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Shallow landslides around Port Blair, Andaman, India using multi - variant geospatial analysis techniques

*Shiva Shankar & Dharanirajan
Department of Disaster Management, Pondicherry University, Port Blair, India, 744103
*[: shivashankar_vj@yahoo.co.in]

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Risk intensity for eight geo-environmental parameters viz., Drainage density, Slope, Lithology, Geomorphology, Lineament, Soil texture, Soil depth, landuse land cover were used for demarcating the landslide Hazard Zone (LHZ) using geospatial techniques. The results reveal that humans have settled around moderate (18.69%) and high (11.95%) landslide hazard prone area. Majority of the study area 69.35% falls in low hazard category and is covered by forest. Low hazard zone is highly suitable for future expansion of built up area.

[**Keywords:** Landslide, GIS, Remote sensing, Multi-criteria analysis, Andaman]

Introduction

Landslides are among the costly and fast spreading geo-epidemics around most of the mountainous regions of the world due to massive developmental activities[1-2]. Shallow landslides, often called mudslides or debris flows, are rapidly moving flows of mixed rocks and mud that move downhill under the spell of gravity, kill people and destroy homes, roads, bridges, and other property. They are caused primarily by prolonged, heavy rainfall on saturated hill slopes[3].

Socio-economic losses due to slope failure are great and apparently are growing as the built environment expands into unstable hill side areas under the pressure of expanding population[4]. Human activities disturb large volumes of earth materials due to ongoing activities of construction of buildings, transportation routes, communication systems, etc., and thus have been major factors in leading to slope failures and increasing the damages[5-6].

In lieu of these damages, stakeholders pay high attention to landslide research in order to furnish zoning map to identify susceptible areas and stable locations for future development[7]. Therefore, the preparation of landslide susceptibility map is a major step in overall landslide hazard management. There are many qualitative and quantitative techniques available to analyze the relationship between landslide and conditioning parameters[8]. Over the years, numerous studies have been carried out on landslide hazard evaluation using Geospatial technology[9-16]. Around Port Blair, South Andaman has been witnessing miniscal shallow landslides in recent times due intense rains and anthropogenic influence. Hence, the objective of this article is to map the shallow landslide hazard zone (LHZ) using geospatial techniques.

Andaman and Nicobar Islands (ANI) (92° to 94° East and 6° to 14° North), an archipelago with > 500 islands/islets, stretching over 700 km. There are 38 inhabited islands with a population of approximately 356,000 [17]. They are closer to the Indonesian landmass than to mainland India (1200Km), with the southernmost island only 150 km from Sumatra and the northernmost landfall ,190 km south of West Myanmar. The Andaman group of islands is made up of the South, Middle and North Andamans, whereas the Nicobar group is made up of several smaller islands, including Car Nicobar[18]. They appear to be un-submerged portion of a continuous belt from Manipur - Nagaland in north to the Indonesian islands in south, through Arakan Yoma range of Myanmar[19-21].

Study area, Southern part of South Andaman bound between 11°27’00” and 11°45’00” N and 92°30’00” and 92° 46’ 47” E covering an area of 384.79 sqkm with a population of Population of 133337 in 30299 house holds[22]. Area runs roughly in a North-South direction for about 30.78 km from Wimberley Ganj to Chidiatapu. Along East-West direction, it runs for about 25.80 km. Coastal fringes of the study area are creased with sensitive and fragile wetland ecosystems such as estuaries, mudflats, sandy beaches, mangrove forests and coral reefs[23]. Also it has tropical evergreen, semi-evergreen, and moist-deciduous forest with exuberant biodiversity and productivity[24-25]. Area under investigation has undulating topography with steep slopes and cliffs. Human settlement has flourished around this zones.The important tourist places within the study area are Port Blair town, Cellular Jail, Anthropological Museum, Fisheries Museum, Naval Marine Museum, Chatham Saw Mill, Zoological Garden, Mount Harriet, Sipighat Farm, Viper Island, Corbyn's Cove (Beach) and Ross Island. These places attract both national and international tourists.

The study area receives copious rainfall amounting about 3000 mm. per year. May to October is the peak rainfall months which brings almost 2500mm of rain[26].

Causative factors of landslides in the study area

Seismo-tectonic activity result in crustal movement along faults, folds and flexures coupled together with the effect of gravity may trigger sliding of land[27-30]. Anthropogenic activities directly or indirectly are responsible for landslides[5-6]. Denudation of vegetation cover initiates erosion during wet season resulting in sliding [31]. Slope modification either by humans' or natural cause can result in changing the slope angle so that it is no longer at the angle of repose. A mass-wasting event can then restore the slope to its angle of repose[32].

Heavy rains saturate soil reducing grain to grain contact, thus triggering a landslide event. Heavy rains can also saturate rock and increase its weight. Changes in groundwater system increase or decrease fluid pressure in rock initiating mass-wasting events[33-37]. Undercutting by streams eroding their banks or surf action along coast can make a slope unstable[28].

Materials and Methods

The following materials were used to suffice the objective of the investigation. Survey of India (SOI) restricted toposheet's on 50K scale (87A/10, 87A/11 & 87A/14) were used to generate base maps. Collateral data (Soil map, Lithology map) was regenerated as per the demands of the investigation. Multi spectral satellite data product of the year 2011 Indian Remote sensing (IRS) P6 LISS-IV (Linear Imaging Self-scanning Sensor), ASTER GDEM (Global Digital Elevation Model) 2009 and The following software's ArcGIS 10 and Erdas 2011 were implemented to process the above mentioned data products.

Landslide occurrence depends on complex interactions among a large number of partially interrelated factors. These parameters, according to Dai and Lee[38] can be grouped into two categories: (1) quasi-static (preparatory) variables including slope, soil properties, elevation, aspect, land cover, Lithology etc; and (2) the triggering variables such as heavy rainfall and earthquakes[39-40].

Geospatial demarcation of shallow landslide hazard zone requires the following inputs viz., slope class, drainage density, Lithology, geomorphology, lineament, soil texture, soil depth and Land use Land Cover (LULC) on 1:50K scale were prepared using standard procedure using Arcmap 10 and ERDAS 2011 software. Each layer's class was given a rank and these layers were converted into a raster of similar pixel dimension. Weighted overlay analysis was carried out to get shallow landslide hazard zonation map as output. The methodology adopted is depicted in the figure 1.

Results and Discussion

Drainage Density

Dendtritic and Trellis type of drainage is observed in the study area. Drainage segments have been digitized to include the consequence of this contributory factor. Drainage density is the total length of the entire stream in a watershed divided by the area of the watershed[41]. Firstly, drainage map were digitized from SOI topographic map and updated using 2011 satellite image followed by demarcation of watershed boundary. Drainage density is classified into three intensity classes (table 1) like low (0-1.5 Sq Km), Moderate (1.5-2.5 Sq Km) and high (>2.5 Sq Km). Higher the drainage density lower is the risk of landslide[42]. Port Blair, Delinepur, Chidyatapu, Guptapara, Andromeda point, Leda Point, Portmouat, Hathitape and most of Labyrinth island's has low drainage density indicating high susceptibility of landslide. A map of the drainage density is as shown in the figure 2a.

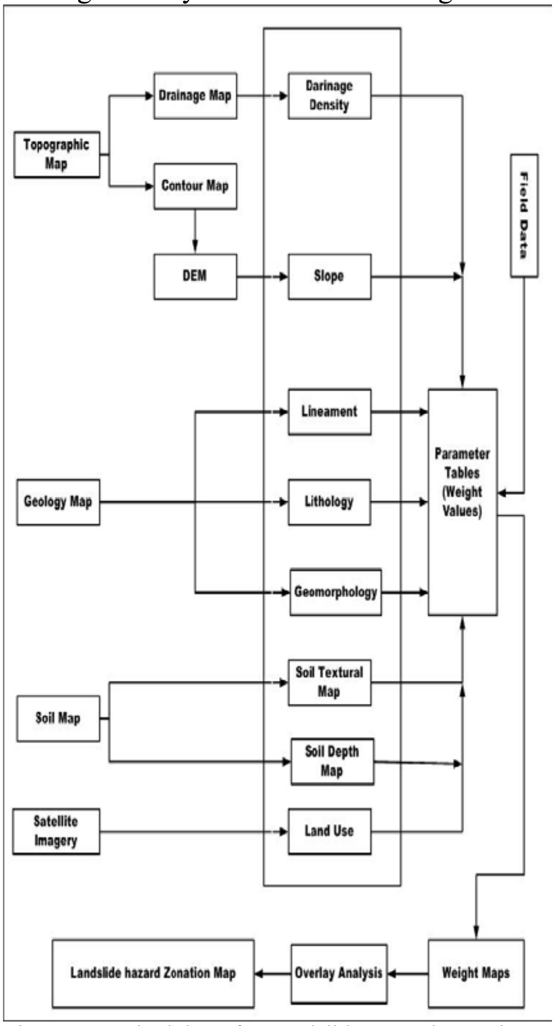

Figure 1: Methodology for Landslide Hazard Zonation

Slope

Slope is used to describe the degree of the steepness, incline, gradient, or status of a straight line. Slope angle is an essential factor that influences landslide occurrences. A higher slope value indicates a steeper slope and vice versa. Slope (steepness or flatness of the region) is linked to the susceptibility of a landmass to landslide Slope angle ranging from 15 to 35º are highly prone to landslide[43]. Higher slope higher susceptibility of landslide[42].

Very steep slopes were observed around Ferrar gunj, Collinapur and Wimberly gunj. Moderate slope and moderate to steep slope is distributed through out the study area. Slope map was generated from the DEM.

The slope image of the study area has been classified into four classes. A slope map has been prepared from the mentioned classification and is presented in the figure 2b. Moderate to steep slope and very steep slope areas are more prone to landslides. A scale ranging from 0 to 3 was used to define the landslide occurrence based on slope. Higher the rank greater is the susceptibility of landslide. A rank of 3 was given to areas with very steep slope followed by rank 2 for moderate to steep slope. Least rank was given to areas with gentle slope. The ratings of the slope are provided in the table 1. Steeper the slope higher is the risk of landslide.

Geological setup

Geology is one of the primary causative factors controlling the slope failure. The first account on the geology of the Andaman Islands was given by Helfer in 1840 [44]. Geologically, the rock types occurring in these islands can be broadly divided into two major groups: (i) *sedimentary rocks*, consisting mainly of the unfossiliferous flysch sequence (dominant greywacke – siltstone – shale) of the Palaeogene Port Blair Group and fossiliferous Neogene Archipelago Group (chalk – limestone) and (ii) *magmatic rocks* of the Saddle Hill Group, comprising mainly ultramafic to mafic plutonites and predominant basic volcanics. The major magmatic rocks of ultramafic plutonites (dominant serpentinite with lesser and variously serpentinized dunite and harzburgite plus rare pyroxenite) and basalt, together with minor radiolarian chert (Steinman trinity), constitute the 'Andaman ophiolite suite' [45-46]. This ophiolite suite is divided into two phases – an earlier basic volcanic and later ultrabasic to basic intrusive. Volcanic rocks are more predominant in the island of South Andaman (Carbyn's Cove to Chidiyatapu; Sipighat) and occupy a small area toward north. Ultramafic plutonites, Mafic rocks like gabbro are associated with ultramafites, as at Chauldari and Kodiaghat in South Andaman. Ophiolites occur mostly near to the east coast of the major islands and along linear belts trending approximately in N-S direction,

Table 1: Risk Intensity for different classes of various geo-environmental parameters

Class	Rank	Class	Rank
Drainage Density (SqKm)		**Soil Texture**	
High(>2.5)	1	Clay, Clay Loam	1
Moderate (1.5 to 2.5)	2	Sandy clay, sandy clay loam	2
Low (0 to1.5)	3	Loam sand, Sandy	3
Slope (Degree)		**Soil Depth**	
Gentle (0 to 5) to Moderate (5 to 15)	1	Very Shallow (0 to 25 cm)	1
Moderate to steep (15 to 35)	2	Shallow (25 to 50 cm)	2
Steep (> 35)	3	Moderately shallow (50 to 75 cm)	3
Geomorphology		Deep (75 to 150 cm)	4
Valley, Intermountane valley, Pediment	0	**Land Use**	
Escarpment, structural hills	1	Water body & water inundation	0
Lithology		Forest	1
Acid igneous rock, Volcanic rocks (basalt) and Agglomerate, Ultrabasic rocks	1	Plantation	2
Undifferentiated Mittakhari group rocks, Upper White Claystone Formation	2	Settlement with plantation	3
Flysch Sediments (Sandstone, Siltstone, Shale), Melville Limestone, Alluvial soil, coral reefs, loose sand, shaly limestone, shale conglomerate, Mangrove swamps	3	**Lineament**	
		Lineament buffer of 100m	1
		other areas	0

Figure 2a

Figure 2b

Figure 2c

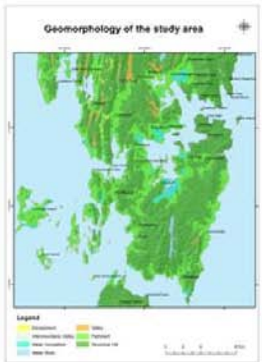

Figure 2d

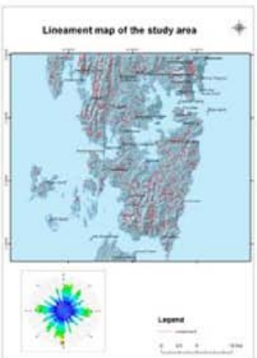

Figure 2e

Figure 2f

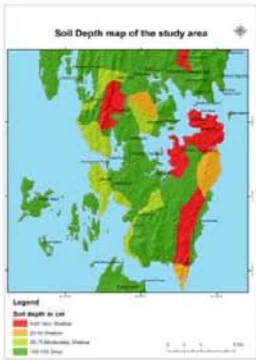

Figure 2g

Figure 2h

Figure 2: maps of various geo-environmental parameters considered for LHZ mapping

Generally, in the contact zones between magmatics and sedimentaries, hybrid rocks are observed at many places like Garacharma, Pahargaon, Sipighat, Chidiyatapu, Pema Nala, Bambooflat and Shoal Bay in South Andaman. Bands of chert and tuffaceous beds, interbedded with the Port Blair Group, are observed at many places as near Sipighat, Basundhara nala, Hobdyapur in South Andaman. The Andaman ophiolites show the following field characters: (i) close spatial association of ultramafites, basalt and gabbro; (ii) dominance of serpentinite, over other ultramafites, and basalt; (iii) presence of a layered complex at Kodiaghat and many layered serpentinites and dunites showing 'flow-layering'; (iv) ultramafites traverse gabbro at Kadarinala in South Andaman and contain an inclusion of basalt (6 x 4 m) in the Rutland island; (v) presence of hornfelsic and hybrid rocks in between ultramafites and sedimentaries; (vi) occurrence of ultramafites and basalt along major N-S trending fault zones (as delineated in the Tectonic Map of ONGC, 1968); (vii) ultramafites show greenschist facies metamorphism, together with local chilling and other contact metamorphic effects; and (viii) field relations suggest the intrusion of ultramafites into relatively older basalt and sedimentary rocks[44,47-49]. The Lithology map derived from the geology map is as shown in the figure 2c. Sedimentary rocks are more susceptible to weathering due to rain hence a rank of three is given. Igneous, ultrabasic and volcanic rocks weather least hence given a rank of 1. The table 1 shows the ranks from lithological units.

Geomorphology

The study area of south Andaman is bestowed with different geomorphology feature which is unique in landscapes (Figure 2d). It has undulating and rough topography of land forms especially low range of hill and narrow stretching valley. Flat low lying area are more prone to erosion which small tributaries are more vibrant agent to erode surface of the soil were pediment are formed, besides the escarpments are associated feature in study area. Slopes are moderate to steep, ragged and prone to erosion. Valley are form in intermediate region were flat lands are comparatively scare and restrained to large valleys. Waterlogged areas are formed in low lying area where subduction had taken place. Southern part of the area are mostly subducted due to 2004 earthquake, shippighat is a best example of waterlogged area.

Five geomorphic features viz., structural hills, pediment, valley, intermountane valley and escarpment were observed in the study area are : Structural hills are representing the geological structures of land forms such as-bedding, joint, lineaments etc[50]. They are distributed throughout the study area trending N-S direction. In The Study Area, Pediments are gently sloping areas or erosional surface of bed rock[51]. Pediments covered by a thin layer of alluvium and are mostly developed at the foot of the hills occurring along the coastal fringes.

Valley are formed depression with predominant extent in a direction, mainly it controlled river pattern. These valleys are characterized by a variable width with an alternation of narrow segment marking the former location of watersheds and wide sections together with branches with no outlets[52]. They are predominant in the northern parts of the study area. Fine texture, irregular shape and linear, elongated pattern, occupying low-lying areas associated with natural vegetation with light greyish for moisture to dark red for natural vegetation as revealed by the false colour composite (FCC) of the satellite image interpretation.

Escarpment

An escarpment is a steep slope or long cliff that occurs from erosion or faulting and separates two relatively level areas of differing elevations. These are more susceptible to erosion by fluvial action[52]. They are found along the mountainous chains in the northern parts of the study area.

Intermountane valley

The intermontane valleys are mostly structure controlled. These are broad to narrow and linear depressions, filled with colluvial and fluvial deposits brought down from the hills, and are of varying grain size mostly sand, silt and clay. The tone is light to dark red due to presence of natural vegetation, texture is coarse, irregular shape, and the drainage pattern is sub-parallel[53].

Valley, Intermountane valley, pediment were given a rank of zero. On the other hand escarpment and structural hills was given a rank of one (Table 1).

Structural Lineaments

Lineament is a mappable, simple or composite linear feature on the earth's surface, where parts are aligned in a rectilinear or slightly curvilinear relationship and which differs distinctly from the patterns of adjacent features and presently reflects a sub-surface phenomenon[54]. These are weaker zones which have been formed due to movement of the earth crust and are defined as the significant lines of landscape, which reveals the hidden architecture of the rock basement. Such features may represent deep seated faults, master fractures and joints sets, drainage lines and boundary lines of different rock formations along which landslide susceptibility is higher[55].

Major lineaments can be detected in the raw image data; most of the finer details are more easily recognizable in the filtered satellite images. The lineaments for the study area were inferred from the satellite image and are as depicted in figure 2e.

A rose diagram (figure 2e) of lineament indicates majority of the lineament trend is NE-SW directions. Also there are few lineaments trending NW-SW. Both these trends are found cutting across each other at several places. The majority of the lineaments correspond to dyke ridges, faults or stream channels. A buffer of 100m was generated around the lineaments, this buffer was given a rank of 1 and the rest of the region as zero (table 1).

Soils

Soil texture and soil depth have been important consideration in this investigation. Soil texture represents the relative proportions of sand, silt and clay. Six type of soil texture were encountered viz., Clay, Clay loam, Loamy sand, Sandy, Sandy Clay, Sandy Clay loam. Clay loam was the dominant textural class of soil well distributed through out the study area followed by clay. Sandy texture was seen along the coastal fringes. Loamy sand was noticed in the area around Wimberley gunj, Steward gunj, Tunisabad, Manjeri and Guptapara. Sandy clay loam was observed around Wandur, Colinpur, leda point, Lmlidera point, Ferrar gunj, Nimboo Bagicha, North point Tarmugli island, Boat island, Jolly Boys island, Redskin island and Ross Island. The soil texture map is as shown in the figure 2f. Clay and clay loam was given a rank of 1. Rank 2 for sandy clay, sandy clay loam. Loamy sand and sandy was given rank 3 (table1).

Soil depth is the depth of unconsolidated mineral matter over the bed rock and is the part of overburden. Soil depth influences the total mass of the overburden which in turn includes landslide. However soil texture affects the water holding capacity and flow of water. Soil depth in the study area is classified into four viz., very shallow (0-25 cm), shallow (25-50 cm), moderately shallow (50-75 cm) and deep (75-150 cm). Greater the over burden higher the risk of loss due to land slips hence soil depth greater than 75 cm receives the highest rank of 4. Least rank of 1 is given to very shallow (table 1). The depth of the soil in the area under investigation is portrayed in figure 2g.

Land Use

Five classes of landuse viz., settlement with plantation, forest, plantation, waterbody and water inundation were observed in the study area (figure 2h). These classes of landuse were inferred from 2011 IRS-P6 satellite image. The landuse class was ranked from 0 to 3 (table1). Settlement with plantation was given the highest rank of 3, plantation (2), forest (1), waterbody and water inundation (0).

Landslide Hazard Zonation (LHZ)

The factors that influence slope instability is varied and their communication processes are complex depending on terrain setup and climatic conditions. The most important terrain evaluation factor in hazard zone mapping is the recording of the landslides that occurred in the area. Parameter weight map techniques were applied to create a landslide density map with each parameter map. LHZ map was prepared by integrating the effect of various triggering factors. Individual ratings of Drainage density, Slope angle, Lineament, Lithology, Landuse, Geomorphology, Soil texture and Soil depth were summed up to get total hazard rating. LHZ is a process of ranking different parts of an area according to the degrees of actual or potential hazard from landslide. LHZ of the study area (figure 3) was prepared on the basis of the distribution of total hazard rating. Total hazard rating of 4-10 was considered as low hazard zone, Moderate hazard zone (11-12) and High Hazard zone (13-17). Out of the total area, the maximum area lies in low hazard zone i.e. 69.35% followed by moderate hazard zone (18.69%). High hazard zone occupies the lowest areal extent of 11.95%. LHZ map indicates majority of the human population are housing around moderate and high hazard zones. Most of the low hazard zone is under forest.

From the figure4 it is imperative that all the landslides have occurred in the moderate and highly vulnerable zones also during the peak rainy months.

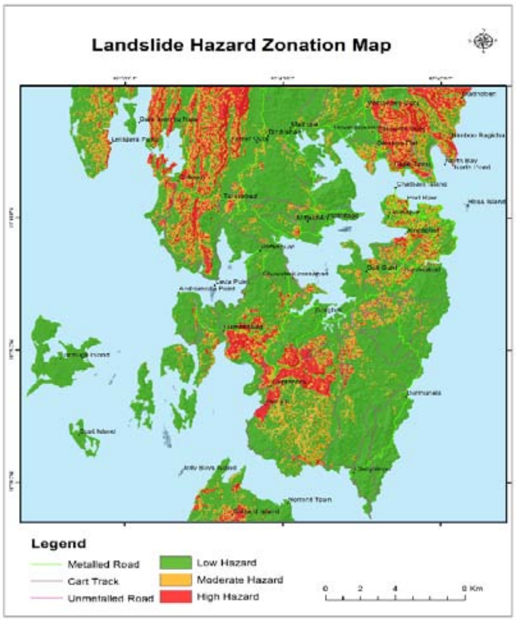

Figure 3: Landslide Hazard Zonation map

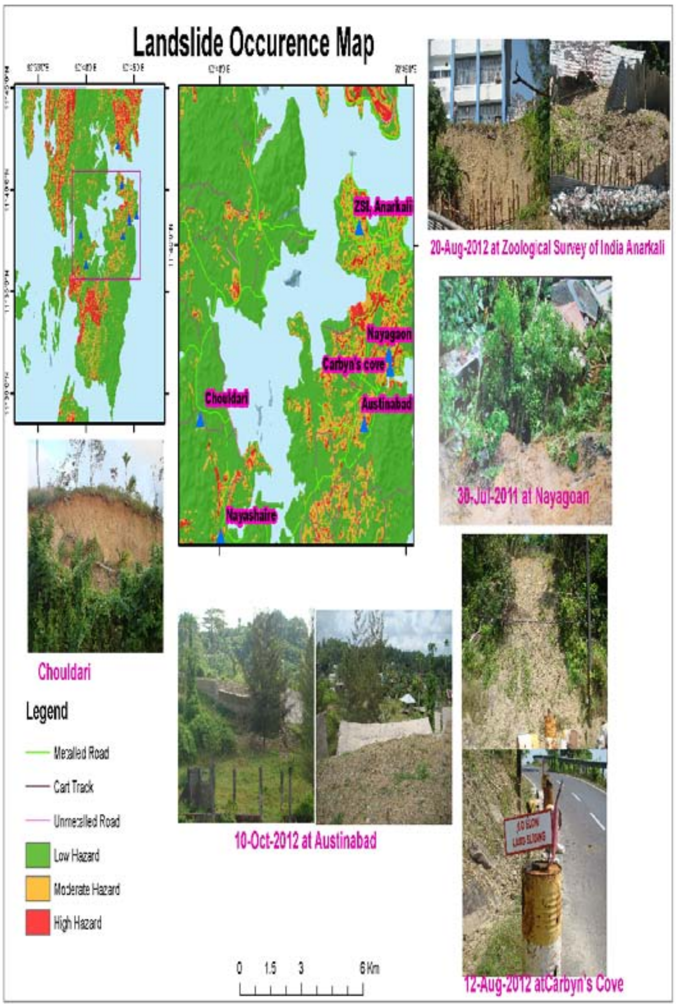

Figure 4: Map Showing Landslide Occurrence

Conclusion

The studies carried out around the world demonstrated that in general landslide vulnerability mapping has been executed by considering geo-environmental parameters either independently or conjunctively and accordingly mitigative strategies have been broadly suggested either generally or in-situ specific way with special reference to individual landslide. Further, the state of art geospatial technology has not been used deservingly. But the present investigation has comprehended these issues and all the geo-environmental parameters were considered in landslide vulnerability mapping. In addition, as against the user biased assignment of weightages to different landslide controlling geo-environmental parameters in the present investigation, thresholds were established for each geo-environmental parameter on the basis of landslide occurrences. GIS database were generated on such threshold zones and integrated to arrive at a landslide hazard zonation map. Hence, it is expected to give a precise landslide vulnerability map.

It is therefore concluded that shallow landslide hazard zones are marked out to forecast the risk of the coming up of future built-up areas. Hazard zones were used as inputs to suggest potential sites for the future growth of the built-up area. Low hazard zone is highly suitable for future expansion of built-up area. On the contrary high hazard zone is least suitable. Landslide hazard zonation mapping is made easy through the application of geospatial techniques.

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