Understanding the Types and Characteristics of Landslides in Sri Lanka

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Abstract: *Landslides of various types are considered as a significant hazard as it brings intense impacts to the communities living in the landslide prone areas of Rattota in the Matale district. Thus, understanding the characteristics of landslides in this region is imperative in terms of landslide risk reduction.This geographical study is mainly concerned with identifying the nature and characteristics of different landslides occurred at different sites. Field investigation, interviews and secondary data sources, including maps were accommodated to obtain the necessary data for this study. 25 small and large-scale landslides were analyzed for this purpose. The results revealed that, large-scale landslides are infrequent while small scale landslides are frequent phenomenon. The study area is exposed to different types of landslides such as rock slide/rock fall, earth slide, cutting failures, soil creep, and debris flow. In terms of spatial distribution, North-Western part is mostly exposed to risk from man-made cutting failures while few events have been recorded in the rest of the area. Debris flows were common in Southern and Eastern part which consists of more river channels. Cutting failures are high in frequency when compared with other types of naturally induced landslides. However, debris flows have brought intense impacts in terms of environment and socio-economy. Therefore, this study concludes that having an obvious perceptive of spatial characteristics in landslides, the planning process should be carried out to minimize the risk of landslide hazard.*

Keywords: *Characteristics, Hazard, Landslide, Risk, Types, Rattota*

I. INTRODUCTION

Landslide hazard manifests a wide range of ground movement in different geographical settings in different parts of the world. The term landslide is defined as "a gravitationally directed movement of rock, debris or soil," (Cruden & Varnes, 1996). It is a widespread geological process with complexity than any other geophysical natural hazard. It is mostly associated with some other natural hazards in terms of cause and consequences. "Landslides commonly occur in conjunction with other natural hazards such as storms, floods, earthquakes, volcanic eruptions or tsunami," (Jelinek et al., 2007). When compared with other natural hazards, landslide processes are very complex in their characteristics and consequences.

Many parts of the world susceptible to one or more of landslide types and have diverse effects on natural and human environment. Highland and Bobrowsky (2008) emphasizes that, "most countries in the world have been affected in some manner by landslides". This geological phenomenon occurs in a wide variety of ways and at many spatial scales on the earth surface. There are many experts in the field, proposing various classifications from different perspectives. Those various classifications of landslide are coupled with precise mechanics of failure, properties and characteristics of slope failure (Highland and Bobrowsky, 2008). In particular, type of movement and material involved are important in classification of various types of landslides (ibid). According to Gabler et al., (2007) factors of classification are described based on speed of movement, type of earth materials and kinds of motion. Accordingly, "Landslides are characterized by their spatial and temporal occurrence and by their intensity," (Malet & Maquaire, 2002).

Accordingly, there have been well – known classifications of landslides. Geomorphologic classification proposed by Varnes (1958) is mostly used to distinguish principle types of landslide movements, (Cruden & Varnes, 1996; and Dikau et al., 1996). It includes fall, topple, slide, spread, and flow. Moreover, another important classification based on the combination of surface material and the kind of motion includes rock fall, rock slide, debris flow, earth slide, earth spread etc. (AGS sub-committee, 2000).

Chau et al., (2004) states that "landslide can manifest themselves in many different forms, including rock falls, rockslides, debris flows, soil slips, rock avalanches, and mudflows,". According to Gabler et al., (2007) varieties of rapid mass movement include landslides, rockslides, rock falls, slumps, earth flows, and mudflows. "These five types may sometimes be combined or may succeed each other, forming a sixth type: a composite and complex movement" (Malet &

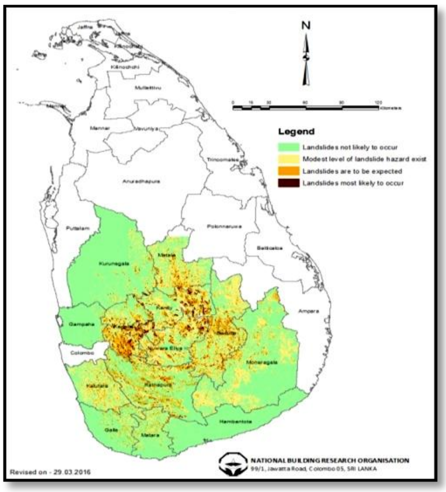
Maquaire, 2002). A complex landslide comprises a number of features.

The different types of landslides that have been discussed above consist of certain characteristics. They vary in size, type of the material involved, and the velocity scale and distance they travel. AGS sub-committee, (2000) emphasizes that the characteristics such as location, degree, classification, speed, material, and their occurrence probability within a given period of time should be considered when depict a landslide hazard. Thus, these unique characteristics are important factors in determining the risk level as well. Because, varying effects of landslide entirely coincide with characteristics belongs to the particular type of landslides. Moreover, the velocity and intensity of the landslide mostly depend on the material involved. "Intensity of landslides can be defined by the volume of the displaced material (in link with landslide depth) and by the velocity of the movement" (Malet & Maquaire, 2002).

Landslides with larger scale are relatively infrequent, but their destructive qualities make that they are very significant (Gabler et al., 2007). Chau et al., (2004) also emphasizes that some rarely occurred landslides are associated with catastrophe. Similarly, landslide with various velocities causes varying effects. Some fast - moving landslide may destruct the entire structure, whereas landslide with gradual movement may cause slight damages. Hence, landslides with rapid movement can destroy properties, and cause sudden deaths, (Hutchinson, 1988). However, gradual downhill movement, moves only few centimeters a year, also can cause severe damages in some cases.

II. CHARACTERISTICS AND TYPES OF LANDSLIDES IN SRI LANKA

Past studies have clearly portrayed that the Hill country of Sri Lanka has exposed to various types of landslide at various geographical settings. Thus, landslide prone areas in Sri Lanka are either located in Central Massif or its proximity areas covering about 13 districts, including Nuwara-Eliya, Kandy, Kegalle, Badulla, Ratnapura, Matale, Kalutara, Galle, Matara, Moneragala, Kurunegala, Gampaha, and Hambantota (Map 1). Some parts of these districts expose to various types of landslides due to the certain factors.



Map 1: *Distribution of Landslide Hazard Zones in the Central Highland of Sri Lanka, (Source: National Building Research Organization, Sri Lanka (NBRO))*

The geographic location, climate and geophysical structure of a region greatly influence in determining the types of landslide. Thus, the distinctive climate condition with physiographic, geological and soil characteristics make the hill country of Sri Lanka to prone more than one type of landslides. The wide variety of complex topographical features with rugged terrains such as ridges, peaks, plateaus, escarpments, basins and valleys and various geological structures are leading to various forms of landslides in the hill country.

Similar to the topographical features, diverse pattern of rainfall from monsoon and Inter-Monsoon season also make the hill country to expose various types of slope failures. Silva and Sonnadara (2009) state that the hill country is generally defined as an area experiencing the rainfall above 1905 mm. It receives more and intense rainfall from second Inter-Monsoon and South-West monsoon season. Amount of rainfall during South-West monsoon season varies from 100 mm to over 3000 mm.

The mid-elevations of the western slopes of the Central Highland experience the highest rainfall in the island which exceeds 5000 mm occasionally. In turn, a considerable amount of landslides occurs in the Northern and the Eastern slopes during North-East monsoon rainy season. "Almost all the Sri Lankan landslides investigated to date are known to be rainfall triggered" (Wickramasekara & Sinnathamby, 1994; Bhandari & Dias, 1998). Similarly, Dahanayake (2009) states, most of the Sri Lankan landslides are caused by percolation of rain water into the fractures and foliation planes of weathered rocks.

In terms of geological factor, most of the catastrophic landslides in Sri Lanka are found in Highland Complex. Wet and Intermediate climatic zones where most landslides occur mainly consist of crystalline metamorphic rocks like metaquartzites, quartz schists and various kinds of quartzo-feldspathic gneisses (Cooray, 1994).

Past and recent landslides have occurred on gneisses which form a significant proportion of Sri Lankan Precambrian rocks (Dahanayake, 2009). The combination of these different factors, underpinning the characteristics of different landslides, makes the hill country to prone various forms of landslide. Thus, classification of landslides in Sri Lanka is a complicated process, however, various classifications have been proposed so far. Among those efforts, the classification of Fernando (1951), Cooray (1958, 1994) and Dahanayake (1998) are rather important.

Fernando (1951) included several terms in his definition. He stated that “the occurrence of almost every type of slope failure, from typical earth slips, with well-defined surfaces of sliding, to slumping of soils and talus deposits, rock fall and debris fall, to definite cases of flow caused by erosion along drainage channels swollen by unusually heavy rains" (Cooray, 1994). Another classification was primed by Cooray in 1958, and it includes the terms debris avalanche, earth flow, slump, debris slide, rock slide, rock fall and subsidence.

Dahanayake (1989) classified landslides and mass movement in the Central Highland of Sri Lanka: topple, slide, lateral spread and flow. Following these efforts, again in 1994 Cooray classified the landslides and the mass movements into three main types: slides, falls and other movements. This attempt was made for the purpose of exploring the geological conditions of landslides in Sri Lanka. As he suggests, mass movements such as soil creep, earth flow, slump, debris avalanches, debris slides, mud flow, and subsidence are the commonest types of landslides in Sri Lanka.

When considered the characteristics of the landslides in Sri Lanka, some unique characteristics based on its volume, shapes, depth, and speed can be found. Landslides with high volume either hardly found or not recorded in Sri Lanka. “Unlike any other major landslides reported from different parts of the world which sometimes involve volumes as high as 200 million cubic meters, the areas and volumes of Sri Lankan landslides are rather from modest to low” (Bhandari & Kotuwegoda, 1998). Similarly, various depths of the landslide in Sri Lanka differ based on the type and nature of landslides. Bhandari (2000) explains various types of landslides and their depths as follows,

Type of landslide	Maximum depth (in m)
Surface landslide	less than 1.5
Shallow landslide	1.5 – 5.0
Deep landslide	5.0 – 20.0
Very deep landslide	20.0 and above

Table 1: *Type of landslides and their depths (Source: Bhandari, 2000)*

Most of the Sri Lankan landslides are either shallow or surface landslides. Bhandari & Kotuwegoda (1998) identified the shapes of the Sri Lankan landslides by analyzing of 114 landslides at a scale of 1:10,000. Further, they grouped those landslides in terms of length: width ratio of 1 to 2, 2 to 3, 3 to 6, 6 to 9, 9 to 12, 12 to 15, 15 to 18 and more than 18. Based on their findings, the most common length to width ratio turns out to be 3 to 6. It was concluded that “barring failure of cuttings in residual soil, most Sri Lankan landslides on natural slopes tend to acquire elongate geometry, and their depths are generally shallow” (Bhandari & Kotuwegoda,1998).

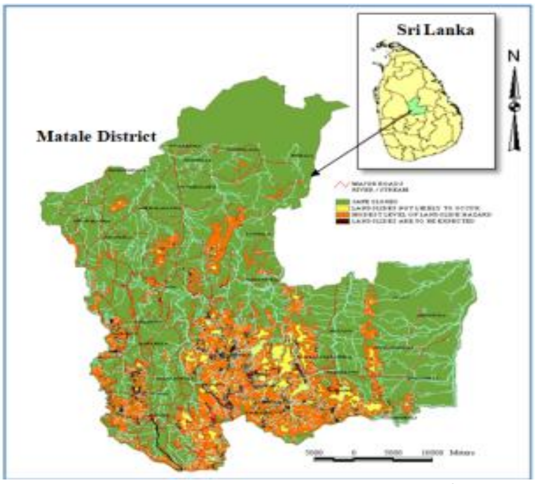
Another important characteristic identified in Sri Lankan landslides is coupled with newly formed and reactivated old landslides. Abeysinghe (1998) in his study emphasizes that the reactivation of dormant ancient slides is an important characteristic of landslides in the hill country. Dahanayake (2012) also states that “old landslides are common at the foot of steep scarp slopes characteristic of Sri Lankan Precambrian landscape”.

Combinations of all these factors determine whether landslide is catastrophic or not. For the reason that the impacts of landslides are diverse based on the type of movement (Malet and Maquaire, 2002). Moreover, Bhandari (2000) states that a massive landslide in Sri Lanka has to have several characteristics as follows “either when house and property is damaged, or when many people lose their lives, or when the area under the landslide exceeds 10,000 sq. feet or when its volume is 100,000 cubic feet or at least 150 meters across the length”.

III. CHARACTERISTICS OF LANDSLIDES IN RATTOTA IN THE MATALE DISTRICT

In terms of natural hazards, landslides and subsidence are important and most destructive geological hazards in the district. Matale District is an attractive creation of nature, representing all topographical features existing in different parts of the Island (Kularatne, 1984).

Thus, the Geomorphologic regions of the Matale District are embodying three different zones, such as (1) Northern flat land, (2) Matale trough and the Knuckles range, and (3) Laggala parallel hilly ridge zone (Kularatne, 1984). Most of the areas in Northern and eastern parts are less prone to landslide hazard since they belong to the category of flat lands. Only about 15% of the area lies above an elevation of 1000 meters in this district (Madduma Bandara, 1991) Most of it lies in Southern, Central and Western part of the district. Divisional Secretariat Divisions such as Matale, Ukuwela, Yatawatta, Ambanganga Korale, Laggala-Pallegama and Rattota with significant concerns in terms of landslide vulnerability. The spatial pattern of landslide hazard is clearly illustrated in the Landslide Hazard Zonation Map (Map 02) below.

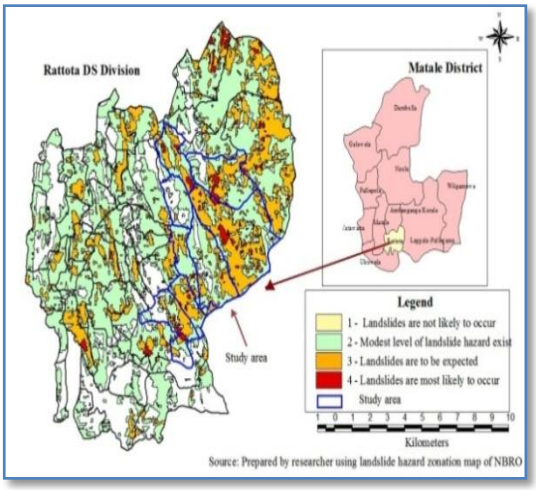


Map 02: *Landslide Hazard Zonation Map of Matale District, (Source: NBRO)*

Madduma Bandara, (1991) also states "in some southern parts of the district with hilly terrain, landslide occurs often after heavy rain". Some of the landslides and subsidence events occurred in these divisions are shown in Plate 01 below.

Plate 01: *Landslides and subsidence events in Matale District (A & B) Slope failure in Yatawatta and Rattota. (C) Subsidence in Rattota (D) Rock slide in Pitakande in Rattota (DMC, NBRO and field survey).*

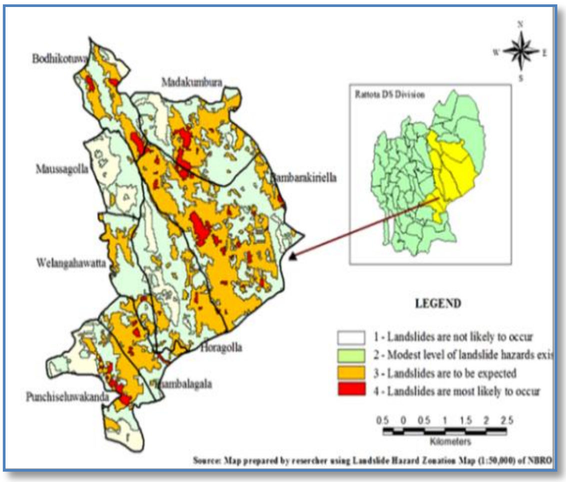
Major proportion of Rattota DS division, with significant mountainous physiographic features, is with the threat of different types of landslides and subsidence hazard too. Consequently, it has a high vulnerability to landslide hazard than other divisions in terms of landslide frequency and magnitude. Moreover, more landslide hazard prone areas are concentrated in the Eastern part of this division (Map 03)



Map 03*: Landslide Hazard distribution in Rattota DS division (Map based on hazard map of NBRO)*

Various physiographic features found in this division cause various types of landslides with significant spatial variation. Consequently, people reside in this division exposed to various threats generated by different types of landslides. It is very difficult to assess vulnerability to landslide in this area due to the complexity and the wide range of landslide process. Therefore, understanding of landslide types and their significant characteristics with spatial pattern is imperative in several ways. Bandara & Jayasingha, (2018) states that "identification of landslide in Central Highland leads categorization which is important in setting selection criteria for mitigation". Accordingly, by distinguishing and recognizing the landslide types and their characteristics this study would assist to inhibit the potential landslide occurrences and for landslide risk reduction procedure in this division.

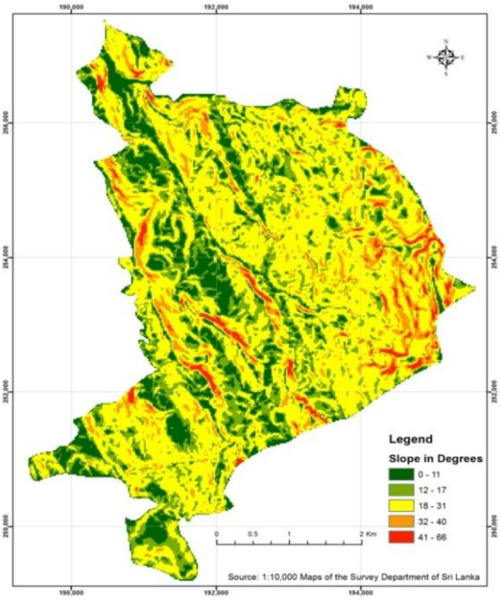
Accordingly, to carry out the above geographical study, eight Grama Niladari Divisions namely; Madakumbura *(Bambaragala & Madakumbura divisions)*, Bambarakiriella *(Nicholoya division)*, Mousagolla, Thambalagala, Bodhikotuwa *(Dikkumbura & Bodhikotuwa divisions)*, Punchyselwakanda *(Pitakande & SVK divisions)*, Welangahawatta *(Kotagahawela & Welangahawatta divisions)* and Horagolla which belong to Rattota Divisional Secretariat Division (DSD) have been selected for this study (Location Map 04).



Map 04: *Location Map of the study area (based on the Landslide Hazard Map of NBRO)*

The study area has an elevation of 1600 meters above mean sea level. However, altitude varying from 360m to 1600m mean sea level. It consists of rugged terrains with various topographical features such as mountain ranges, steep slopes, valleys, flat lands and erosional remnants. The major part of study area consists of lithology which is more vulnerable to landslide hazard such as Charnokitic gneiss, Charnokitic biotite gneiss, Granite gneiss, Quartzite and Marble. Moreover, Red Yellow Podzolic soils and Mountain Regosols are the major soil types. Another important factor which contributes for various kinds of landslide hazards in the study area is slope gradient. The slope gradient map (Map 05) of the study area, based on the contour map of Survey Department, shows that the major part of the slope belongs to slope gradient class within 18^0-31^0. The slope gradient above 31^0 exists in the Eastern part and some locations in the Western part of the study area.

Mean annual rainfall exceeds 2400 mm at most part of the study area as it belongs to Agro Ecological Regions of Intermediate Zone Upcountry (IUI). Certain parts of the study area belong to the characteristics of the Wet zone (WM3b). Both Second-Inter monsoon (SI) and North-East monsoon (NE) bring considerable rainfall in the later part of the year. The South-West monsoon (SW) season brings rainfall in the middle of the year. Hence, the study area consists of a number of tributaries originating from Eastern and Southern mountain slope and which feeds the four important sub watersheds such as Delewala Oya, Nicholoya Oya, Rattota Oya and Moragolla Oya (Vasanthakumary, 2018). Landuse of the study area is mainly covered with natural forest, plantation forest, Pinus plantations, tea lands, paddy lands, and homesteads.



Map 05: *Slope gradient map of the study area (Source: Vasanthakumary, 2018)*

IV. MATERIALS AND METHODS

This study mainly involves in identifying the characteristics of the landslide hazard. Accordingly, past landslides were studied to identify their major features and characteristics. Type of the movement, velocity and material involved in the landslides were primarily considered. This study was conducted using multiple data sources and methods. Data sources such as Landslide Hazard Zonation map and Google earth images, field investigation and interviews were important data sources.

An extensive field survey was conducted to identify the landslide features and characteristics in the study area. More than 25 small and large-scale landslides were studied for this purpose. Past landslide locations and their characteristics were studied and recorded using GPS technology, Google earth maps and field investigation. During the field survey existence of past landslides, length and width of the landslides, travel distance were visually inspected and recorded. Evidences of creep type movement, such as cracks, tilted trees and poles, formation of mud water, and subsided areas were also observed and recorded.

V. RESULTS AND DISCUSSION

A. VARIOUS TYPES OF LANDSLIDES IN THE STUDY AREA

Based on the results, occurrences of different types of landslides are found with significant spatial variation. In most cases, risk level from landslides ranged at various places based on the types. Small scale cutting failures have caused deaths while some large scale earthslides with no deaths as there was no exposure. However, debris flow *(Pitakande, 1982), complex landslide (Nicholoya debris washout, 2012),* rock slide *(Pitakande, 2012),* cutting failures

(*Bodhikotuwa, 2012, 2014)*, earthslide *(Madakumbura, 2012)*, slump *(Welangahawatta, 2012 and* subsidence *(Mousagolla, 2011)* are some of the important events in terms of the negative effects of landslides identified in the study area. As a whole, 4 major types of landslide hazard and subsidence events were found in the study area (Fig 01).

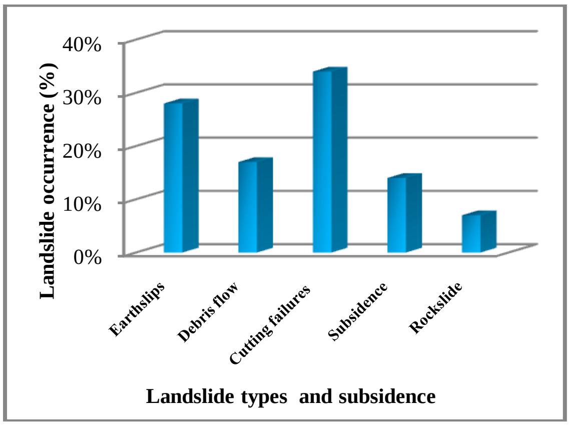


Fig 01: *Occurrences of landslides by types and subsidence in the study area (based on the past landslide records and the field investigation)*

Based on the occurrences, cuttings failures were high in terms of frequency following earth slips. Among other types of landslides, rockslides were very low in frequency. Debris flow and subsidence events were occurred at modest level. Soil creep is a widespread phenomenon while rock fall events are infrequent. However, debris flows carry more risk than other types.

a) DEBRIS FLOW

Debris flows are important and fast moving type with destructive characteristics in the study area. Among various types of mass movements, debris avalanches and slumps of various forms are common in Sri Lanka (Cooray, 1994*)*. This rapidly moving process generally occurs along drainage channels. Both Eastern and Southern parts are susceptible to debris flow type landslide due to the drainage channels in this area.

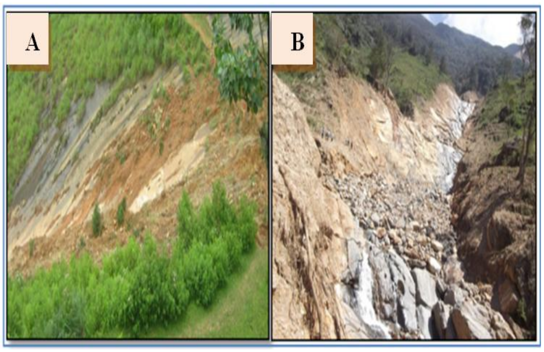


Plate 02: *Debris flow. (A) Pitakande debris flow. (B) Nickloya debris flow (Washout debris) (Office of Grama Niladari, & Field survey)*

Two major landslide events occurred in the study area; 1982 in Pitakande and 2012 in Nickloya estate (Plate 02 B) which were debris flow along the drainage channels. Both powerful debris flows were occurred without warnings and destroyed the structures. As the speed of debris flows was high, it brought severe negative impacts to the physical and social environment. In addition, there was another minor scale debris flow (debris washout) occurred in Pitakande in 2012 with less effect (Plate 02 A).

b) ROCK SLIDE AND ROCK FALL

Generally, rockslides and rock falls would bring much impact; however, the frequency and severity of the rock fall / slide in the study area are very low. There were no events of the catastrophic rock fall / slide reported so far except some small scale events.

Plate 03*: Rockslide in Pitakande (Field survey)*

In terms of spatial distribution, small scale rock slides have occurred in Bambaragala, Pitakande, Welangahawatta and Bodhikotuwa division and such events have only brought the disturbance to the transportation and minor damages to the houses. The Plate 03 shows the rock slide occurred in 2012 which had resulted disturbance to the transportation along Pitakande – Kandenuwara Road in Punchyselwakanda division. Moreover, risk of rock fall is high in the Kotagahawella area in Welangahawatta division. When rock fragments fall down, the people residing in the lower slope area are facing the negative impacts for last few years.

c) CUTTING FAILURES

The study found that cutting failures are considered high in frequency. Similar to the general trend of cutting failures in Sri Lanka, an increasing trend was noticed in the study area. As a result of increasing human interventions on the mountain slope, cutting failures have increased within the last 5 years. Excavation activities on slope for various purposes (improper settlements and quarry works), and haphazard steepening of slopes are the major cause behind the increasing cutting failures and the risk associated in this area. Cutting failures were common along the roads such as Punchyselwakanda - Thambalagala, Rattota - Riverston, and Madakumbura. Hence, Grama Niladari divisions such as Bodhikotuwa, Mousagolla, Welangahawatta and Bambarakiriella divisions are also exposed to similar hazard. In terms of frequency, cutting failures have been reported relatively high in Bodhikotuwa following by Madakumbura division. The Plate 04 below shows some of the cutting failures occurred in the study area.

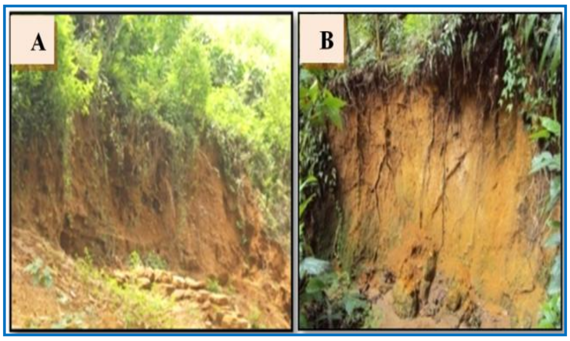


***Plate 04**: Cutting failures. (A) Pitakande. (B) Madakumbura, (Field survey)*

d) EARTH SLIDE

Both rotational and translational type earth slides are common in the study area. Since various levels of colluviums are existing here (from ½ m to more than 4 m thickness of soil), earth slips are varying in size. And most of the earth slides have occurred following the heavy rainfall. Madakumbura, Welangahawatta, Thambalagala, Bhodhikotuwa, Punchyselwakanda, and Bambarakiriella divisions are mostly exposed to earth slides. The Plate 05 below shows the earth slides occurred in Pitakande and Nickloya. Madakumbura division has faced larger earth slide so far, yet no massive losses were reported. The slump like movement occurred in Welangahawatta though small in size claimed human life and damaged about 7 houses due to the sudden movement. In addition, another rotational type earth slide occurred in the Bhodhikotuwa division along the sub-road caused entire area with unstable condition.

***Plate 05:** Earth slides (A) Pitakande. (B) Nickloya. (Field survey)*

e) SUBSIDENCE

Subsidence was another important hazard associated with landslide occurrences in the study area. The sudden collapse of the land surface into the subsurface has increased the landslide threat in this area. The study revealed both Bodhikotuwa and Mousagolla divisions are more vulnerable to subsidence hazard. Though it is quite difficult to recognize prior to the event, it brings severe negative impacts. Head of the NBRO district office of Matale states that "the land subsidence investigations carried out following the unusual observations in this area clearly revealed that the cavities prevail underneath the earth surface was the primary cause of land subsidence". The situation has brought a higher level of risk to people and settlements in the study area. The damages to settlements caused by land subsidence are shown below (Plate 06).

***Plate 06:** Houses damaged by subsidence in Mousagolla and Bodhikotuwa division (Field survey)*

f) SOIL CREEP

Soil creep also one of important indicators of slope instability in certain areas of the study area. Evidences of widespread downhill movement clearly indicate the initial movement of slope failure and consequently, materials resting on the slope are slowly pushed downward the slope (Table 02)[1].

*[1]- Earlier failures: Below 2 events - **L**ow; between 2-3 events-**M**oderate; more than four-**H**igh.*
*- Tension cracks developed on the land surface: If any tension cracks-**Y**es; If not-**N**o*
*- Cracks: If the number of houses with cracks below 5-**L**ow; if between 5 – 10 **M**oderate; more than 10-**H**igh*
*- Tilting and J-curve trees: If most part of the slope consist of Tilting and J-curve trees - **H;** Particular areas-M; Only a spot-**L***
*- Subsided areas: If the number of subsided areas are below 2-**L**ow; if between 2-4– 10 **M**oderate; more than 10-**H**igh*
*- Formation of mud water and wetness of the floor: If any houses found with mud water or wetness-**Y**; If not-**N***

Indicators of slope instability	Thambalagala	Punchyselwakanda	Bhodhikotuwa	Madakumbura	Horagolla	Bambarakiriella	Mousagolla	Welangahawatta
Earlier failures	L	H	**L**	**M**	L	H	L	**H**
Tension cracks on the land surface	Y	Y	-	**Y**	-	-	-	-
Cracks developed in the houses	L	M	**H**	**H**	L	M	M	**H**
Tilting and J-curve trees	L	L	**M**	**H**	L	L	M	**H**
Subsided areas	L	M	**H**	**H**	L	L	H	**M**
Formation of mud water	Y	Y	**Y**	**Y**	Y	Y	N	**Y**

Table 02: *Evidences of soil creep (Field survey)*

It was confirmed visually through several environmental indicators. Earlier slope failures, tension cracks developed on the slope, cracks developed in the houses, tilting and J-curve trees, subsided areas and formation of mud water are importantly identified indicators with spatial variation. However, this study found that the rate of soil creep generally intensify following a heavy rainfall. The slope gradient and slope material with water content play a major role in triggering soil creep. The North-Western part, consisting steep slope and more colluvium, is mostly exposed to soil creep in this area.

Moreover, tension cracks which appeared at various times on the slopes of the Bambaragala, Thambalagala, and Pitakande divisions, and along the roads in Kandenuwara–Rattota were also considered as an indication of the slope instability and potential for future slumping in this region. Thus, the development of tension cracks in conjunction with the slope instability demands the remedial works to inhibit landslide processes. The Plate 07 below indicates the cracks appeared in the road and line rooms in SVK division.

Similar to the tension cracks, cracks which are developed in the houses also another important indication of slope instability in this region. Such cracks were a perceptible phenomenon in the floors, concrete roofs and walls of the houses and exterior area. The details of cracks shown in Fig 02 reveals that most of the houses have cracks in the walls and floors, however, number of cracks in the walls are relatively higher than the cracks in the floor. Fewer cracks identified both at concrete roofs and fences. Similarly, vertical cracks are relatively higher than horizontal cracks.

Plate 07*: Evidences of soil creep (Kandenuwara–Rattota & SVK division). (Field survey).*

In terms of spatial distribution, the Northern and Western part, particularly in Bhodhikotuwa, Welangahawatta, Madakumbura and Mousagolla divisions have a higher number of cracks as these areas consist of steep slopes with more human interventions. Houses, located in both the offside and on side roads of Dikkumbura in Bodhikotuwa GN division, consist of more cracks than others. While these cracks associate with the man made factors, the cracks appeared in the line houses located in the Eastern and Southern slopes (Pitakande, Bambaragala and SVK Divisions) are mostly associated with the slope instability caused by natural factors. Being located at the lower part of the slope, SVK division encountered intense impacts with more number of cracks. Apart from the houses, the building of the Samurdhi Bank in Bodhikotuwa Division also has cracks at several places due to the instability of the slope. As such, monitoring of environmental indicators of soil creep should be continued.

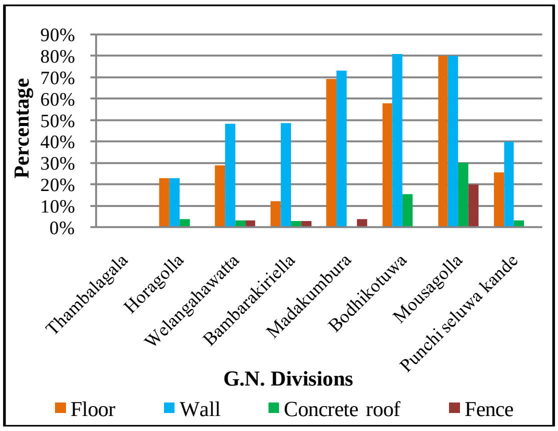


Fig 02: *Details of the cracks*

B. CHARACTERISTICS OF LANDSLIDES IN THE STUDY AREA

Similar to landslide types, characteristics of landslides were inspected based on velocity, the material involved, length, width, depth and time of the occurrence of past landslide. The study found that these factors vary based on the associated geological and geographical factors. In terms of scale, landslides in the study area vary from very small to large. As states by Kularatne, (1984) a number of large scale earth slips has been reported from the localities of Nickloya (Bambarakiriella GN division), Bambaragala (Madakumbura GN division), on the Western slope of the Knuckles range which gets a heavy rainfall.

Plate 08: *Small and large scale landslides. (A)Thambalagala. (B) Madakumbura. (Office of Grama Niladari and Field survey).*

Plate 09*: Material involved in landslides (A) Large-scale rock boulders. (B) Soil mass with plants (C) Small boulders. (D) Soil mass with boulders. (E) Plant logs & (F) Soil mass and plant logs (office of Grama Niladari Divisions & Field survey)*

Large scale landslides are infrequent while small scale landslides are frequent phenomenon in this region. Within the period of the last three decades, a major landslide occurred in 1982 in Pitakande estate and thereafter there was a second massive landslide in Nickloya estate in 2012. A number of minor scale landslides, including rock falls with lower magnitude are a frequent phenomenon in Welangahawatta, Bodhikotuwa, Madakumbura and Pitakande divisions. The plate 08 above shows examples of landslides occurred at various scales. Similar to the scale, velocity of the landslide movement is an important factor which determines the impacts of landslide because the sudden movement of landslide would cause much impact than the typical landslides. The impacts of a landslide increase significantly with the velocity and the travel distance (Malet and Maquaire, 2002).

The study reveals that during the past landslide events, movement of rock and soil mass at high speed has caused threats to lives, buildings, bridges and utility lines. This condition was obvious in the case of both Pitakande and Nickloya landslide events. Both events occurred as sudden movement with high velocity, and therefore caused about 18 deaths with more injured and destruction to properties. The material involved in the landslides consists of various combinations of the surface materials in most cases. Both rock and soil masses were common in most landslides. Plate 09 and Table 03 show various materials involved in the past landslides at different places. The major landslides such as Pitakande and Nickloya landslides consisted of varying sizes of rock boulders, plant logs and soil masses.

Hence, Welangahawatta landslide mostly consisted of soil mass with plant logs while rock boulders were relatively low in proportion. In Bodhikotuwa division, surface deposits consisted of small scale rock boulders and soil mass which is about 2m - 3m height. Accordingly, the surface material of cutting failures occurred in this area typically consist of soil mass. However, the materials involved in these failures were small in size.

Location	Involved materials
Pitakande	Rock, soil mass and plant logs
Dikkumbura, Bodhikotuwa	Soil mass
Galgewatta	Soil mass
Nicholoya	Rock, soil mass and plant logs
Welangahawatta	Soil mass and plant logs
Madakumbura	Rock boulders and soil mass
Bodhikotuwa	Soil mass
Dikkumbura, Bodhikotuwa	Soil mass

Table 03: *Various materials involved in landslides (Field survey)*

Similar to different materials involved, the length of the landslides is also an important factor in characteristics of landslide. Landslides with various lengths were identified in the study area and some of the important landslides with their length have been given in the Table 04. The length of the flow path is nearly 3 km in Nickloya landslide and it was identified as the longest debris flow in the landslide history of the study area. Excluding Nickloya landslide, the length of remaining landslides has recorded as below 3 km in length. Besides, landslides occurred at various depths. All the landslides reported so far were surficial (< 2 m) landslides and no deep-seated landslides (< 5 m) were found. In terms of width, highest width was identified in Madakumbura landslide. Similarly, certain places along the Nicholoya landslide path also consisted of higher width. Similar to the spatial factor, time factor also play an important role in the negative consequences of a landslide. The occurrence time of the landslide determines the magnitude of the negative impacts of the landslides in several ways.

Location	Length of flow path
Pitakande	Long (0.75 – 1 km)
Nicholoya	Very long (3 km)
Welangahawatta	Short (below 0.25 km)
Madakumbura	Moderate (0.5 – 1 km)
Bodhikotuwa, Galgewatta: cutting failures and other slope failures	Very short (1 – 4 m)

Table 04*: Important landslides and their length in the study area, (field survey, and past records)*

Potential negative impacts from landslides would higher at night time as less opportunity to get away from the impacts and delayed rescue operations. The two major landslides in the study area occurred at night time. Raveendrasinghe et al., (2014) states that the Nicholoya killer landslide occurred during the night and washout debris had caused deaths and damages due to its destructive attributes. Therefore, there were no prior actions were done either by the community or relevant institutions in pre-disaster state or during the landslide. Moreover, rescue operations were also delayed until the next day. As a result, both landslides caused much impact not only to the social environment, but also to the physical environment as well.

VI. CONCLUSION

This geographical study mainly focused on identifying the types and characteristics of landslides in the study area. The study reveals that, various types of landslides such as rock slide/rock fall, earth slide, cutting failures, soil creep, and debris flow were identified with some unique characteristics. The spatial characteristics of landslides in terms of material involved, the size of the landslide were also evident. In addition, subsidence is another important geological hazard coupled with landslide hazard in this region. The study reveals that cutting failures are higher in frequency while debris flows are associated with more negative impacts. Therefore, this study concludes that according to the characteristics of the landslide hazard identified, planning and implementation process should be carried out to minimize the risk of landslide hazard.

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