A GEOSPATIAL APPROACH FOR LANDSLIDE SUSCEPTIBILITY ASSESSMENT IN MALAPPURAM DISTRICT, KERALA, INDIA

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ABSTRACT
Landslide susceptibility analysis, a precursory stage in landslide hazard and risk assessment was carried out in the study using geospatial techniques. Malappuram district which consist of highly undulating terrains including ecologically sensitive segments of Western Ghats selected for the analysis. Five major Landslide influencing factors such as geology, geomorphology, slope, soil and landuse/landcover were delineated in the ArcGIS platform and generated suitable weights for each of these factors based on their influence on landslide occurrence. The resultant susceptibility analysis pointed out that the 13.46 % of the total area is the most landslide vulnerable and about 17%, 3% and 66% were contributes unstable, moderately stable and highly stable terrain respectively. The prediction accuracy ensured through the validation analysis using recent landslide occurrence and resultant map will enable to reduce the future landslide hazards in zone through the appropriate and adaptive land use planning and innovative management techniques.
Keywords: Landslide susceptibility; GIS; Stability; Malappuram

INTRODUCTION
Landslide is one of the natural catastrophes which cause adverse effect on human lives and also cause damage to communication routes, human settlement, agricultural and forestland. It is the movement of a mass of rock, debris or earth down the slope (Cruden, 1991) when the shear stress exceeds the shear strength of the material. In the hilly terrains of India including the Himalayas, landslides have been a major and widely spread natural disaster the often strike life and property (Dortch et al. 2009; Parkash, 2011). Approximately 15% of land area of the country is vulnerable to landslide hazard. Out of these 0.098 million km² is located in north eastern region and rest 80% is spread over Himalayas, Nilgiris, Ranchi Plateau and Eastern and Western Ghats (Geological Survey of India, 2006). In Kerala, landslides are common in hilly ranges and caused many deaths and major destructions. Among the 14 districts of Kerala, 13 are prone to landslides and in which Idukki is the worst affected with 217 landslides (Geological Survey of India, 2006, Kuriakose et al. 2009). Kerala receive high amount of rainfall during monsoon which make the slopes of hilly areas vulnerable to landslide. The heavy rain from the monsoon had saturated hill side of the Ghats during summer months triggering landslide. The progressive weakening of slope materials by slow natural process such as continuous weathering and tectonic forces (Sajinkumar et al. 2011) enhance the slope failure. Failure of hill slope modifications carried out for developmental activities and plantations in disaster prone areas are a major concern in rain related events. The highlands of Kerala experiences several types of landslides, of which debris flow are the most common (Kuriakose et al. 2009). Rainfall-triggered landslides are difficult to monitor due to lack of adequate data (Omman et al. 2018).

Remote sensing serves as the best practical tool for mapping, monitoring and analysis with reasonable...
accuracy within a small period of time (Metternicht et al. 2005; Pardeshi et al. 2013; Casagli et al. 2017). Prediction of rainfall triggered hill slope disasters has relied mostly on the valley slope, rainfall intensity and duration that can cause hill slope failure (Lazzari and Piccarreta, 2018). Recently, theoretical models have been developed to predict landslide susceptibility based on watershed topographic, geologic and hydrologic variables as well as changes in land use (Ramachandra et al. 2010). Based on the spatial and temporal distribution of the landsides and their triggering factors, it is possible to identify areas susceptible to similar slide (Nagarajan et al. 1998). The use of satellite data combined with ground-based/field data facilitates the geological interpretation of landslide and enables a better understanding of the geometry and kinematics of landslide (Tofani et al. 2013).

The ranking method in landslide susceptibility analysis synthesizing weights of the factors/classes through three major processes, viz. decomposition, comparative judgment and synthesis of priorities (Jesiya and Gopinath, 2019). It breaks complex decision making problem into a hierarchy of factors and alternatives. Factors and alternatives are assigned weights on a nine point ordinal scale by virtue of comparison between them. The present study attempted to analyse the susceptibility of landslide in Malappuram district which consist ecologically sensitive zones of Western ghats.

**STUDY AREA**

Malappuram district is bounded by the Nilgiri Hills in the east, the Arabian Sea in the west and Thrissur and Palakkad districts in the south. It spreads over an area of 3550 km² confined by the North latitudes 10° 50’ and 11° 15’ and East longitudes 75° 50’ and 76° 15’ (Figure 1). The study area is mainly drained by the Kadalundi River, Chaliyar River and Bharathapuzha (locally known as Ponnani River).

The climatic conditions of the study area consist of dry season (December - February) and hot season (March–May), the South-West monsoon (June–September) and the North-East monsoon (October–December). The normal rainfall of the district is 2793.3 mm. Out of this, major rainfall contribution is from SW monsoon followed by the NE monsoon. The South West monsoon is usually very heavy and nearly 73.5% of the rainfall is received during this season. NE monsoon contributes nearly 16.4% and March to May summer rain contributes nearly 9.9% and the balance 0.2% is accounted for during January and February months.

**MATERIALS AND METHODOLOGY**

The methodology of the work can be summarized into three major steps, (i) Database preparation of Landslide triggering parameters, (ii) Relative ranking of influencing parameters (iii) Spatial and non-spatial integration through ArcGIS 10.5.1.

**Preparation of geo-database of landslide influencing parameters**

Preparation of various parameters responsible for slope failure have been prepared using remote sensing and other conventional data sources as shown in figure 2. Geology map of the area was prepared using toposheets of Geological Survey of India in the scale of 1:2,50,000. Data from National Bureau of Soil Survey (NBSS) at 1:2,50,000 scales were used for the preparation of soil texture map. Topographic sheets from Survey of India with scale of 1:50,000 were
Figure 2. Flowchart showing methodology for landslide susceptibility analysis

used for the delineation of base map and drainage pattern.

Satellite image of remote sensing satellite IRS-P6-LISS III used to generate geomorphology and land use land cover map of the study area. The satellite image georeferenced and classified through supervised classification technique in the ERDAS imagine. 2011 software. Digital elevation data was extracted from SRTM-1 Arc Second Global (Shuttle Radar Topography Mission-1 Arc Second Global) of 90m resolution. The Digital Elevation Model (DEM) for the study area was extracted using the extraction by Mask in Spatial Analyst tool of Arc GIS and Filling of the DEM as reconditioning is used for filling the sinkholes in the DEM. It is done by fill in the hydrology option of Spatial Analyst tool. The slope had been prepared from the DEM using slope tool in surface analysis of Spatial Analyst tool. All the collected data were processed with the state-of-the-art of GIS techniques and converted to a raster data with a grid size of with 25 m × 25 m cells in ArcGIS10.5.1 platform.

Relative ranking of influencing parameters

The normal ranking method were used in the study for relative comparison of criteria and sub-criteria which were influencing landslide susceptibility of the area. Criteria selected for the analysis includes geology, geomorphology, slope and landuse/landcover. And subclasses of all these criteria were considered as sub-criteria. Each landslide parameter was assigned a subjective ranking of 1–10 based on experts’ opinion and from relevant scientific outcomes. Ranking 1 was assigned for components with least landslide vulnerability and 10 for the highest landslide vulnerability. These ratings were again rescaled with a saaty’s 1–9 analytical scale.

Spatial and non-spatial integration through ArcGIS 10.5.1.

In Spatial and non-spatial integration through ArcGIS 10.5.1., the crisp value obtained from ranking was used to calculate landslide Susceptibility Index (LSI) using the equation;

\[ LSI = GrGw + GMrGMw + SLrSLw + SrSw + LrLw \]  

Where Gr and Gw are rating and weightage of geology, GMr and GMw are rating and weightage of geomorphology, SLr and SLw are rating and weightage of slope (%), Sr and Sw are rating and weightage of soil texture and LUr and LUw are rating and weightage of landuse/landcover. Here the ranking thus assigned given to the raster form of thematic layers after reclassification analysis using spatial analyst tool in Arc GIS platform. The overlay analysis is performed with weighted sum analysis through Eq 1 in spatial analyst tool and the resultant map generated classified in to five landslide susceptibility zones viz. highly stable, stable, moderately stable, unstable and highly unstable.
RESULT AND DISCUSSION

Description of landslide influencing parameters
Lithology is one of the most significant determining factors in landslide susceptibility studies because degree of landslide susceptibility varying with different lithological units. The major rock types present in this study area are charnockite, composite gneiss and schist, granite, laterite and meta volcanoes (Figure 3). Charnockite Group includes charnockite/charnockite gneiss are the most dominant geological units in the study area which covers about 1489.68 km² of the total area (Table 1). Among the geological units of the study area charnockite has the most susceptibility to landslide. The geology of recent landslide (in the year 2018) which hit in the locations such as Perakamanna, Cholara and Kappakkallu was charnockite formation. Magnetite quartzite, pyroxene granulite, amphibolite/hornblende granulite and pyroxenite, which occur as concordant as well as discordant bands, lenses, layers and enclaves both within charnockite as well as within gneisses of Migmatite Complex. The Migmatite Complex is represented by biotite-hornblende gneiss and quartzo-feldspathic gneiss/garnet-biotite gneiss with enclaves of garnet-sillimanite gneiss and graphite distributed mostly in the central and northeastern part. Lateritisation is widespread, at places attaining a thickness of more than 10m (District survey report of minerals, Malappuram, 2016).

Quaternary unconsolidated sediments occurred in coastal plain classified into different morpho-stratigraphic units based on their lithic content and environment of formation viz. Guruvayur Formation (palaeo-marine), Periyar Formation (fluvial), Viyyam Formation (fluvio-marine) and Kadappuram Formation (marine). These quaternary unconsolidated sediments were assigned with least rating in landslide susceptibility analysis.

Geomorphology of the area is the one of the prime factor controlling the occurrence of landslides. The coastal plain exhibits depositional landforms of marine, fluvial and fluvio-marine origin. Paleo-beach ridge suggestive of marine regression in the Quaternary period are well developed in the coastal tract. The coastal plain was assigned with least rating towards landslide vulnerability. The area lying between the coastal plain in the west and the high ranges in the east is occupied by midlands which is the most prominent physiographic unit of the district. The midland region is relatively wide with elevations ranging between 200 and 300m. It is a denudational terrain characterised by flat-topped laterite capped flats, mesas, interfluves, hills, mounds and spurs interspersed by narrow valleys as well as wide alluvial valleys and flood plain. Therefore midland region of the study area were characterized by a mixed response towards landslide susceptibility. The hilly region in the east is more than 600m high.
which is characterised by hills and narrow incised valleys representing structural cum denudational landforms (Figure 4). This is characterized by flat topped hillock with steep ‘U’ shaped valleys and ridges. The hill tops are generally barren and covered by thick and compact laterite. The eastern parts of the district are characterized by steep hills, gorges and escarpments. The elevation of the hill ranges goes up to 1127 m asl. Most of the high lands are occupied by forests. Therefore hill ranges with structural and denudational landforms were characterized by highest rating towards landslide susceptibility.

Slope is the measure of surface steepness and is expressed in degrees. Since land sliding is directly related to slope angle, it is one of the major and frequently used parameters in the preparation of landslide susceptibility maps. About 598.8 km$^2$ area with steep slope (>25%) falls in the “critical” zone characterized by high vulnerability to landslide. The area with 0-5% slope is considered as “stable” for landslide (Figure 5). It covers an area of 1345 Km$^2$ of the total area. 364 km$^2$ area belongs to steep sloping (15-25%) falls in the “highly unstable” zone. About 380.9 km$^2$ area with moderate slope (10-15%) falls in the “moderately unstable” zone and gentle slope (5-10%) with 860.6 km$^2$ area belongs to “moderately stable” zone (Table 1).

The thickness of soil column is very sensitive and significant. Infiltrated pore water pressure when increased reduces the shear strength of the soil. Reduction in shear strength is a factor causing landslide. The mostly seen soil type in the study area is Gravelly clay (1844.9km$^2$). Clay (937.4km$^2$), loam (624.5km$^2$) and sandy soil (97.89km$^2$) are other kinds of soil seen in the area (Table 1). Coastal plains and valleys were with alluvial soil. The soils range from exclusively drained to moderately/well drained sand to sandy clay in nature. Due to the predominance of sand alluvial soil having poor water holding capacity hence least weightage on landslide susceptibility (Figure 6). Soils of mid/Up lands of the study area were mostly lateritic soil which are deep to very deep, well drained, and gravelly to clayey. Hydromorphic soil in the study area are deep moderate, well drained and clayey soils with high gravel content. Its erosion is moderate to severe, hence moderate to high chance of landslide vulnerability. Soils of eastern part of Malappuram district is forest loamy soil which are deep or very deep well drained with loamy to clayey textures and having fairly high gravel content.

While analyzing the recent landslide events it was clear that along with rainfall and other geological factors changing landuse change pattern is
the triggering factor behind landslide events. Remote sensing data and GIS technique provide reliable and accurate information for land use land cover mapping. It also plays major role in determining land use pattern and changes there in different times. The areas with sparse vegetation are more prone to erosion and instability whereas, the densely vegetated areas are less prone, being more stable. The main land use of the area is coconut mixed crop and rubber it is about 1093 km$^2$ and 428.4 km$^2$ respectively (Table 1 and figure 7). At Perakkanam one of the recent landslide location in Malappuram District the major landuse/landcover is rubber plantation. The cause of landslide in the area was natural slope which had been benched for rubber cultivation in the area thereby blocking natural drainage. Heavy antecedent rainfall for 3 days during August 2018 preceding the event resulted in building up of excess pore water pressure and reduction of strength on saturation. Landslide was initiated as planar failure along rock-overburden contact and then transformed into debris flow in sequence (Geological Survey of India, 2018). Hence the area with plantations and built-up areas in high land terrain assigned with highest rating towards landslide susceptibility.

**Landslide susceptibility zones**

Overlay analysis of all influencing parameters viz. geology, geomorphology, slope, soil and landuse/landcover landslide were carried out after reclassifying the factors with suitable weights depends on their influence on landslide process in the GIS platform. The resultant map thus generated is a Landslide susceptibility map which classified the study area in to five classes based on their degree of vulnerability (Figure 8). The zonation in terms of landslide susceptibility of the study area indicate that out of the 3550.05 km$^2$ about 478.01 km$^2$ (13.46%) area is falling under highly unstable/high susceptibility category (Table 2). About 601.9 km$^2$ (16.95%) area is falling under unstable susceptible category. The highly unstable zone characterized with steep
slope terrain occupied with denudational hills and soils are mostly friable and subject to heavy soil erosion.

Majority of recent landslide events were occurred at these highly unstable zone and analysis on recent landslide events stated that along with heavy rainfall unscientific modification of original slope viz. vertical slope excavation, potential wedges and blocks formed by weathered rock mass were the causative factors for the slope failure. Heavy rainfall resulted in reduction of strength due to saturation and subsequent failure. The coastal plain with gentle slope terrain together imparts stable to highly stable topography and which together constitutes an area of 1079 km², i.e 30.5% of the total study area. The remaining part of the study area having 109 km², i.e 3% of the total area was categorized as moderately stable towards landslide susceptibility. Most of the locations of previous landslide incidents were overlaid on highly susceptible zone as shown in figure 8, pointed out the accuracy of the analysis.

**CONCLUSION**

Landslides cause enormous loss of life and property every year hence, landslide susceptibility mapping is very essential to delineate the landslide prone areas. Many areas of Western Ghats of Kerala are highly prone to the landslide activity in the past. Recent landslides and characteristics of the land, point out the relevance of the present work of landslide mapping of Malappuram district. The integrated geospatial analysis of landslide susceptibility adopted in the study depicted the significant role remote sensing and GIS in the identification and mapping of landslide susceptibility zone. The obtained susceptibility map indicated that the unstable to highly unstable class covered an area of 30 % of the total area while about 66.5% were classified as being the stable and highly stable zone. Spatial correlation between previous landslide locations and landslide susceptibility map pointed out the accuracy of landslide analysis and its significance to planners and decision makers in effective and rapid prevention and mitigation measurements.

**REFERENCES**


