	13.84	1.38
8	>600	82.02	0.00	0.00
	Total		100.00	10.00

6.4 Exposure Aspect:

Another highly significant factor in slope stability determination is the aspect. It represents the direction of slope and refers to the direction in which a mountain/hill slope faces a possible amount of sunshine and shadow. Slope aspect influence terrain exposure to storm fronts (Rajakumar et al 2007). It also effects the fluctuation of pore water pressure and mechanical weathering process. Degree of saturation of slope forming materials is also a major factor controlling the occurrence of landslide. Moisture retention and vegetation is reflected by slope aspect. The contrasting steepness and southwest slopes appear to be explained in terms of difference in exposure (Hack and Goodlett 1960). The north facing slopes are sheltered more than south west facing slopes from drained wind and sunrise and as a result retain more moisture. The more moist slope is consistently steeper than the drier south west slope due to the greater intensity of the surficial process acting on the drier slope flattening it more easily. In Malappuram district slopes with north aspect determined as 38.15%. In Malappuram north and west, trending slopes shows maximum slides (Table 4).

Table 4: Exposure Aspect

S.No	Class	Area	LS% / km^2	LSI
1	Flat	22.65	0.00	0.00
2	N	401.42	38.15	1.91
3	NE	398.75	0.00	0.00
4	E	390.35	0.00	0.00
5	SE	419.89	9.12	0.46
6	S	487.90	3.92	0.20
7	SW	508.15	3.77	0.19
8	W	477.25	28.08	1.40
9	NW	451.51	16.96	0.85
	Total		100.00	5.00

6.5 Curvature: Based on the curvature of the slopes it has categorised into 3 types, concave, convex and flat. The distribution of the area in each category is provided in table 5. In Malappuram, concave curvature exhibited the maximum slope.

Table 5: Curvature of slopes

S.No	Class	Area	LS% km^2	LSI
1	Concave	1799.80	63.05	3.15
2	Flat	124.33	0.00	0.00
3	Convex	1638.09	36.95	1.85
	Total		100.00	5.00

6.6 Drainage Density: Rivers and its distributaries mainly carry out the natural method of landscaping of a region in Western Ghat. The running water is a very important geological agent in effecting transportation of the weathering product from a elevated area to lowland area. Therefore it is necessary to evaluate the drainage characteristics of the terrain. An understanding of the drainage network helps us to learn how this factor involved in land degradation. The initial finger tip tributaries are called the first order streams when two first order streams join a second order stream and two second order stream join to form a third order and so on. The number, length, gradient etc of streams can be evaluated in terms of total drainage density. Drainage density is defined as the ratio of the total length of streams to the total area. High drainage densities are indicative of impervious strata, high rainfall, little vegetation and active stream incision all of which may be associated with mass movement (Cook and Doornkamp 1978).The drainage map Malappuram exhibits the dendritic pattern. In Malappuram 90.09 % of the area is covered by second and third order stream (Table 6). In the district the slope failures are more frequent in stream orders first, second and third.

Table 6: Drainage Density

S.No	Class	Area	LS% / km^2	LS1
1	0 -1	281.37	0.00	0.00
2	1 - 2	1381.92	9.91	0.69
3	2 - 3	1013.87	90.09	6.31
4	3 - 4	275.17	0.00	0.00
5	4 - 5	143.71	0.00	0.00
6	>5	457.77	0.00	0.00

6.7 Drainage Frequency: The drainage map was over lied by grid cover of size 1 square kilometer. The number of drainage lines present in each grid is counted which will give the drainage frequency value. The study area has been classified into five types based on the number of drainage incidences (Table 7). Most of the landslides are associated with drainage frequency class 3-4 in Malappuram district.

Table 7: Drainage frequency

S.No	Class	Area	LS% / km^2	LS1
1	0 -1	795.13	0.00	0.00
2	1 – 2	1525.41	2.61	0.21

3	2 – 3	611.40	4.35	0.35
4	3 – 4	489.92	32.57	2.61
5	>4	131.94	60.47	4.84
	Total		100.00	8.00

6.8 Landuse / Land Cover: Slope failures in the Western Ghats are generally associated with the monsoon period. Vegetation cover is found to be an important factor that is influencing the landslide occurrence during this period. From various investigations, it is under stood that Landuse / land cover, especially of a woody type with deep root and strong roots helps to keep the material intact (Gray and Leiser 1982). The natural features on the slope undergo continuous change. The degree of change varies in the districts. In Malappuram district the plantation covers 76.98 % of the total area (Fig 3). Within the plantation, rubber covers an area of 29.81 %. The slope failures are more often found in rubber plantations (Table 8).

Table 8: Land Use

Class	Area	LS% / km^2	LS1
Rubber	404.91	29.81	5.96
Cashew	58.67	29.39	5.88
Mixed plantation	1453.58	4.74	0.95
Forest plantation	132.70	12.99	2.60
Forest	605.00	17.10	3.42
Cropland	394.03	0.00	0.00
Grass land	1.07	0.00	0.00
Built up	69.58	0.00	0.00
Sandy area	31.15	0.00	0.00
Water logged	45.36	0.00	0.00
Barren area	63.79	0.00	0.00
Scrub	288.53	5.98	1.20
Fallow land	4.11	0.00	0.00
Mangrove	1.33	0.00	0.00
Total		100.01	20.00

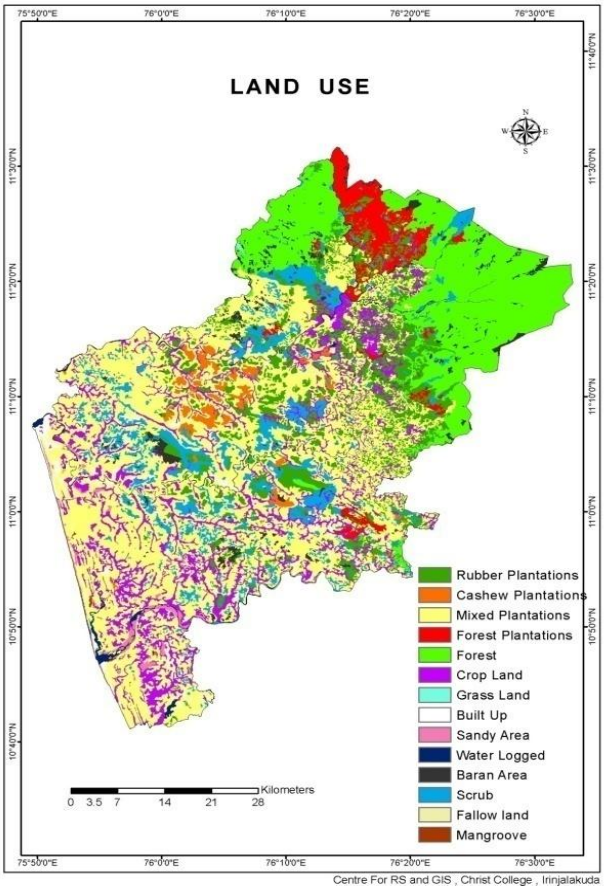

Figure 3: Land Use Map

6.9 Road Buffer: The micro level study has revealed that many slopes are at the threshold of failure. During continuous and excess rainfall three or four days during monsoon can result in the reduction of factor of safety and leads to failure. The heavy traffic along the road produces vibration and this can act as a triggering force in such locations. The proximity to communication arteries is definitely a factor in making the slope vulnerable to slide. Depending upon the distance of the slope from the road six categories has been defined (Table 9). In Malappuram districts majority of the hill slopes are much closer to the road. More incidences are reported in slopes with in 100m from the road. However, the influence of the traffic in Malappuram inducing slide is not much evident.

Table 9: Road Buffer

Class	Area	LS% / km^2	LSI
1	0 – 100	0.0129	33.76
2	100 - 200	0.0119	31.20
3	200 - 300	0.0080	21.09
4	300 - 400	0.0000	0.00
5	400 - 500	0.0000	0.00
6	>500	0.0053	13.96
	Total	0.0381	100.00

6.10 Drainage Buffer: As the distance from the drainage line increases landslide frequency generally decreased because the seepage of water near the drainage network is more compared to distant one. The water seepage can reduce the shear strength of the slope material and can activate landslides. The earlier study on drainage frequency and density reveals that the area has a good drainage network. In Malappuram district all the slopes are within 450m from the drainage.

Table 9: Drainage Buffer

Class	Area	LS% / km^2	LSI
1	0 -150	0.0132	84.85
2	150 -300	0.0000	0.00
3	300 -450	0.0024	15.15
4	>450	0.0000	0.00
	Total	0.0155	100.00

6.11 Landslide Susceptibility Zonation: The LSI values have been classified into five classes to yield five Landslide Susceptibility Zones, viz. No risk, lowRisk, Moderaterisk, High risk and Critical risk. The LSI values of Malappuram are between 0 to 43.67.If the LSI value is high, it means a higher susceptibility to landslide, a lower value means a lower susceptibility to landslides. The five susceptibility zones and areas covered under each zones are given in Table 11.

Table 11: Landslide Susceptibility Zones and areas coming under each zones

Zone	Range	Area (Km^2)	Area %
No Risk	0 – 10.00	1250.05	35.14
Low Risk	10.00 – 17.50	1312.20	36.82
Moderate Risk	17.50 – 25.00	581.92	16.36
High Risk	25.00 – 32.50	333.61	9.38
Critical Risk	32.50 – 43.67	79.55	2.24

6.12 Risk zones in Gramapanchayath Level: Slope failures have wide ranging impact on the people of the affected area in terms of the dangerous caused to property and humanlive.The magnitude of the destruction depends on the location of failure many areas susceptible to landslide hazards are inhabited by the people. Local self government is not aware of the critical areas where the risk is high.

Table 12: Distribution of Panchayath areas in different risk zones

Panchayath	No Risk (km^2)	Low Risk (km^2)	Moderate Risk (km^2)	High Risk (km^2)	Critical Risk (km^2)
Karulai	8.46	32.04	65.95	77.57	17.27
Chungathara	25.31	33.89	32.21	42.10	12.84
Karuvarakundu	12.45	17.69	17.68	18.42	8.21
Amarambalam	16.03	31.78	34.71	32.53	7.97
Vazhikkadavu	8.86	39.90	55.07	37.06	6.66
Chaliyar	3.30	12.14	33.49	27.20	5.46
Puthukkal	2.40	28.31	64.62	34.61	4.97
Kallikkavu	16.71	20.85	11.48	9.78	3.73
Urangattiri	7.10	20.81	27.81	18.58	3.52

Chokkad	5.50	19.61	22.68	11.01	2.37

Therefore the panchayath with more critical and highlyunstable areas have beencategorized into C (Critical Risk), HR (High Risk), MR (Moderate Risk), LR (Low Risk) and No risk zone to indicate very high to very low damage potential.The areas coming undereach class in the district is presented in table 12.The risk map of the panchayath withCritical zone greater than 10 Km^2area is illustrated in the Fig 4.This includes Karulai and Chungatharapanchayathof Malappuram

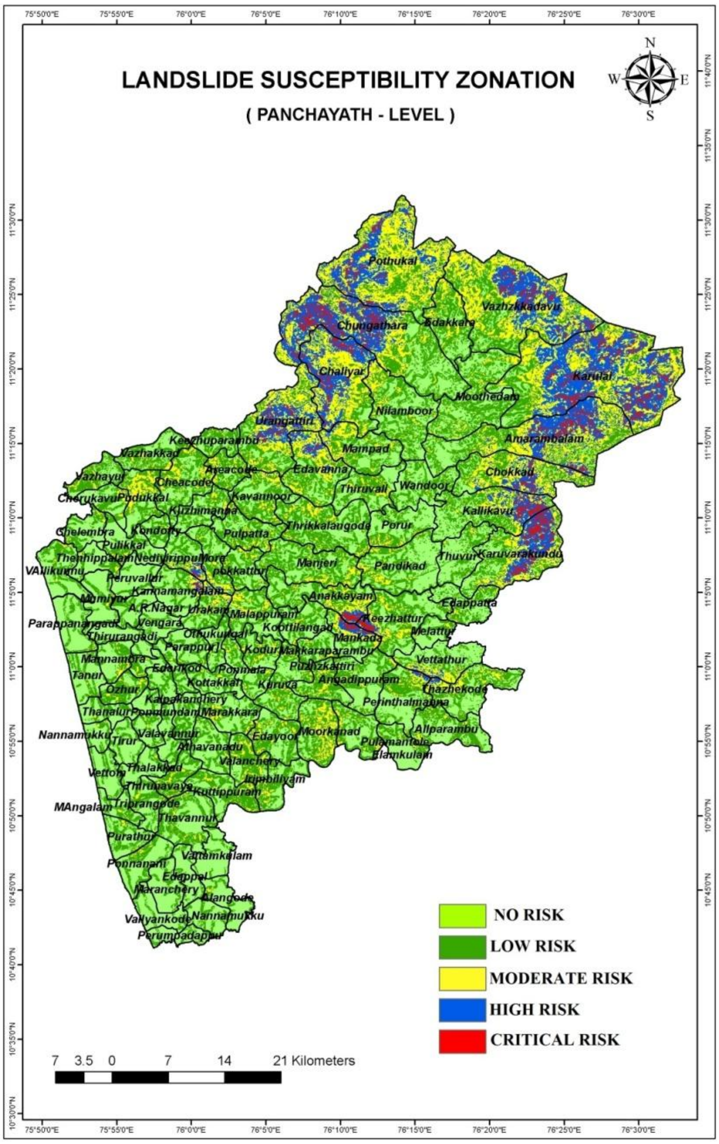

Figure 4: Landslide Susceptibility Zonation Map

7. Validation of Landslide Susceptibility Zonation Map:

It is observed that Vallankolli, Karuvaarakund, Chengara, Kodaleri mala, Odakkayam and Arthala Estate where debris flow occurred (Fig5 and 6)in later period falls in the area of high risk and critical risk zones identified in the landslide susceptibility zonation map. These failures validate physically the landslide susceptibility zonation map prepared.

Figure 5: Arcuate failure in the Vallankolli

Figure 6: Crown of the debrisflow in Arthala estate

8. Preventive Measures:

One of the most important triggering factors for the slope failure is rainfall. The water infiltrating in to hill slope materials increases the pore pressure within the overburden and ultimately reduces the factor of safety of the slope and causes failure. In the present study the areas in the high risk and critical risk zone has developed wide open cracks and therefore construction of proper drainage system inorder to remove excess water is to be given priority. Another important measure is to discourage the public from obstructing natural drainage on slopes. An awareness campaign among the people is an urgent measure to compact debris flow. In critical zones construction activities and quarrying should only be allowed after studying engineering properties of slope material. The intensity of blasting must be regulated depending on the prevailing geological conditions. Quarrying must be banned particularly during monsoon periods.

9. Conclusion:

The geospatial analysis and landslide susceptibility map provides a general picture on the stability status of the different areas in Malappuram district. Accordingly the Karulaigramapanchayath has maximum area under critical risk zone (17.27 Km^2) followed by Chungathara (12.84 Km^2) and Karuvarakund (8.21 Km^2). People can be evacuated from critical and high risk zones by the local administrators if heavy rainfall continues for couple of days. Restrictions in the landuse practices can be imposed in the high risk zones. Effective mitigation measures like slope correction, regeneration of natural vegetation, provision for smooth natural drainage are to be carried out. All kinds of disaster preparedness have to be initiated in these high risk zones with the involvement of the panchayath officials and the public.

10. Acknowledgement:

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