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Original Paper

Lion Mountain Landslide in Non-urbanized Terrain: Changing the Myth of Landslide Occurrence in Western Sierra Leone

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Abstract

Freetown has documented one of the most devastating landslides in the world in 2017. Many debates in the media, few scientific papers and technical documents, have argued with eloquence ascertaining human factors, particularly deforestation and urbanization, as the dominant causative factor. This notion seems to be widely accepted for all other slides by the communities, government agencies and departments. Therefore, this work attempts to expand on existing public knowledge by demonstrating the less influential or insignificant human factors which can have impacts on certain landslide occurrences in the Freetown Layered-Complex.

The representative landslide considered for this study occurred beyond the vicinity of urbanized zone. Therefore, to establish a clear understanding of the actual causative factors, fieldwork and laboratory investigations were undertaken. During the field survey, we assessed the rock type, discontinuities, geomorphology and hydrological influence of the landslide. The specific rock series underlying the landslide was confirmed through thin section analysis at the National Minerals Agency (NMA). DCP tests and laboratory analyses enhanced the derivation of geotechnical properties of the residual soil/regolith.

This work systematically presented how natural conditions, such as: geology (rock types and tectonic signatures), geomorphology, hydrology and the geotechnical properties of the slope soil, have interplayed in the occurrence of the landslide event. In addition, the slip surface of the landslide occurred at a depth below the reach of plant activities (2.6 m). This information may help modify public messages by institutions and can be a source of useful information for the country's Landslide

Disaster Management Department (LDMD).

Keywords

dynamic cone penetration, geotechnical properties, human factors natural conditions

1. Background of the Study

Freetown is located in the western area of Sierra Leone, which sits on the edge of the Atlantic Ocean in West Africa. Rapid population growth in this region became eminent during the civil war (especially from 1999 to 2001) because of its insulated nature against rebel activities. Economist intelligence unit (2002) and Kaldor and Vincent (2006) mentioned that one- third of the country’s 2.6 million displaced persons and 500,000 farm families relocated to the safe haven (Western Area) (Gbanie et al., 2015). This has accounted for the rising population in Freetown (Weekes & Bah, 2017; Sesay et al., 2006; Gogra et al., 2010) amounting to enormous pressure on the small space between the mountains and the sea.

The unavailability and affordability of suitable lands at coastal and inland settlements, have forced many people to settle on steep hills/mountains of the city. Over time, their migration to those terrains, has facilitated rapid encroachment into vital forestlands (once-protected forest highland) without any adherence to land policies and laws. As a consequence, the uncontrolled urban developments have caused several environmental issues, ranging from pronounced changes in natural channels from a significant increase in the storm water run-off and erosion (UNDP & EPA, 2017), to over-harvesting of timbers on the hillsides, leading to deforestation, and eventually causing soil erosion. In effect, these intense anthropogenic activities, mainly deforestation and urbanization, have contributed to landslide occurrences in the Freetown-Layered Complex, which are captured in few available documents/articles (e.g., Munro, 2009; UNDP & EPA, 2017; cui et al., 2019) as the dominant causal factors for the Regent rainfall-triggered landslide. This information on causal factors seems to be a widely accepted phenomenon for any landslide event within the Complex irrespective of the terrain/zone of occurrence, indicating an absolute dearth in knowledge regarding landslide causal factors. This necessitates scientific investigation of landslide occurrences in areas unaffected by deforestation and urbanization.

Historically, landslide events have occurred in forested area (Redshaw et al., 2019), including an area formally designated as the Western Area Peninsula Forest (Sesay, 2005). Recent landslide inventory conducted through field surveys and the exploration of Google Earth satellite images (-accessed in 2019 and 2020) in the area represented by Figure 1, has shown greater percentage of landslide scars in forested area than the urbanized zone**s (**Lahai, 2020**)**. The landslide used as a case study affected the Lion Mountain located 938m northeast of Fula Town community; hence, the name Lion Mountain landslide is adopted in this paper. It is a non-urbanized terrain: an area that is sparsely vegetated, but enough to preserve its beneficial action in terms of mechanical (root anchoring) and hydrological (suction generated by root water uptake) effects (Balzano et al., 2019).

Landslides have caused numerous destructions to forest in many parts of the world, and are seen to affect hugely the tropical areas due to the combination of intense rainfall and earthquakes. Studies done by Garwood et al. (1979); Martinez et al. (1995); Schuster and Highland (2007) have demonstrated elsewhere where the above triggering factors existed (i.e., rainfall and earthquakes). Similarly, the study area belongs to the tropical climate, which has a characteristic heavy rainfall, but the seismic hazard level in the entire country is very low and landslides triggered by earthquakes would be extremely unlikely within a 50- year return period (Arup et al., 2018). This makes the case unique, indicating strong relationship with geological instability and other geoenvironmental factors, which this study seeks to unravel.

Furthermore, no attempt has been made to investigate landslide occurrence in non-urbanized areas and by extension the effects on its biodiversity. The few studies focused on landslide occurrences within the urban areas and specifically on Regent Landslide (e.g., UNDP & EPA, 2017; Arup et al., 2018; Cui et al., 2019; Redshaw et al., 2019; Lahai et al., 2019): which has accounted for the worst fatality in the country and the world during the year of occurrence, Madina Landslide (e.g., Sillah et al., 2011; Lahai et al., 2020), and Charlotte Landslide (Lahai et al., 2020). Information pertinent to these slides is not adequate and as such lacks the realistic basis to be extrapolated to other areas affected by landslides within the Freetown-Layered Complex, particularly in forested areas where little or no human activities are not experienced. This constraint in knowledge extension to other areas could be due to marked lithologic, topographic, hydrologic and tectonic variation across the terrain. Therefore, this work provides a comprehensive and better understanding of the actual causes of the Lion Mountain landslide through the following approaches: an intensive field assessment of the slide, laboratory analyses on soil samples, soil strength determination using Dynamic Cone Penetration (DCP) and data analyses obtained from the United States Geological Surveys (USGS) pertinent to the landslide location and its surroundings.

This work presents detailed and accurate information on the geology, hydrology, geomorphic and geotechnical properties of the residual soil/regolith of the landslide. This is a significantly generated scientific fact on the conditions responsible for landslides in non-urbanized zones (forested areas). The information is hoped to eliminate knowledge gap and change the general notion on landslide causative factors, which will support the modification of public documents and government policies.

2. Description of Landslide Area

The area falls in the northwestern part of Freetown, which is located 0.93km northeast of Fula Town (8.430708N, 13.243174W) and 1.12km southwest of the Regent landslide. The geographic coordinates (latitude and longitude) of the landslide is recorded as 8.417325N and 13.230336W, which falls within the non-urbanized zone (forested area).

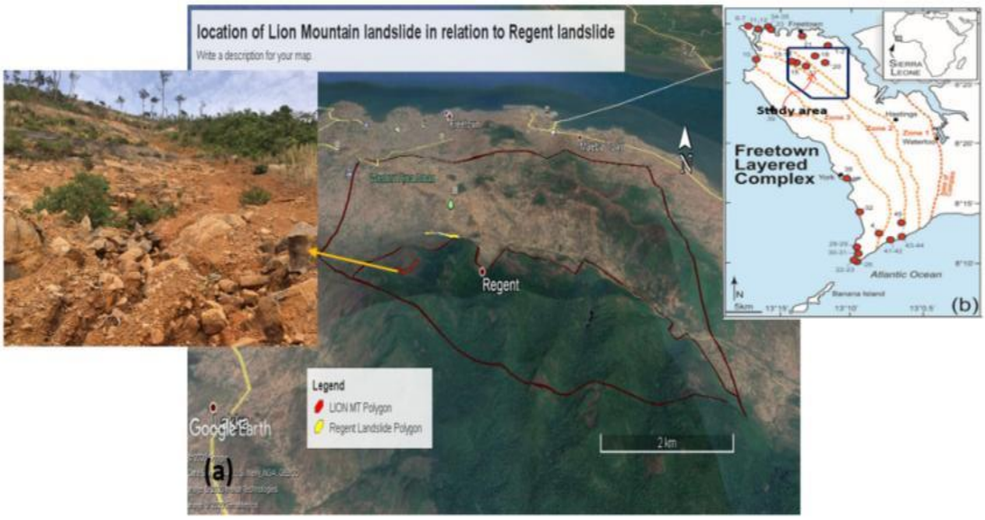

Figure 1. Location of Lion Moutain Landslide (a) Map Showing the Two Landslides and Area of Interest (Source: Google Earth-Accessed 2020), (b) Freetown Map with Inset of Interested Area Encompassing Zone 1, 2 and 3 of the Complex

The area consists of mountain ranges trending from NNE to SSW direction, which are separated by fault planes (they are seen as stream valleys, representing an area of discharge) as observed in Figure 1.The landslide seems to have affected one of these mountainous slopes/faces (WSW) of the Freetown Peninsula. They have a vegetation cover ranging from thick to sparse forest, with patches of barelands (exposed rocks and soil), which represent landslide scars (Figure 2).

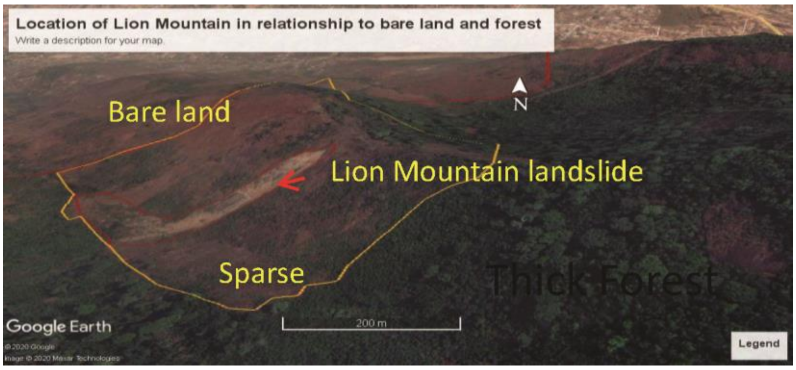

Figure 2. Location of Landslide Scar in Relationship to Bareland, Sparse Forest and Thick Forest Reserve

Like any other locality in West African country, the landslide area experiences tropical and humid type of climate that is strongly controlled by the tropical air mass blowing the entire sub region. Unfortunately, there is an absence of an accurate rainfall time-series data representing Freetown, which may prevent the determination of location-specific values (Redshaw et al., 2019), but analyses on data obtained from the country's Meteorological Agency present a general understanding of how rainfall conditions lead to both flooding and landslides. From the analyses, high amount of precipitation (100mm-1200mm) are received from July to September. This landslide event is reported to have taken place within this time bracket (especically August, 2018), and there has been a confirmed information on backward extension of the landslide head wall during the rains in 2019.

3. Methodology

3.1 Field Work

This survey was undertaken in March 2020,which coincided with the dry season, and included field assessment of the landslide with keen interest on the underlying geology, tectonic structures (fractures and joint sets), surface and subsurface hydrology and its geomorphology. The Dynamic Cone Penetration (DCP) was used to conduct in-situ soil (regolith) test. Only three tests at random intervals along the slope were undertaken to give an insight into the overall slope cover (residual soil) strength. This assumption is connected to the homogeneity of the underlying rocks (same chemical and physical composition) and also number of DCP blows (NDCP) per penetration depth plots for the three testing points show high consistency (Coefficient of variance is less than 30%). Additionally, recording of vital information pertinent to the landslide (point coordinates of the landslide, landslide area, perimeter, length, width and slide volume) was achieved, and finally, description and classification of the slide done in accordance with Varnes (1978) and Cruden and Varnes (1996). Extraction and measurement of parameters (landslide's point coordinates, area and perimeter) from Google Earth image corresponded with field data obtained using the Global Positioning System (GPS). Information on the landslide's occurrence times and activities was derived from interviews with nearby local people who often visit the area for wood fetching prior the incident.

Rock samples were logged using field-based approach (field description). The discontinuities (layering, fracture/crack and joints) on the landslide main body and adjacent surfaces were identified, their attitudes (strike and dip) measured using the Silva Compass and Clinometer and recorded appropriately. Other parameters noted include: diameter of boulders, thickness of bouldery debris, and slide volume. Both rock and soil samples were later collected for thin section analysis and for geotechnical soil investigation at the National Minerals Agency's laboratory and the Sierra Leone Road Authority (SLRA) materials laboratory respectively.

Hydrologically, we also assessed the bottom slope and nearby darinage system (current river and streams) that may have affected the landslide or affected by the landslide materials in addition to the lineaments on post landslide surfaces (evidence of groundwater source); which provide clue to hillslope hydrology and flow path during the rains. Key parameters noted were: the flow direction, proximity to landslide site and any erosive evidence on the stream bed. Extraction of these hydrological elements including drainage density of the landslide area and environs represented by the inset in Figure 1(b) were derived from the Digital Elevation Model (DEM). Finally, the landslide geomorphological elements recorded along its entire length are: elevation, degree of slope, slope aspect and they were compared with the DEM for validation.

3.2 Laboratory Tests/Analyses

Laboratory work was conducted on both rock (grab) and soil samples in different laboratories at NMA and SLRA respectively. The grab sample was cut into two parts using the slab cutter. One half of the grab sample was used for the preparation of slide (30-micron thickness) for thin section analysis, and the other for XRF analysis. For the purpose of this work, the result of thin section analysis formed the basis in ascertaining the specific gabbroic series underlying the landslide.

Two soil samples (small and bulk) were obtained at 1.5m depth in each of the three trial pits within the landslide area for geotechnical soil investigation. The small samples were well preserved to prevent any loss of water component between the time of sampling and testing in the laboratory. These samples were used for the determination of moisture content using oven-drying method and the consistency limits of the soil. The bulk samples were utilized for the analysis of particle size distribution using the sieve method and the determination of specific gravity using 50ml or specific gravity bottle. Finally, a cone cutter (used in the field) and a weight balance were used to determine the bulk density at each of the three sampling sites.

3.3 Data Analyses

The DEM data, which we obtained from the United States Geological Surveys (USGS) were pre-processed and the 3-D analyst tool in the GIS environment utilized to generate classified maps of geomorphic factors (slope, aspect, curvature and elevation) and hydrological factors (drainage density, drainage system, flow direction). Also, the location of the landslide (point coordinates) was integrated in each of the factor maps to establish it links with the terrain-specific factors, and Google Earth image utilized to enhance derivation of landslide dimensions that correlated with field data. Finally, geotechnical data were inputed, double checked for errors in data capture, arranged, and analyzed in the Microsoft Excel spreadsheet. This facilitated the presentation of data in tables and graphs.

4. Results

4.1 Lion Mountain Landslide

The Lion Mountain landslide with dimension 420m by 86.3m and a perimeter of 1,257m, is broadly **translational** involving rock fragments (angular and sub-rounded) and residual soil. It is a large landslide (area > 3000 m^2) (Skrypczak et al., 2017), with a slide volume estimated as 94239.6 m^3 using the method presented by Adegbe et al. (2014). The sliding took place along the interface between bedrock (resistant gabbroic rock) and the overlying soil (weaker material) at few portions along the slope (upper and mid slope in Figure 2), and along discontinuities (joints and layered planes), with clear evidence at the landslide base. The failure surface is planar, which is persistent and slightly undulating at post landslide bedrock exposures. The estimated depth of rupture ranges from 2.5m to 2.9m (below the zone affected by plant roots).

The boulders found at the landslide base were released either together with the debris or from the fractured rock mass. They bounced and slid along the slope to their point of deposition in the lower plain: a process refered to as boulder bounce. Also a proportion of debris and large boulders formed bulge with approximate elevation of ≈0.9m in the lower plain, whilst others (mainly debris) mixed with the surface runoff water to give rise to debris-laden flow (Flow-like behaviour of the landslide), which became enhanced by basal diverted streams, and carried into the major stream valley (a valley that contained a river named the Lion Mountain river). The total run-out is estimated as 1,273 m (1.28km), which spans from landslide headscarp to a point where the Mountain Lion river connects to the Babadorie valley (confluence point). Indigenes of the nearby community (Fula Town) confirmed the presence of water seepages on the slide's body for a couple of days following rainfalls, which could have emerged from the vertically dip fractures and joint sets.

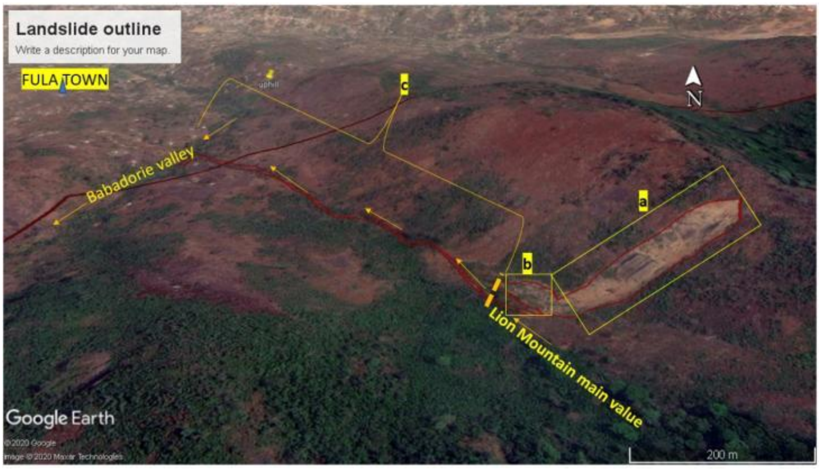

Figure 3. Landslide Tracjectory and Typology (a) Translational Landslide Body from Crown to Toe, (b) Debris-Laden Flow, (c) Lion Mountain Landslide with Implied Flooding Carrying Medium and Fine-Sized Particles (Debris-Laden Flooding)

4.2 Geological, Geomorphological and Hydrological Conditions of the Landslide

4.2.1 Geological Conditions

The landslide is underlain by a pegmatitic gabbro (very coarse-grained ultramafic rock) comprising up to 90% mafic minerals (pyroxene). The lithology is quite extensive, and belongs to zone 3 of the Freetown-layered Complex proposed by Chalokwu (2001) and Chalokwu et al. (2010). Identification and analysis of specific-rock series within the Freetown Complex unit affecting the landslide is particularly important than determining this lithologic unit with a very general approach. This approach unravels the distinct characteristic features corresponding to compositional variation within the unit. Post landslide observations revealed few fractures on the slightly undulating, but generally planar exposed fresh surfaces at the upper slide section and in the center; which are alternated by weathered and partially weathered materials along slope’s length from top to base. They also show evidence of exfoliation joints, that could make the affected section appear to be flaking off in sheets, and linear marks (striation) indicating downslope rock sliding against each other (Figure 4). But much degree of rock fracturing are visible on weathered and partially-weathered rock surfaces at slide’s base, starting just beneath the mid rock exposure, forming joint sets (NNW-SSE) to the toe (planar portion of the landslide). Some of the lineeaments are parallel to the slope while others are not and most of the dips are near vertical (~90 degree). The most obvious fracture has an offset of 15mm and it is orientated in the NNE-SSW direction with a vertical dip as well (Figure 5**)**. The initial sliding surface may be associated to this weaker zone, followed by detachment of regolith from the lubricated surface of the underlying fresh rock (bedrock and overlying soil interface). However, this entire process of landslide seems difficult to track in post-disaster investigation.

Also, the orientation of rock layering (ESE-WNW) and dip (43^0 NW-almost the same as sliding plane) at the landslide site when compared with the strike and dip of outcrops on adjacent slopes and the mountain village (8.430708N, 13.243174W) showed correspondence. This aided in distinguishing in-situ rocks from boulders. The boulders with diameters ranging from 2m to 5.5m, were deposited at the bottom slope and along the stream valley underneath. They range from rounded old black surface colour weathered corestones to angular chunks released from the fractured rock mass.

Figure 4. Local Geology (a) Distinct Zones along Slope Face Showing Differential Weathering, Separated by a Tranverse Crack, (b) Typical Rock Type with Evidence of Exfoliation Joints, (c) Intensely Weathered Landslide Basal Section Where the Slipage/Failure may Have Initiated, (d) Parallel Proto-Joints in the Process of Developing as Full Mechanical Fractures but Maintaining Considerable True Cohesion

The constituent rock is susceptible to chemical weathering, with clearly weathered zones at the ridge top (weathering profile is estimated as 2.6 m thick) and very thin along the flanks (1.5m-2.5m). Rocks at the upper landslide base are strongly affected by weathering (block weathring/rind weathering) (Figure 5a), and is seemed concentrating in the fractured planes/zones, which together with upward groundwater flow and increased pore-pressure on key joints may have initiated basal failure.

Figure 5. (a) Joint Sets (Vertical Dip) in Highly Weathered Pegmatitic Gabbro, (b) The Largest Offset Fracture (15mm) within the Landslide Area

4.2.2 Geomorphological and Hydrological Conditions

Geomorphologically, the landslide slope is cataclinal or a dip slope (i.e., topographic surface dips in the same direction and approximately by the same amount as the true dip of the underlying rock). Field data on landslide elevation and slope (recorded at the main scarp) are 335m and 35^0 respectively, and the event affected west-south westerly (WSW) facing slope (slope aspect). These values correspond with those extracted from the DEM, with the slope belonging to class four (4) as seen in the figure 6 below. Excluding the slope aspect, elevation and slope values decrease from landslide crown to toe.

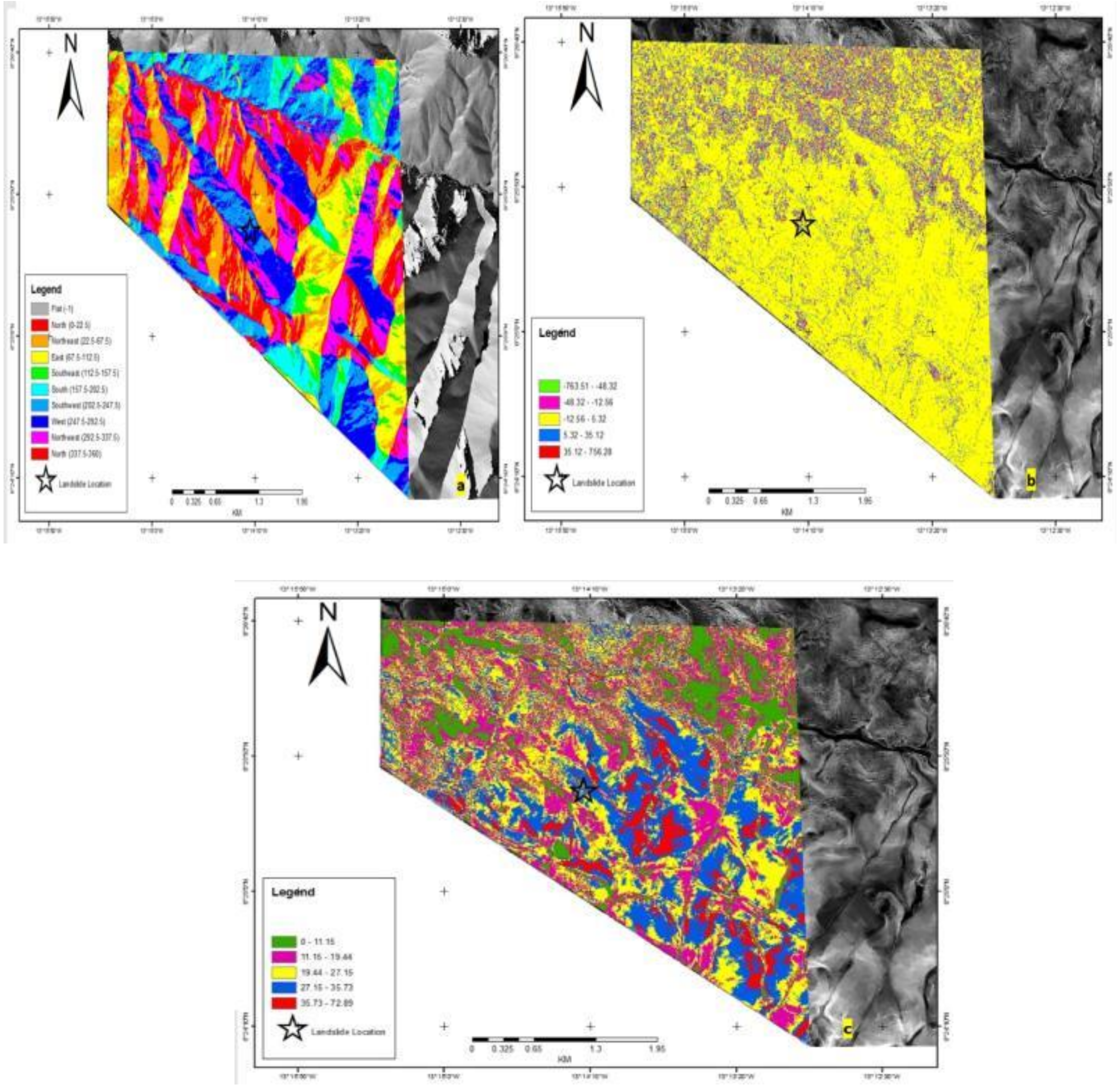

Figure 6. DEM for Geomorphic Factors (a) Slope Aspect, (b) Slope Curvature, (c) Slope Angle

The toe is characterized by two minor streams (quick stream) separated by 0.9 m accumulated debris, which eventually may have built significantly poor drainage properties, making it prone to the development of excess pore water pressure when saturated and sheared (undrained loading). These streams emerged due to barriers to natural flow path, causing the surface water body to diverge into two channels. The diverted streams could be traced up to 100m from the landslide toe to the confluence point (point of intersection with the Lion Mountain stream). They may have eroded the sediments (relatively loose materials) along their paths into the Lion Mountain stream, but could not significantly affect the centre material (sedimentary pile).

The two minor stream channels at slope base and the Lion Mountain valley (main stream channel controlled by north westerly striking valley)-which connects the study area drainage system to Babadorie valley constitute the surface hydrology. Specifically, the landslide area is drained by 1st order streams and the entire area belongs to sixth Order basin, which joins rivers and tributaries based on the topography (Figure 7b). There is no evidence of effective erosional action (e.g., removal of material from the foot of the slope in the river bed by river bank erosion prior to the landslide event), which could have influenced any downslope movement. The drainage density of the slide area belongs to class three, which is moderate (19.88-2.81 km/km^2) and may favour groundwater recharge (Figure 7a). The main channel is separated from the landslide area by a relatively flat plain that is approxmately 20m wide, which always become flooded during persistent rainfall. Following the landslide event, the basal accumulated sediments extending towards the river may have been over-saturated with the flooded water leading to an increased pore pressure. This accounts for the loose nature of the materials when stepped into by nearby local people.

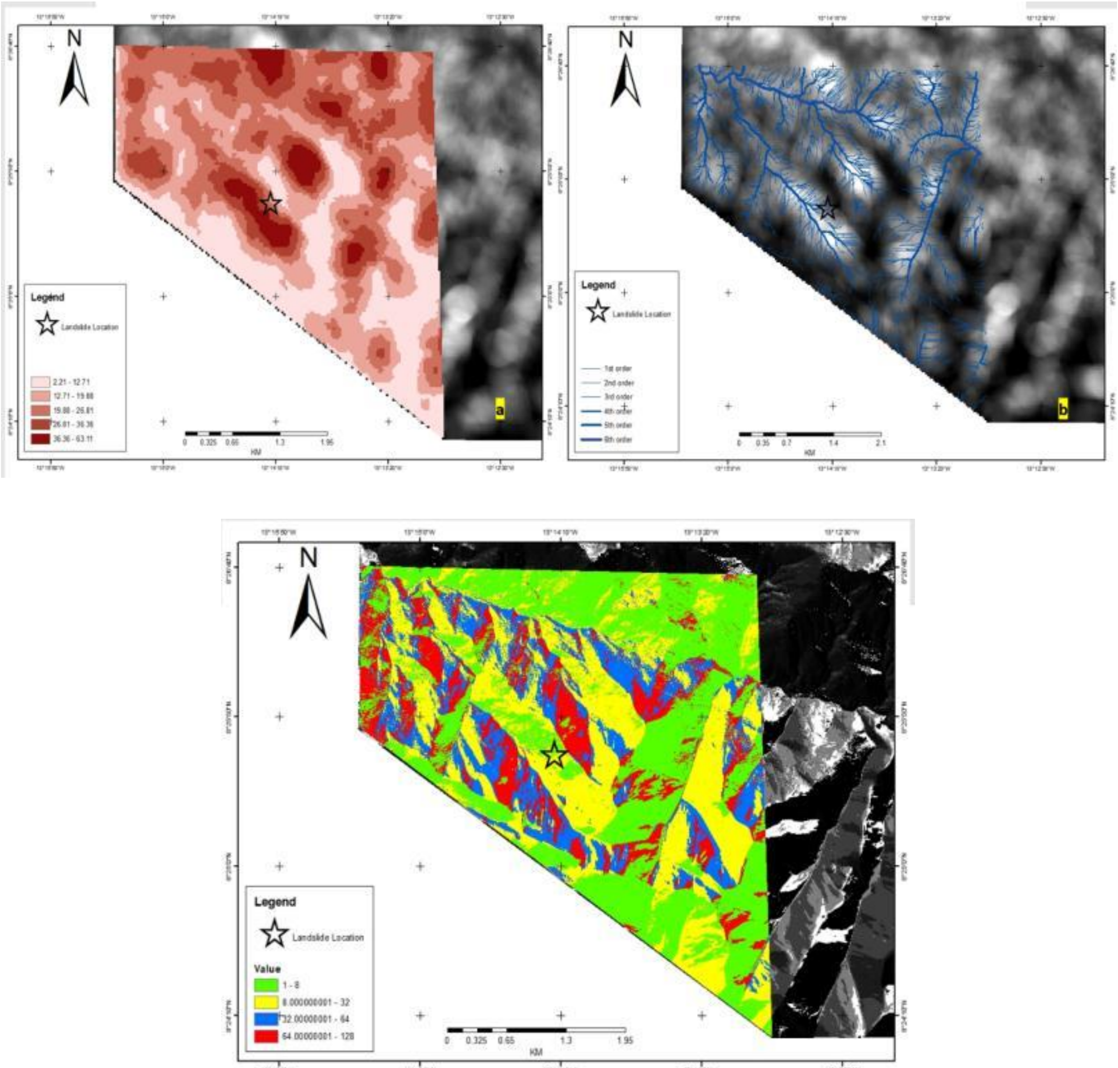

Figure 7. DEM for Hydrologic Factors (a) Drainage Density (b) Drainage System (c) Flow Direction

However, evidence of water seepages/springs from open joints after rainfalls confirmed by local inhabitants of the nearby community, indicates interaction between precipitation and groundwater. The moderately and hghly weathered pegmatitic gabbro is attributed to the accumulation of the infiltrated rainfall water through the vertical joint sets (open fractures), thereby raising the groundwater level. Therefore, the landslide stability would have been impacted by the upward migration of groundwater through the joints to weaken the regolith above. This hydrological principle is supported with few studies that have established the influence of upward groundwater flow on slope stability (Weng et al., 2018). The groundwater in the discontinuities would also have exerted an uplift force to the rock and undermined the stability of the weak stratum and rock-soil interface.

4.3 Geotechnical Assessment

The properties of landslide’s underlying geology are extremely important for the propensity for landslide occurrence. The decomposed/weathered zone acts as soil considering mechanical perspective, making the determination of its geotechnical properties necessary (Yalcin, 2011). This assessment was carried out using in-situ field test by DCP and laboratory tests for the purpose of evaluating the geotechnical properties of the slope cover soil (regolith).

The DCP probed or revealed information on the thickness of weathered soil cover (depth > 1.5m) and its bearing strength. The strength factor, which according to UNDP & EPA (2017) was not considered by the affected populations at Regent prior construction in supposedly a non built-up areas. However, results of DCP tests presented in Figure 8 show variation in soil bearing strength with depth along the soil profile, which generally decrease towards the bed rock. The average number of DCP blows (NDCP) plot also varies with depth and shows strong correlation with the weak to moderate gabbroic layering. This method evaluated the susceptibility of the bottom soil layer that slipped down the slope and extrapolated the potetial effects of overloading (e.g., precipitation/rainfall, infrastructures, sediment piling and dam) on landslide occurrence (i.e., implied anthropogenic impacts).

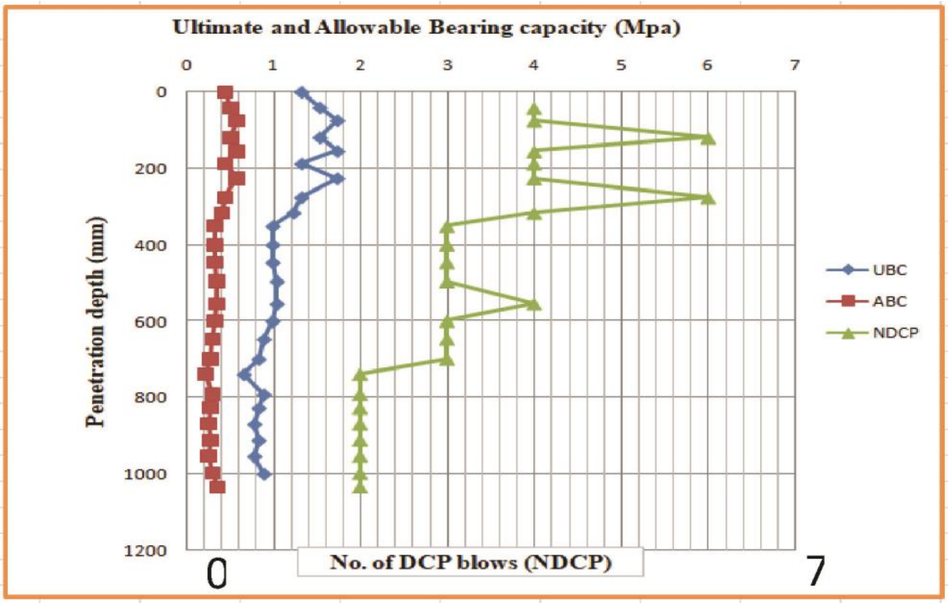

Figure 8. Variation of Average Bearing Strength Capacity and NDCP in the Soil Profile Overlying the Bed Rock. UBA: Ultimate Bearing Capacity, ABC: Allowable Bearing Capacity and NDCP. Number of DCP Blows

The second part of the geotechnical assessment involves the determination of natural moisture content, specific gravity (G), grain size distributions consistency limits (PlasticLimit, Liquid Limit and Plasticity Index), and Liquidity Index (LI) of the landslide soil. Results of these parameters are presented in Table 1. The soil moisture content is within range, average specific gravity estimated as 2.41, which is below the specific gravity of the fresh rock sample (2.8). The soil is well-graded, which have been grouped into three divisions corresponding to the major constituents. They include: gravel, sand and fines (clay and silt), with the fines exceeding the gravel component. The fine fraction can affect permeability and enhance pore pressure following periods of persistent rainfall. With the absence of X-Ray Diffraction (XRD) facility in the country to identify and determine clay fraction, analysis at the British Geological Survey (BGS) laboratories in Nottingham on Regent bulk debris samples, presented by Redshaw et al. (2019), has given an insight into the probable clay mineral type called halloysite. This clay mineral is linked to collapsible soil, which Moon (2016) has mentioned as one that can yield very suddenly when rapidly loaded. As noted by EL Jazouli et al. (2020), plasticity is regarded as one of the important parameters in the properties of water retention and corresponding swelling. Therefore, larger plasticity correlates to greater volume change that could impact landslide susceptibility. The Unified Soil Classification System (USCS) plasticity chart enabled further classification of the representative soil sample as seen in Figure 9. The laboratory-derived atterberg limits (PI=22.37%, and LL=53.46) aided in distinguishing the fines by plotting the values in the plasticity chart. The sample location falls below the “A” line (a line which Casagrande emperically plotted in his devised plasticity chart in 1948, separating inorganic clays and silt and organic soils), indicating that the soil sample contains silts and clays with large constituent of ‘rock flour (finely ground non-clay minerals). The Liquidity Index (LI) or a measure of the consistency of the soil is negative (-0.24), signaling drier nature of the soil than the plastic limit. This is due to the lower moisture content (23.70%), which correlates strongly to the period during which sampling was done (dry season), relative elevation, aspect and fine content (silt).

Table 1. Geotechnical Properties of Slope Soil Covering Lion Mountain Landslide

Location and sample ID	**Lion Mountain Landslide (S9-FT)**	
	Properties	**Average/Mean Value**
Physical properties	Natural Moisture content (%)	23.70
	Specific gravity	2.407
	Adsorption (%)	16.900
Particle Size distribution (%)	Gravel (63mm-2mm)	32.30
	Sand (2mm-0.063mm)	32.30
	Fines (Silt and Clay) <0.063	35.30
Consistency limits (%)	Plastic limit (PL)	31.09
	Liquid limit (LL)	53.46
	Plasticity index (PI)	22.37
	Liquidity index	-0.24

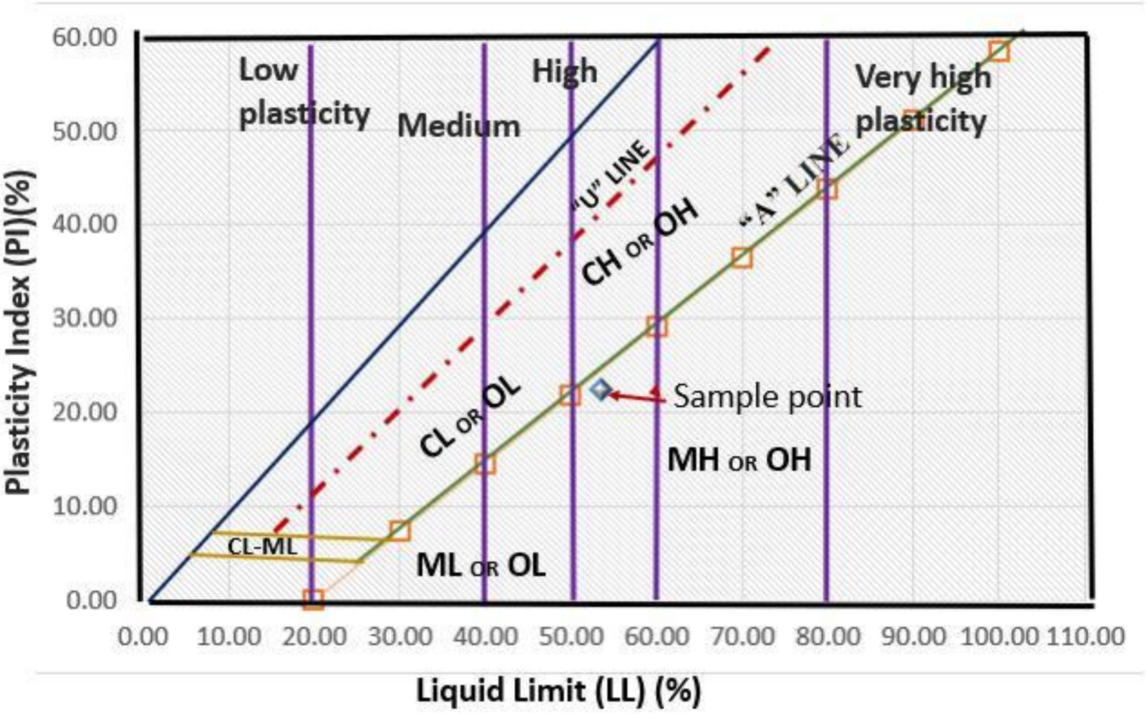

Figure 9. Plasticity Chart of the Representative Soil Collected from Lion Mountain Landslide

5. Discussion

This study has presented the first detailed assessment of landslide occurrence in an area with little or no anthropogenic activities (e.g., urbanization and deforestation) in the country. On the basis of the analyses above, conclusion could be reached, designating natural conditions as the dominant causative factors for the occurrence of Lion Mountain landslide.

This landslide shows characteristic signatures distinct from the others. This may be linked to the site-specific geo-environmental conditions, particularly the lithological variation and density of tectonic features (fractures, joints and cracks). The rock type is not only susceptible to chemical weathering (the degree of weathering reduces vertically with increasing depth), but shows evidence of discontinuities on the fresh rock and weathered surfaces (upper base and toe of the landslide). This makes the underlying material porous, permeable and direct receipient of the infiltrated rainfall water through percolation in the open joints and porosity. Hydrologically, the groundwater level may rise under this condition, which eventually migrates upward to lubricate/wet the overlying soil, thereby reducing its shear strength and increasing landslide susceptibility. At the basal section, there would have been an increment in the joints' pore-pressure, which further exacerbated slope instability and subsequent resulted to the failure. Geomorphologically, cataclinal slope are susceptible to translational landslides, and slope angle falls within the range of slope angle values that have accounted for many ground failures reported by Thomas (1983 &1998).

Geotechnical investigation revealed the nature, characteristic and type of landslide soil cover. It is a well-graded soil with a percentage of fine fraction greater than gravels (see Table 1)-a characteristic contributing to landslide susceptibility. Laboratory-derived Atterberg limits have shown the soil to be plastic with high expansion potential (LL=53.46). The DCP tested the in-situ soil strength along the soil profile, with the two strength parameters (ultimate Bearing Capacity and Allowable Bearing Capacity) generally displaying reduction in their values towards the bedrock, indicating weaker layer at the bottom that is prone to to failure. This variation indicates different zones/layers marked by varied modal percentages. The weaker zone indicates greater tendency to slope failure than hard layers.

The landslide occurs beyond the depth of plant activities, eliminating any influence of plant root in the event. Also, very little or no human intervention exists at bot the slide area and surrounding (e.g., slope profile modification, usually by cut- and- fill in the area for houses, groundwater modification by a dam, a pipe leak or overflow path modification as in the case of Tacugama forest reserve, and bush burning). Also, average UBC (1.0744 Mpa/1074.4 KN/m^2) determined from DCP are within presumed bearng values for the soil (>600 KN/m^2). This should be rendering anthropogenic/human factors insignificant in the occurrence of landslide, thereby establishing a close association between geologically unstable ground and landslide events. To adress this, detailed ground investigation (Engineering Geological Mapping) is necessary. This is useful in understanding the relationship between the failed area and their main geological features. Also, Redshaw et al. (2019), convincingly presented scientific facts linking Regent landslide occurrence to deep-seated failures, further implying evaluation of subsurface conditions. Finally, detailed geological studies to understand compositional and tectonic variations in the context of landslide occurrence should be considered to note their unique impacts on landslide characteristics. In addition to this, shear strength property of the soil should be determined, and confirmatory test for the clay type using XRD to further establish the material properties and behaviour.

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