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GIS Based Landslide Hazard Zonation Mapping (LHZM) for Rattota DS Division, Matale District, Sri Lanka

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Abstract: ***Landslides have become the most significant disaster and frequent phenomenon in Central Highland of Sri Lanka in recent decades. And also, the recent landslides have brought intense impacts to the communities living in landslide prone areas of Rattota, in Matale District. Thus, preparation of Landslide Hazard Zonation Maps (LHZ) has become an essential tool in the landslide risk reduction especially in this area. This study has been mainly focused on producing LHZ map as the beneficial to community as well as the relevant institutions. The LHZ map was prepared for the selected 8 GN Divisions from Rattota DS Division, based on the influence of different causative factors. These causative factors, including geology, landforms, land use, slope gradient, past landslide locations, and drainage density were considered for the generation of LHZ map. The data for the generation of LHZ map were obtained from several sources and then were integrated using GIS to the demonstration of map. GIS based bivariate statistical approach (Weighted Overlay Model) was adopted in this study. The map delineated the unstable hazard-prone areas in the study location. Based on the results from the hazard map, different levels were identified as follows; very high hazard, high hazard, moderate hazard, low hazard, and very low hazard. Most part of the study area was belonged to moderate to high hazard area. Very high hazard areas, and low hazard areas were found at lower level. High hazard areas of landslides widely existed in Bambarakiriella, Madakumbura, and Bodhikotuwa GN Divisions. Subsequently, Horagolla, Mousagolla and Welangahawatta Divisions were also resulted as high hazard with the lowest proportion. Accordingly, these results clearly emphasize that hazard level varied from division to division and some zones in the study area potentially dangerous for further development of habitation. There must be immediate implementation of proper mitigation works in the high hazard zones like Bodhikotuwa Division. Accordingly, effective utilization of this map would considerably reduce the damage potential and also facilitate the planning process in the study area.***

Keywords: GIS, Hazard, Landslide, Mapping, Rattota, Zonation

1. Introduction

Landslides are among the most common natural hazards and are the most damaging, leading to a variety of human and environmental impacts (Dhakal *et al.*, 2000). Thus, landslide hazard constitutes as an important natural hazard in most parts of the mountainous regions in the World. It is a multifaceted process caused by the intrinsic and external parameters which elicits the process of landslide (Shit *et al.*, 2016).

Sri Lanka has been frequently subjected to different types of landslides in hilly areas. The Central Highland of Sri Lanka is comprised of different physiographic feature, geology and monsoon rainfall contributes to the landslide occurrences, each year. The population of the Central Highland accounts for 30% of the total population which covers 20% of the total land area of the country and it is divided into 12 districts where most of the places are prone to landslide hazard (Jayasinghe, 2016). Similarly, studies show that landslide disaster will continue to increase in magnitude and intensity in Sri Lanka. Consequently, future landslides will have severe effects on more people in larger geographical areas. Therefore, several measures have been taken to minimize the negative impacts of landslides for the crucial need. Among such methods, preparation of Landslide Hazard Zonation Map is considered as the most fundamental tool and is one of the most important stages in landslide hazard mitigation.

2. Landslide Hazard Zonation Mapping

Landslide hazard zonation is an important step in landslide risk management (Pardeshi *et al.*, 2013). As noted by Wang & Peng, (2009) LHZ is a very important content of landslide hazard prediction modeling. LHZ has been defined as the division of land into somewhat homogeneous areas or domain and their ranking according to the degrees of actual or potential landslide susceptibility, hazard or risk or applicability of certain landslide related regulations (Courture, 2011).

Sarkar and Anbalagan, (2008) defined LHZ as the division of land into a homogenous area and ranking of these areas according to their degrees of actual or potential hazard caused by landslides and mass movements. Varnes (1984) applied the term “Zonation” in a general sense of division of the land surface into areas and the ranking of these areas, according to the degrees of actual or potential hazard from landslides or other mass movements on the slopes.

The main purpose of LHZ mapping is to protect the people and the environment from the negative impacts of landslides. It mainly studies the relation of landslide hazard inducing factors, establish factor analysis models and finally perform hazard zonation (Wang & Peng, 2009). Thus, studies on landslide hazard mapping have received more attention in recent past and as a result, several LHZ techniques have been developed for LHZ mapping, as well. However, modern Geographic Information Systems (GIS) are the key to this map user-map interaction process as GIS allows for dynamic interaction with a map and its data (Tomaszewski, 2015). It provides essential disaster management decision support and analytical capabilities (Tomaszewski, 2015).

Development in GIS and Remote Sensing has been proved to be the most effective tools for the preparation of landslide hazard map. Moreover, the development in spatial technology has also led to increase the applications of GIS for mapping purposes. In particular, GIS with capability of handling and integrating multiple intrinsic variables in relation to the spatial distribution of landslide has gained the success in landslide hazard mapping (Dahal *et al.*, 2008; Dahal and Dahal, 2017). It is widely used in the landslide hazard assessment, especially for the generation of thematic data layers, computation of different indices, assignment of weights, data integration and generation of LHZ maps (Pardeshi *et al.*, 2013).

The hazard and risk maps usually incorporate the estimated frequency of land sliding in a qualitative sense rather than quantitatively (Fell *et al.*, 2008). Early attempts had defined susceptibility classes by the qualitative overlaying of geological and morphological slope – attributes to landslide inventories (Nielsen, *et al.*, 2009; Rahman *et al.*, 2014). More sophisticated assessments involved techniques such as AHP, bivariate, multivariate, logistic regression, fuzzy logic, or Artificial Neural Network (ANN) have been developed in the recent years (Rahman *et al.*, 2014). Frequency Analysis approach, Information Value Model (IVM), Weights of evidence Model, Weighted Overlay Model, etc. are important bi-variate statistical methods used in LHZ mapping (Pardeshi *et al.*, 2013). In the weighted overlay method, weights are allocated based on the relationship of landslide predominant factors with the landslide occurrences (Shit *et al.*, 2016).

3. Landslide Hazard Zonation Mapping in Sri Lanka

Over the last three decades, LHZ Mapping has been carried out in different parts of the world (Pardeshi *et al.*, 2013). Gokceoglu and Sezer (2009) also pointed out that landslide susceptibility assessment is an important part of landslide investigation and has received more attention with highest number of publications in International Journals. Accordingly, GIS based LHZ mapping was adopted by many researchers around the world, Paris, 2002; Ayalew *et al.*, 2004; Lan *et al.*, 2004; Fall *et al.*, 2006; Kanungo *et al.*, 2006; Mathew, 2007; Sarkar & Anbalagan, 2008; Anbalagan et al., 2008; Wang & Peng, 2009; Vahidnia *et al.*, 2009; Chandel *et al.*, 2011; Chingkhei *et al.*, 2013; Pardeshi *et al.*, 2013; Rahaman *et al.*, 2014; Marrapu & Jakka, 2014; Girma, *et al.*, 2015; Jebur, *et al.*, 2015; Raguvanshi *et al.*, 2015; Ray & Pandey, 2016; Chit *et al.*, 2016; Ajin et al., 2016; Kanuwal, *et al.*, 2017; Dahal & Dahal, 2017; Acharya & Pathak, 2017; Hamza & Raghuvanshi, 2017; using various methods in the recent past.

In Sri Lanka, most of the landslide prone areas have been already identified and mapped by landslide hazard mapping project of the National Building Research Organization (NBRO). NBRO is the prime research and development institution which maps the landslide hazard areas since 1992 (Jayathilake and Munasinghe, 2015).

The mapping carried out at 1:50,000 and at 1:10,000 scales. 1:50,000 scales maps covering the entire District of Kalutara, Galle, Hambantota, Nuwara Eliya, Matale, Kandy, Kegalle, Ratnapura, Matara, Badulla, Moneragala, Gampaha and Kurunegala are available for the use of planners, developers, decision makers and general public (NBRO, 2018). Maps at 1:10,000 scales limited to the areas with potential to development and extremely high vulnerability to landslides (NBRO, 2018).

Focus on the landslide studies in NBRO has been emerged with the catastrophic landslides occurred in the 1980's (Arambepola *et al.*, 1998). LHZ mapping in Sri Lanka started with the technical and financial assistance from UNDP/UNCHS. It paved the way for better preparation on effective guidelines for timely preventive actions, introduction of proper engineering practices for site selection and development planning (Arambepola *et al.*, 1998). Accordingly, LHZ mapping in Sri Lanka may be considered as a unique experience and in this context it is perhaps the first comprehensive attempt to generate maps of human settlements and infrastructure on 1:10,000 scale conjointly with other nature maps (Jayathilake and Munasinghe, 2015). The graded landslide hazard maps are intended to serve as the tools for planning of housing and infrastructure in the Hill Country (Bhandari *et al.*, 1994). In 2005, the NBRO's landslide zonation maps were used by the National Physical Planning Department in the formulation of the National Physical Planning Policy of Sri Lanka (South Asian Disaster Report, 2016).

Jayasinghe, (2016) also emphasizes that the identification of potential hazard zones and issuing early warning have considerably been improved during the last decades in Sri Lanka due to LHZ mapping program and rainfall based regional early warning system established by NBRO. Except the efforts of NBRO, the studies combined with GIS in LHZ mapping still remain limited in Sri Lanka.

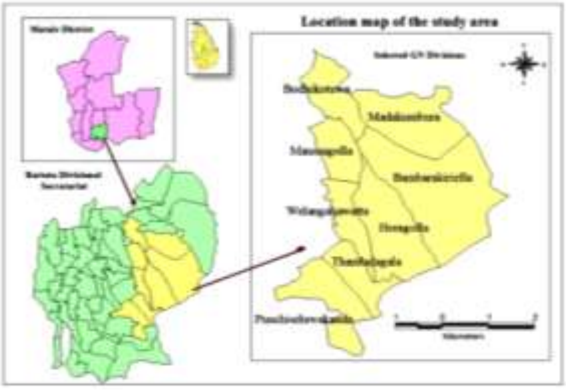
4. Problem definition and objective

Landslide prone areas within Matale District have been already identified and mapped at 1:50,000 by landslide hazard mapping project of NBRO. These maps provide necessary information on potential hazard zones in regional scale. However, LHZ maps at 1:10,000 scales are available only for limited areas. The area of 40sq.km has been already mapped at 1:10,000 scales in Matale District and additional 200sq.km is in Progress (NBRO, 2018).

However, frequently occurring landslides are considered as one of the major natural catastrophes in the Rattota region, which accounts for loss of life and damages to properties recently. A combination of unique physiographic features and other important factors collectively lead Rattota region more vulnerable to landslide hazard. The recent tendency emphasizes that the number of people being affected by landslide hazard is on the rise. As a result, its consequences are still a major problem for communities living in landslide prone areas in this region. Therefore, the identification of landslide prone areas becomes imperative need in this region. With this background, the main objective of this study was to prepare a landslide hazard zonation map at 1:10,000 scales for Rattota DS Division in Matale District.

5. Study Area

The study area consisted eight Grama Niladari Divisions namely; Madakumbura, Bambarakiriella, Mousagolla, Thambalagala, Punchiseluwakande, Welangahawatta, Bodhikotuwa, and Horagolla which belongs to Rattota Divisional Secretariat Division (DSD), Matale District, Sri Lanka which was selected for this study. The location of the study area is shown in Map 01 below.



Map 1: Location map of the study area

The study area located in the Northern part of Central Highland and Southern part of Matale District in Sri Lanka. According to Landslide Hazard Zonation map at 1:50,000 scale, landslide is mostly expected in the Eastern part of the Rattota DS Division and past landslide events have been also indicated the same. According to that, closely located 8 GN Divisions were selected for this study. The study area has an elevation of 1600 meters above mean sea level, and it is a subdivision of a second-order administrative division in Sri Lanka.

6. Methodology

The objective of this study was performed within GIS, to derive a landslide hazard map. The Weighted Overlay Analysis method was adapted in this study using GIS. It is a simple bi-variate statistical method wherein weights are assigned based on the relationship of landslide causative with the landslide frequency (Pardeshi, 2013). Accordingly, various relevant environmental factors (bedrock geology, landform, slope gradient, stream density, past landslides and land use) for hazard zone mapping were determined and necessary thematic maps were prepared.

The main step for landslide hazard mapping is data collection and preparation of a spatial database from which relevant factors can be extracted (Dahal & Dahal, 2017). Thus, the study demonstrated the landslide hazard zonation map and integrated the data obtained from several sources such as aerial photo, topographic maps, geological map, LHZ map, Google earth, and the field investigation. Extensive field survey and interpretation of maps using GIS techniques were the important data collection methods. Prior to the field investigation, topographic maps on the scale of 1:50,000 and 1:10,000 of the study area were studied. Past landslide locations were identified and recorded using GPS technology. During the field survey, topographical variation, structural features, rock and soil structure, different land use pattern and the existence of past landslides were visually inspected and recorded. Moreover, all the existing field evidences relevant to the features of slope instability such as tensional cracks, subsided areas, cracks, tilted trees and poles, affected houses, locations of houses and other man-made structures were observed and recorded.

The landside hazard map of the Matale district at 1:50,000 scales were used as an essential input in this study. All the local regions with potential landslide hazard were identified through this hazard map. Lithology distribution was obtained by digitizing the Geological map (1:10,000) provided by Survey Department.

Land use data of the study area were obtained from 1:10,000 topographic maps and updated with field investigation. Since use of Digital Elevation Model (DEM) is very immense in LHZ mapping, Digital Elevation Data generated from contour maps by digitizing the topographic map sheets 48 and 54 (1:10,000). From the DEM slope gradient and landform were generated. Then the weights and rating for each factor and its subclasses were determined by the influence of each factor. The weightings were assigned based on the guidelines of NBRO and Australian Geo-mechanics Society. The factors were assigned a numerical ranking on 1 – 9 scale, in accordance of importance. Finally, prepared thematic maps were integrated using GIS to prepare a landslide hazard zone map for the study area.

7. Results and Discussion

In this study, foremost hazard triggering factors associated with landslide occurrences were mainly considered and the state of nature maps of the above factors were prepared at 1:10,000 scales (Map 02). The validity was given for each major and sub factor as shown in Table 01. High weightings were assigned to slope gradient (25%), geology (20%) and stream density (20%). 15% of weightings was allocated to land use while landforms and past landslide locations were given relatively less weighting (10%).

Table 1: Details of Weightings for landslide factors

Layer	Subclass	Influence %	Weight	Magnitude
Slope gradient	0 -11	25	1	Very low
	12-17		3	Low
	18-31		5	Medium
	32- 40		7	High
	41-66		9	Very high
Land use	Village building	15	7	High
	River		9	Very high
	Pathana		7	High
	Dense forest		1	Very low
	Forest		3	Low
	Playground		7	High
	Mixed trees		3	Low
	Pinus plantation		7	High
	Plantation forest with cardamom		5	Moderate

	Tea		3	Low
	Homestead		7	High
	Other plantation		3	Low
	Paddy		3	Low
	Plantation forest		3	Low
	Rubber		3	Low
	State building		5	Moderate
Landslide	Past landslide location	10	9	Very high
Land form based on elevation	130-170 m	10	1	Very low
	171-350 m		5	Moderate
	350-1250 m		9	Very high
Geology	Charnokitic gneiss Charnokiticbiotite gneiss	20	5	Moderate
	Marble		1	Very low
	Granite gneiss		3	Low
	Biotite-gneiss		8	Very high
	Quartsite		8	Very high
	Charnokite		5	Moderate
	Calc-gneiss		3	Low
Stream Density (m^{-1})	1-333	20	1	Very low
	334-657		3	Low
	658-885		5	Moderate
	886-1191		7	High
	1192-1546		9	Very high

Source: Author, 2016, *Weightings for the above slope categories were adopted from AGC methods and NBRO.

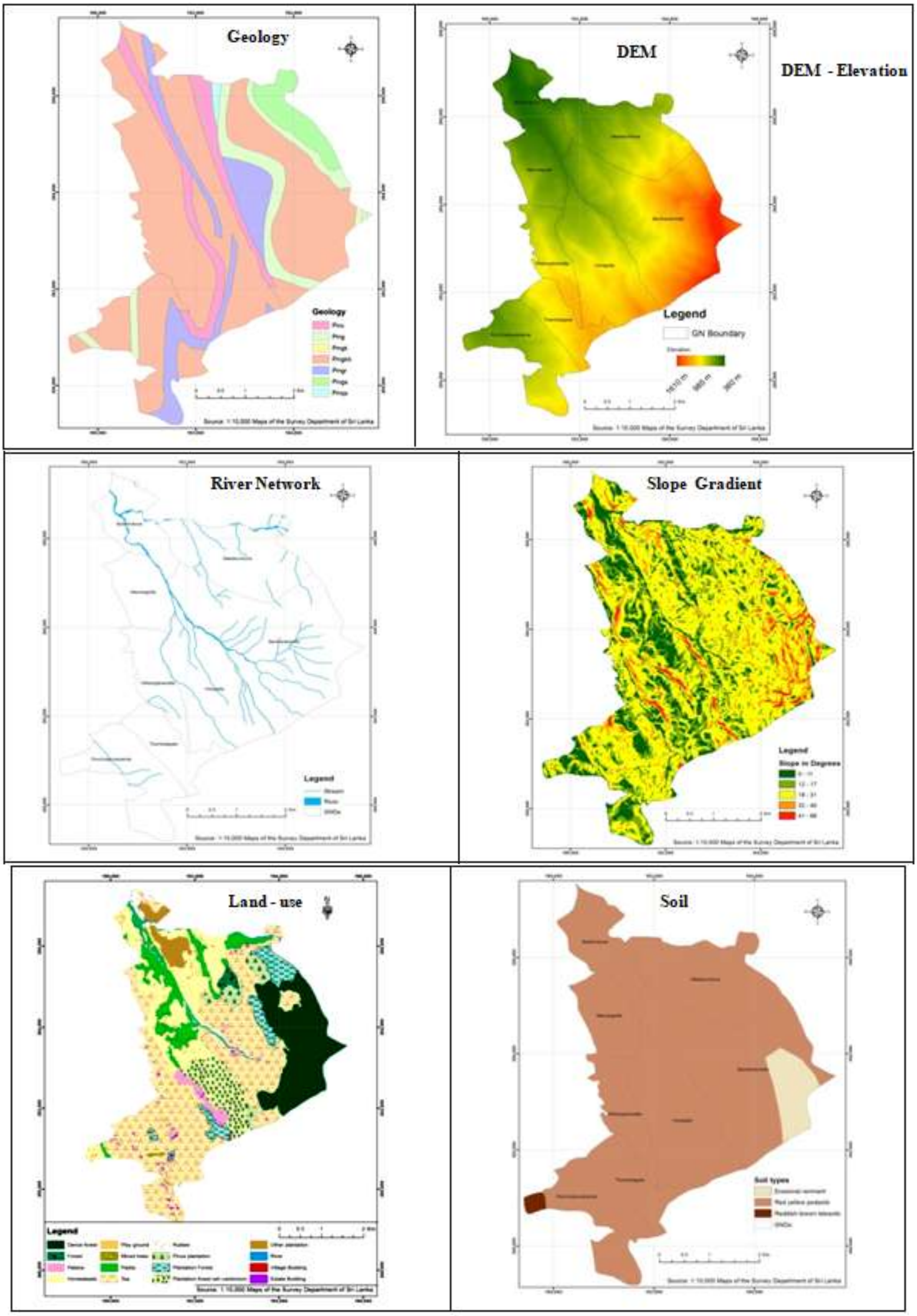
Landform and slope characteristics are very important factors in landslide occurrence in the study area. Geomorphology of the study area is rough and it has undulating mountains with altitudes varying from 360 m to 1600 m above mean sea level. Eastern and Southern parts of the study area dominate with hilly areas. Being a mountainous system, the study area consists of various types of land forms such as mountain ranges, steep slopes, valleys, flat lands and erosional remnant. The Eastern part of the study area covered by the famous range of Knuckles Mountain.

Most part of the slope in the study area belongs to slope gradient class within 10^0- 40^0. It is noted that a large number of landslides have occurred in Sri Lanka when the slope angle exceeds 20^0. Landslides on slopes less than 11^0 and more than 45^0 were rare (Hettige *et al.*, 1994). The study area largely consisted of slope category 18^0-31^0 and such steep slopes were mostly concentrated in the eastern part of the study area. In turn, the area with slope category below 11^0 was rare in this region.

Geological features are the most important factor in landslide occurrence in the study area. Major rocks in the study showed a general strike trend of North West - South East (NW-SE). The study area mostly consisted of lithology which is more vulnerable to landslide hazard. The predominant lithology of the region was Precambrian metamorphic rocks specifically Charnokitic gneiss, Charnokitic biotite gneiss, Granite gneiss, Quartsite and Marble. As noted by Wijewickrama *et al.*, (1994) charnokitic gneiss was found to be the most widespread lithological unit with the highest frequency of slope instability in its overlying soils. Since charnokitic gneiss is widespread or underlain lithology, geologically, the study area has high potential for landslide hazard. Similarly, gneisses weather easily under tropical climatic conditions characterized by intense rainfall and Migmatitic gneisses and gneisses are the most vulnerable to land sliding (Dahanayake, 2009). These geological structures have very important role in landslide occurrences in the study area.

In addition to geological factors, rainfall factors are considered as the major triggering factors in landslide occurrence in the study area. Most part of the study area belongs to Agro Ecological Regions of Intermediate Zone Upcountry (IUI) and consist of mountains where mean annual rainfall exceeds 2400 mm and experiences rainfall from the Second Inter Monsoon (SIM) and North East Monsoon (NEM) periods. The South West Monsoon (SWM) season also brings a considerable amount of rainfall to this area. In addition, part of the study area belongs to the zone with the characteristics of the Wet zone (WM3b) where mean annual rainfall is 1400 mm.

With these climatic characteristics, the study area consists of small and large streams due to its significant physiographic features. Particularly, Knuckles mountain range, being situated in the Eastern boundary of the study area, keeps the area hydrologically rich. The well-known sub watersheds of the study area are; Delewala Oya, Nickloya Oya, Rattota Oya and Moragolla Oya. Tributaries in the study area mainly follow from East to West and South to North-West.



Map 2: Thematic Maps for Landslide Hazard Zonation

The study area is mainly covered with natural vegetation and cultivated land. Natural forest, Pinus plantations, tea lands, paddy lands, plantation forest and homesteads are important land use types in this area. The upper part of the slope was mostly covered with natural vegetation and the area below the natural forest was covered with Pinus plantations and tea. Characteristics of the Wet zone (WM3b>1400 mm) plants such as mixed home gardens, tea, vegetable and paddy are dominant in the lower part of the study area.

Accordingly, man-made land use types were concentrated in the lower slope area.

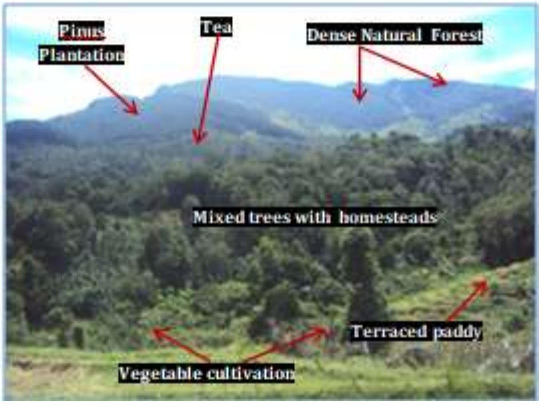


Plate 1: Various types of land use in the study area

Surface deposits and past landslide locations are also important in landslide occurrences. The study area has been affected by landslides for prolonged periods. Visual inspection of surface materials, past landslide locations and landslide scars in the study area emphasize that a number of landslides have occurred at different periods in this area. Fossil landslide scars were identified in Nickloya Estate in Bambarakiriella GN Division. With this, the slope material also has greater influence on landslide occurrence in the study area. Surface deposits in the study areas consisted of residual soil, bedrock exposure, colluviums and weathered rocks. Various thicknesses of residual and colluvial soil layer were identified in this area.

Plate 2: Slope material in the study area

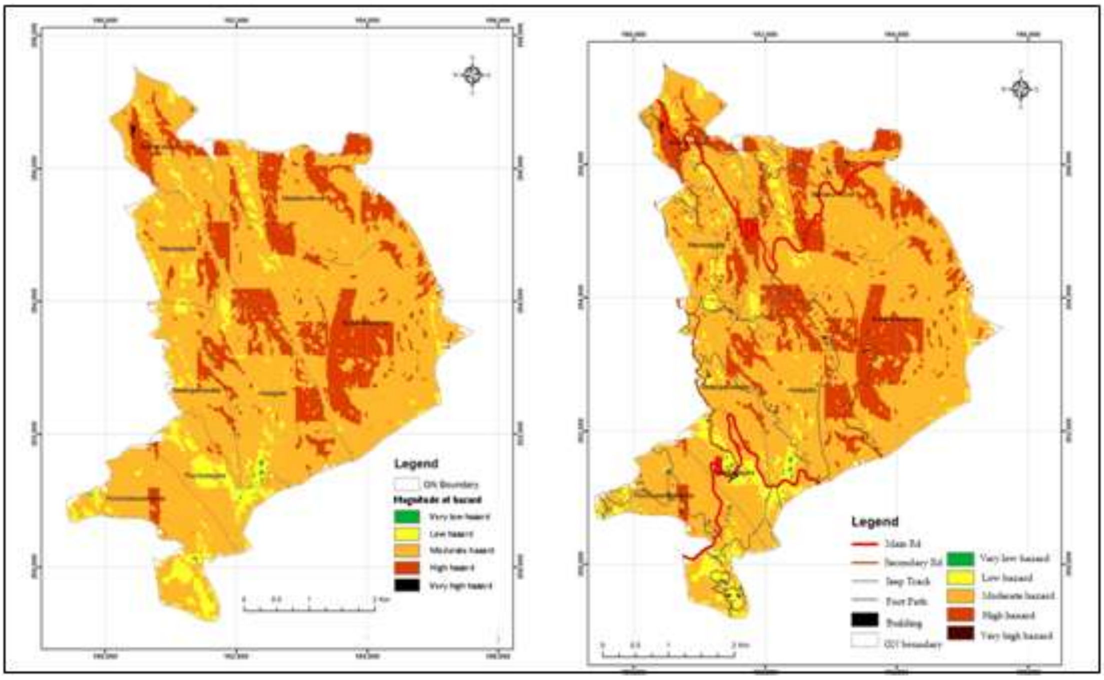
Colluviums were found in the study area which varied in depths. The area has been overburden from ½ m to more than 4 m thickness of soil. As noted by Cooray (1994), Colluvium is common in the Hill country of Sri Lanka and is the site of most of the mass movements that occur in Sri Lanka. Overburden in some parts of the GN Divisions like in Thambalagala consisted of very thin soil layer underlained by solid rock. In turn, Madakumbura GN Division was consisted of thick overburden.

In addition to the slope materials, soil characteristics are another important factor in landslide occurrences. The study area was consisted of two types of soils. The major soil type was Red Yellow Podzolic soils and Mountain Regosols. Top soil of the study area was characterized by Grey Brown. Apart from this, sub-steep rock land and Lithosols and Reddish Brown Earths and immature brown loams; (rolling, hilly and steep terrain) were also found in Western border of the Punchyselwakanda GN division.

Study reveals that factors discussed above are vital important in landslide occurrences in the study area. Accordingly, results were obtained by integrating prepared thematic maps (Map 02) discussed above. The results indicate that landslide hazard potential in the study area shows the uneven distribution (see Map 03 below).

There were different levels of landslide hazard identified as follows; very high hazard (0.04%), high hazard (18.7%), moderate hazard (73.7%), low hazard (7.4%), and very low hazard (0.1%). Results indicate that the high hazard zone cover 18.7% of the total area while about 73.7% was lied in moderate hazard zone. Low hazard zone only covers about 7.4% of the total area. Most part of the study area was belonged to moderate to high hazard area. However, very high hazard areas, and very low hazard areas were found at lower level.

In terms of spatial distribution by GN divisions, very high hazard area was found in Bhodhikotuwa GN division while, high hazard areas were widely found in Bambarakiriella, Madakumbura, and Bodhikotuwa GN Divisions. Subsequently, Horagolla, Mousagolla and Welangahawatta GN Divisions also were consisted of high hazard area with the lowest proportion. Landslide potential in both Thambalagala and Punchysylvakande GN divisions were found to be from moderate to low level of hazard except certain areas. Similarly, lower hazard areas were in very small proportion in Bambarakiriella GN division while, very low hazard areas were only found in a few areas of Horagolla Division. These results clearly emphasize that the hazard level varied from division to division. As discussed above varying factors led to various levels of hazard in the study area.



Map 3: Prepared Landslide Hazard Zonation Map of the study area

8. Conclusion

The main aim of this study was to generate a Landslide Hazard Zonation Map for the study area by adopting GIS based statistical approach. The causative factors such as bedrock geology, landform, slope gradient, stream density, past landslide locations, and land use were considered for the generation of the LHZ map. The map delineated the unstable hazard-prone areas at the study location. Results indicate that the high hazard zone and moderate hazard zone cover most part of the study area. In addition, few areas at the study area were potentially dangerous for further development of habitation. And also, implementation of proper mitigation works in the high hazard zones like Bodhikotuwa areas are on crucial need. Further, slopes with high hazard potential (East Slope) need to be avoided in any other development activities and it should be reserved as a protected area. In addition, effective utilization of this map would considerably reduce the damage potential and also facilitate the development and planning process in the study area.

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