29.

PROPERTIES OF SOIL AND PLANT BIODIVERSITY IN THE LANDSLIDE PRONE AREA OF NIKOLA OYA, RATTOTA

Jinadasa Katupotha* and Sumanajith Kumara

Department of Geography, University of Sri Jayewardenepura, Nugegoda

ABSTRACT

The study analysed surface and sub-surface soils, underlying rocks, vegetation types and relief in the massive landslide prone area at Nikola Oya. The influence of soil properties and identification of dominant, original and effective plant species on landslide occurrences were undertaken by field work on December, 2012; July and August 2013. Other relevant data and information were collected from maps, images and through formal and informal discussions with affected persons and officials.

The study on physio-chemical parameters of soils in the Nikola Oya landslide area has revealed undifferentiated charnockitic biotite gneisses; Quartzite and Marble are the dominant rock types in the area. Likewise, Red-yellow podzolic and wet mountain soils as well as Red-yellow podzolic and immature brown loams appear in this area. A salient feature of the area is the steep, hilly and rolling terrain. The vegetation cover of the Nikola Oya basin comprises Sub Montane Forests and Moist Monsoon Forests, but the vegetation in the landslide affected area is characterized by poor-nutrient content due to the disturbance of plant biodiversity and the deficiency of managing nutrients like Nitrogen. Such nutrients fixing plant species like *Gliricidia* cover parts of the landslide prone but it was found that diverse species with dense vegetation would be more appropriate.

Precipitous slopes and absence of a dense vegetation cover are not the only reason for landslide occurrences in the region. Other environmental factors such as heavy rainfall during the monsoon periods as well as the nature of soil have contributed to slope failure, together with production clammy soils by microbial. Thus, the study has identified the multitude of factors including microbiology responsible for landslides in the area and highlighted the need for urgent short and long term mitigatory measures such as relocation of affected persons and reforestation of this environmentally fragile area.

Keywords: *Environmentally fragile area, Plant biodiversity, Microbial, Properties of soils, Landslides.*

INTRODUCTION

Landslides increase by biophysical (ecological) diversity. Geertsema and Pojar (2007) recognized the biophysical diversity at three levels: site, soil, and habitat (ecosystem) diversity. Specific soil parameters, particularly physical properties, such as bulk density, cohesiveness and shear strength have been noted to

* Corresponding author: *katupotha@gmail.com*

affect stability on disturbed slopes (Mugagga et al 2010). Soils vary in their suitability for specific purposes. For example, in Central Highlands of Sri Lanka a deep, fertile clay soil is suitable for intensive agriculture and dense forest but a shallow, sandy soil is better suited to grazing and growing native trees. Excessive rainfall within two or three days, location of high and moderate slope (between 35° and 50°), soil organic matter and soil carbon sequestration as well as water holding capacity are mainly responsible for landslide process. Similarly, soil depth, soil texture, structure, colour, soil pH level, nutrients, dispensability, permeability and porosity are the other most common properties used to compare and recognize soil in landslide areas. Out of these: pH, salinity (EC), Cation Exchange Capacity (CEC), organic matter and C:N ratio (Carbon to Nitrogen) include into soil chemical properties and others take account as physical properties. Plant biodiversity in any area is governed by those properties, which follows the soil formation factors, and changing or altering of these properties also affect negatively for plant biodiversity, changing or altering of these factors on slope areas in many districts in Central Highland of Sri Lanka distinguish as landslide prone areas, where excessive rainfalls also occur.

When weathered material is saturated with rain water the iron-rich clayey material acts as a lubricant, causing the mass of earth and rock to move rapidly down the slope under the force of gravity. If there is no vegetation cover to bind and hold this material together the lubrication of rocks, debris and earth can be intensified. During the heavy rains, the fall or topple of rock material may be further intensified due to shaking of weathered rocks and debris by thunder and lightning (Katupotha, 1991 and 1992. Katupotha (1995) emphasizes that man-made causes such as construction of reservoirs, blasting of rocks in rolling and hilly areas, forest felling on an extensive scale, periodic uprooting of tea and rubber trees, tunnelling and pumping out of water from gem pits in the valley bottoms have all led to slope failures and subsidence of the lands, creating slope instability. Therefore, inefficient drainage of steep slopes along bare rocky lands and those under plantations may also contribute to slope failure.

A recent devastated landslide at Nikola Oya, which occurred in the dawn of Monday 17, 2012 has followed the common soil properties and plant biodiversity at Nikola Oya stream valley scarifying seven lives and overwhelming houses and other properties' Accordingly, this paper hypothesize that soils at Nikola Oya upper catchment sites are inherently "problem soils", where slope failure can occur even without any human interference.

GEOGRAPHICAL SETTING OF THE STUDY AREA

North-east of the Kandy Plateau is the Knuckles Massif, with several fine mountains over 1,600m, its highest peaks are Gombania (1,905m) and Knuckles (1,863m). The knuckles Massif is really a complex of ranges resulting from a large recumbent fold, and some of finest and most rugged mountains in Sri Lanka are to be found in this comparatively inaccessible and little known region (Cooray, 1984). Long escarpments, some rising over 900m in sheer rock walls are also common, particularly in the Knuckles area. These escarpments may be the results of faults but more often they are the result of jointing and some are resulted from the branching of long anti-clinal folds. Main rocks of the study area are Granite gneiss, undifferentiated charnokitic biotite gneisses, Quartzites (pure coarse-grained ridge forming quartzites locally with <5% each of sillimanite, kaolinized feldspar or biotite: Figure 1).

Figure 1: Photos A-D show that the highly weathered undifferentiated charnokitic biotite gneisses (A & B), Quartzites (pure coarse-grained ridge forming quartzites locally with <5% each of sillimanite, kaolinized feldspar or biotite (C & D)).

Nikola Oya, a small stream located in the Bambarakiriella Grama Niladhari Division (GND), Rattota Divisional Secretariat Area (Figure 2), shows the dendritic drainage pattern, which follows the rugged morphology with steep slopes. From Knuckles Range Nikola Oya flows westward and joins with Sudu Ganga at Rattota. Long and small streams of the Nikola Oya flow across the Medawatta Tea Estate, which is under State Plantation Corporation. The crest of the mountain range extends north – south direction, and height of the starting point of the Nikola Oya extends about 1,610m (7°28'35"N and 80°43'46"E) from MSL'.

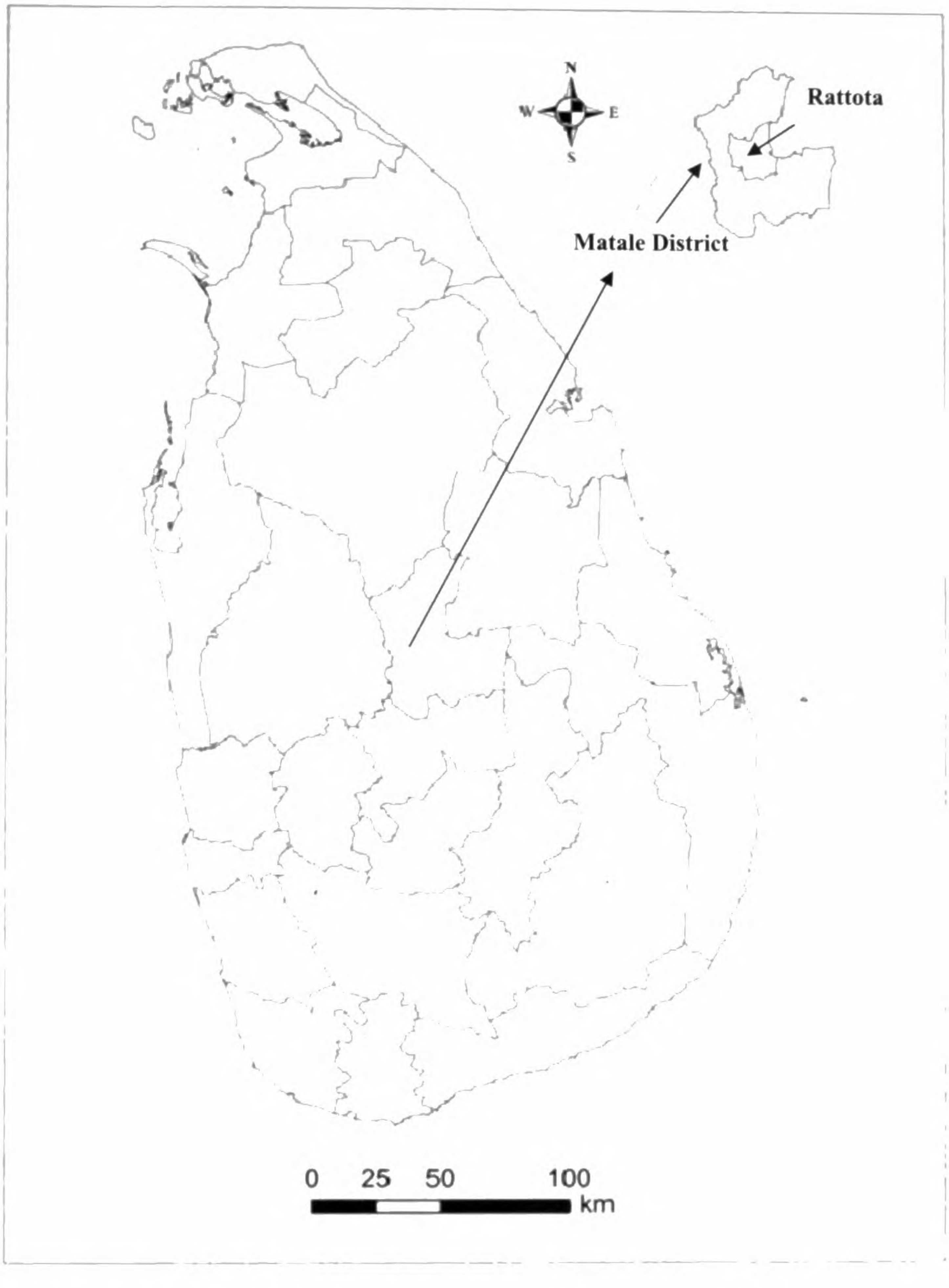

Figure 2: Location of the Nikola Oya landslide at Rattota Divisional Secretariat Area

Red-yellow podzolic and wet mountain soils as well as Red-yellow podzolic and immature brown loams appear in the Nikola Oya and surrounding area. The Red-yellow podzolic and wet mountain soils are predominant in the Wet Zone that is in the Hill Country and the south west region of Sri Lanka. Metasediments and chanockitic gneisses of the Highland Complex are the main rock types (Cooray, 1984). The immature brown loams occur with the Red-yellow podzolic soils. Both soils are on steeply dissected hills and rolling terrains in the study area.

Average rainfall of the Nikola Oya area varies between 2,200 and 3,500 mm. But, excessive rainfall has occurred on 17 (812.80 mm) and 18 (635.69 mm) December 2012. The annual rainfall for the year 2012 was 4,204.80 (Data from Nikola Oya Estate).

The vegetation cover of the Nikola Oya basin comprises of Sub Montane Forests and Moist Monsoon Forests. It plays a key role in providing a water supply to ecosystems and livelihoods throughout the year in the downstream areas. But, the vegetation types are threatened due to the Cardamom cultivation, expansion of tea and human activities. The northern and eastern mountains and hilly landforms in Bambarakiriella GND and adjoining divisions have steep and moderate slopes and which accelerate soil erosion. In some places rocky layers are exposed at steep slopes, and rock falls and debris flow occur in such areas.

The total population of the Bambarakiriella GND is 1,189, at which Nikola Oya basin is located. Out of this figure, 534 (167 families) are included into rural population, and other 655 (151 families) are included into estate sector (Resource Profile, Rattota DSD, 2012). There were 318 permanent houses in the GND area, but no semi-permanents or temporary houses. The estate workers houses and many private houses were distributed along and close to the both side of Nikola Oya banks. Concerning the land ownership, there were 320 land parcels, out of this 55% owners were less than 0.62 ha. A land parcel in size from 2.0 ha to 4 ha belonged to one person. Distributions of Land utilization data of the GND indicate that tea (138.8 ha.), protected lands (247 he.) forest lands (135.6 he.), cultivated (mixed) lands (128 ha) bare lands (88.3 ha) and other lands (113 ha.).

Human population, land use types and activities on steep slopes clearly impact the non-productivity of physical and chemical properties of the soil.

METHODOLOGY

Twenty houses in Nikola Oya (12 completely damaged and 8 partly damaged) of Bambarakiriella GND, Rattota area identified as being prone to landslides were destroyed on in the dawn of Monday 17 of December, 2012 by a devastating and defenseless landslide. Three (3) persons died, 4 persons disappeared and 69 were displaced by this event.

Due to the limited time-frame, three Soil sampling points were selected arbitrarily from the landslide area of the Nikola Oya. The data collected on the characteristics of the profile site was location, soil classification, topography, slope, micro-topography, land use, parent material, effective soil depth, erosion, soil water relationships, flooding, drainage, groundwater depth, moisture conditions and soil horizon description. Some soil parameters of these samples are shown in Table 1. For this purpose field investigations were conducted on 29th of December, 2012, 27-29 July and 11-12 August, 2013. Soil color was described using the Munsell Colour Chart, (2000). Information in relation to fauna and flora were collected during the field investigation and through formal and informal discussions held with officials of the Nikola Oya Estate, labours and general public. Secondary data were collected from "Resource Profile 2012" compiled by Rattota Divisional Secretariat, 1:50,000 Topographic Map and Google Image (coverage the Nikola Oya basin).

RESULTS

Clay Minerals

The clay from the red-yellow podzolic soil differs from all the other soil clays examined, in containing an appreciable amount (about 10 per cent.) of gibbsite. Kaolinite is the predominant mineral in this soil clay, and goethite, hematite and quartz are present in the Nikola Oya area.

Clay minerals are typically formed over long periods of time by the gradual chemical weathering of rocks, usually silicate-bearing by low concentrations of carbonic acid and other diluted solvents. These solvents, usually acidic, migrate through the weathering rock after leaching through upper weathered layers. In many places of the Nikola Oya it is possible to see goethite and hematite diluted solvents spring water pockets

(Figure 3). In addition to the weathering process, some clay minerals are formed by hydrothermal activity. Clay deposits may be formed in place as residual deposits in soil mainly from microbial activity, but thick deposits usually are formed as the result of a secondary sedimentary deposition process after they have been eroded and transported from their original location of formation.

In the Nikola Oya upper catchment, clay minerals are unstable and break down under intense chemical weathering to become *hydrated oxides* of Aluminum (bauxite) and Iron (goethite), which are very poor substitutes for clay minerals in retaining soil nutrients. As a result, jungle soil relies on the presence of humus, an organic substance produced by microbes that cause dead plants to decay; humus takes off the ability of clay minerals to retain soil moisture and nutrients.

Figure 3: Photos show that under the intense chemical weathering, *hydrated oxides* of Aluminum (bauxite) and Iron (goethite) concentrated water pockets are in the study area.

Humus is much more fragile than clay minerals to chemical weathering, and is protected by sub montane forest canopy, which softens the torrential rainfall. Such rainfalls occur in the study area and illegal forest felling in montane or sub montane forest causes the humus to quickly wash away.

Shear Strength

Shear strength, characterized by the angle of internal friction and cohesion is one of the basic geotechnical parameters describing the mechanical characteristics of soil in the aspect of its stability. To withhold or remove the washed way material depend on the shear strength, which is characterized by the angle of internal friction and cohesion. It is one of the basic geotechnical parameters describing the mechanical characteristics of soil in the aspect of its stability. Based on obtained results from southern Poland, Zydroń and Zawisza (2011), state that the values of the shear strength depend on variations in moisture content. Further, the stress-strain relationship of soils, and therefore the shearing strength of the Nikola Oya headstream, is affected by:

1. **Soil composition (basic soil material)**: mineralogy, grain size and grain size distribution, shape of particles, pore fluid type and content, ions on grain and in pore fluid.
2. **State (initial)**: loose, but normally consolidated, stiff, soft, contractive, dilative characteristics are seen.
3. **Structure:** arrangement of particles within the soil mass; the manner the particles are packed or distributed. Features such as layers, joints, fissures, slickensides, voids, pockets, cementation, etc. are part of the structure. Structure of soils in the study area can be recognized as disturbed by mega and meso fauna as well as microbial.
4. **Loading conditions:** drained, dynamic and cyclic.

Biodiversity

The Nikola Oya landslide area and surroundings have different floral types namely, riverine forests, rock-outcrop forests, shrub-lands, semi-natural home gardens, agricultural lands (tea, cardamom, chena, forest plantations *etc.*). Successional status (time) and evolution of these govern by the environmental factors such as climate, geology, soils, topography and drainage network (Figure 4).The montane forests (above 1300m) of the upper catchment are covered by *Calophyllum spp.* (Kina sp.), *Syzygium cordifolium* (Wal jambu), *Semecarpus walkeri* (Badulla), *Strobilanthes spp.*(Nelu sp.), Orchids & Epiphytes. Field visits confirm that during the year heavy mist can be seen in these types of forests.

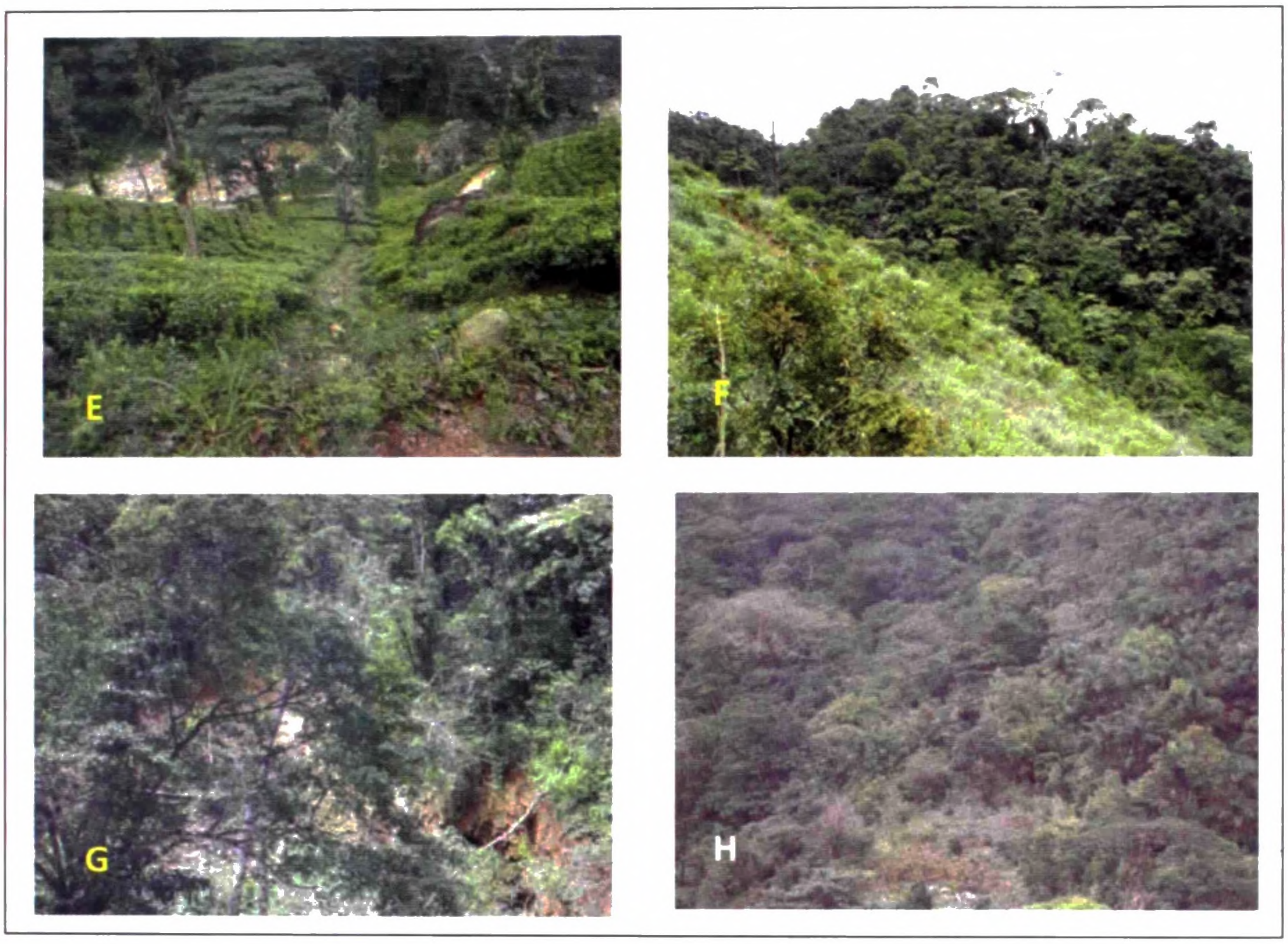

Figure 4 : There is no thick soil cover in old agricultural lands (tea plantations, E, F & G). A thin top soil layer (with humus) has developed in Sub Montane Forests (H) of the Nikola Oya catchment, but the thicknesses vary according to micro morphology of forestlands.

Montane forests are the most important catchments and water shed areas of the Knuckles Range. They play a key role in providing a water supply to sustain the ecosystems and livelihoods through the year in the downstream areas. These types of the forests contribute a lot when it comes to the natural beauty in Knuckles Mountain Range.

The Sub Montane forests of the study area and surroundings are covered by *Aglaia congylos*, *Cryptocarya wightiana* (Gulu Mora), *Elaeocarpus glandulifer* (Titta Weralu), *Symplocos spp.*, *Syzygium neesianum* (Panu Kera) & *Strobilanthes spp*, *Calophyllum spp.* (Kina sp.), *Syzygium cordifolium* (Wal jambu), *Semecarpus walkeri* (Badulla), *Strobilanthes spp.*(Nelu sp.), Orchids & Epiphytes (wet areas) and *Actinodaphne stenophylla*, *Drypetes gardneri*, *Gomphia serrata*, *Psychotria spp.* & *Memecylon spp.* (dry areas). Sub Montane Forest type is threatened by Cardamom cultivation, expansion of tea and other human activities (Photos (E – F). This vegetation type mostly experiences the dry wind during the year, especially during the period of May-August and this forest type also plays a key role as primary catchments and watershed area.

Soil Microbiology

Microbial and faunal activity and ecology in soil are also very significant factors in landslide prone areas. Soil life or soil biota include earthworms, nematodes, protozoa, fungi, bacteria and different arthropods. Soil biology plays a vital role in determining many soil characteristics; and about how the nature of soil is affected. However, organisms in soil, their functions, and how they affect soil properties are very significant phenomena, because they affect the structure and fertility of different soils.

In many soils, earthworms play a major role in the conversion of large pieces of organic matter into rich humus, thus improving soil fertility. Due to moisture content and distribution of annual rainfall, earthworms live in soil layers of the montane and sub montane forests, and they help to make clammy soils. Such conditions can be seen in soil of the Nikola Oya upper catchment area. Similarly, Nematodes have successfully adapted to nearly every ecosystem from marine to fresh water, to soils, and from the Polar Regions to the tropics, as well as the highest to the lowest of elevations. Accordingly, their diversity of life cycles, and their presence at various trophic levels in forest soils help to microbial and faunal activity, which help to produce clammy soils.

As components of the micro and meiofauna protozoa are an important food source for micro invertebrates. Thus, the ecological role of protozoa in the transfer of bacterial and algal production to successive trophic levels is important. As predators, they prey upon unicellular or filamentous algae, bacteria, and micro fungi. Protozoa are both herbivores and consumers in the decomposer link of the food chain. Beside the above, many bugs, known as arthropods, make their home in the soil. Arthropods are invertebrates, that is, they have no backbone, and rely instead on an external covering called an exoskeleton. The 200 species viewed were extracted from one square foot of the top two inches of forest litter or soil. Among such species, mites are poorly studied, but enormously significant for nutrient release in the soil. Arranged in size from microscopic to several inches in length, arthropods include insects such as springtails, beetles, and ants, crustaceans such as sowbugs, arachnids such as spiders and mites, myriapods such as centipedes and millipedes, and scorpions. All these directly and indirectly help aeration and water circulation and to keep nutrition in soils.

Nearly every soil is home to many different arthropod species. Certain row-crop soils contain several dozen species of arthropods in a square meter. Arthropods can be grouped as shredders, predators, herbivores, and fungal-feeders, based on their functions in soil. Most soil-dwelling arthropods eat fungi, worms or other arthropods. Root-feeders and dead-plant shredders are less abundant. As they feed, arthropods aerate and mix the soil, regulate the population size of other soil organisms, and shred organic material.

In addition to microbial, Knuckles range holds a wide variety of meso and mega faunal species. Most importantly it is a home to many endangered and endemic species. 247 vertebrate species have been recorded in this area of which 26% are endemic to Sri Lanka, including 14 birds and 9 fish species. More than 100 of other resident and migrant bird species can be observed at different times of the year. Five of these endemic species, three fresh water fish (Phillips's Gara- *Garra phillipsi*, Martenstyn's Barb- *Puntius martenstyni* and Blotched Filamented Barb-*Puntius srilankensis*), one amphibian (Marbled Rock Frog- *Nannophrys mamorata*) and one lizard (Leaf Nosed Lizard (*Ceretophora tennenti*) are restricted to knuckles forest range. Further, Knuckles Mountain Range is home to most of the mammals found in Sri Lanka. In addition to elephants, leopards and samburs, there are also Small mammals (mice, rats, shrews), bats, buffalo, wild boar, spotted deer, barking deer, mouse deer, fishing cat, jackal, mongoose, porcupine, pangolin, leaf monkey, Sri Lanka Red Slender Loris and Giant squirrel *etc.*

DISCUSSION

Courses and consequence

Rainfall-induced landslides have been a serious threat to people in mountainous areas in Sri Lanka. In-depth understanding of the physical and chemical properties of soil and biodiversity as well as process of soil moisture changes in soil slope during heavy rainfall is therefore important in developing early warning systems for landslide hazards.

Soil properties and plant biodiversity clearly influenced major landslides that occurred recently on moderate slopes in western Knuckles Massifs. A mudflow, located at the Nikola Oya catchment (a protected forest site), create a deep debris flows on the Nikola Oya stream basin, in which deforested unstable soils and steep slopes (30°–50°) were surveyed (Figure 5). This unstable condition is developed due to local weathering conditions, heavy rainfall, root systems of the plants, soil microbial and other plant ecological conditions. The soils at the landslide site at Nikola Oya are particularly identified as "problematic soils" and thus prone to landslides.

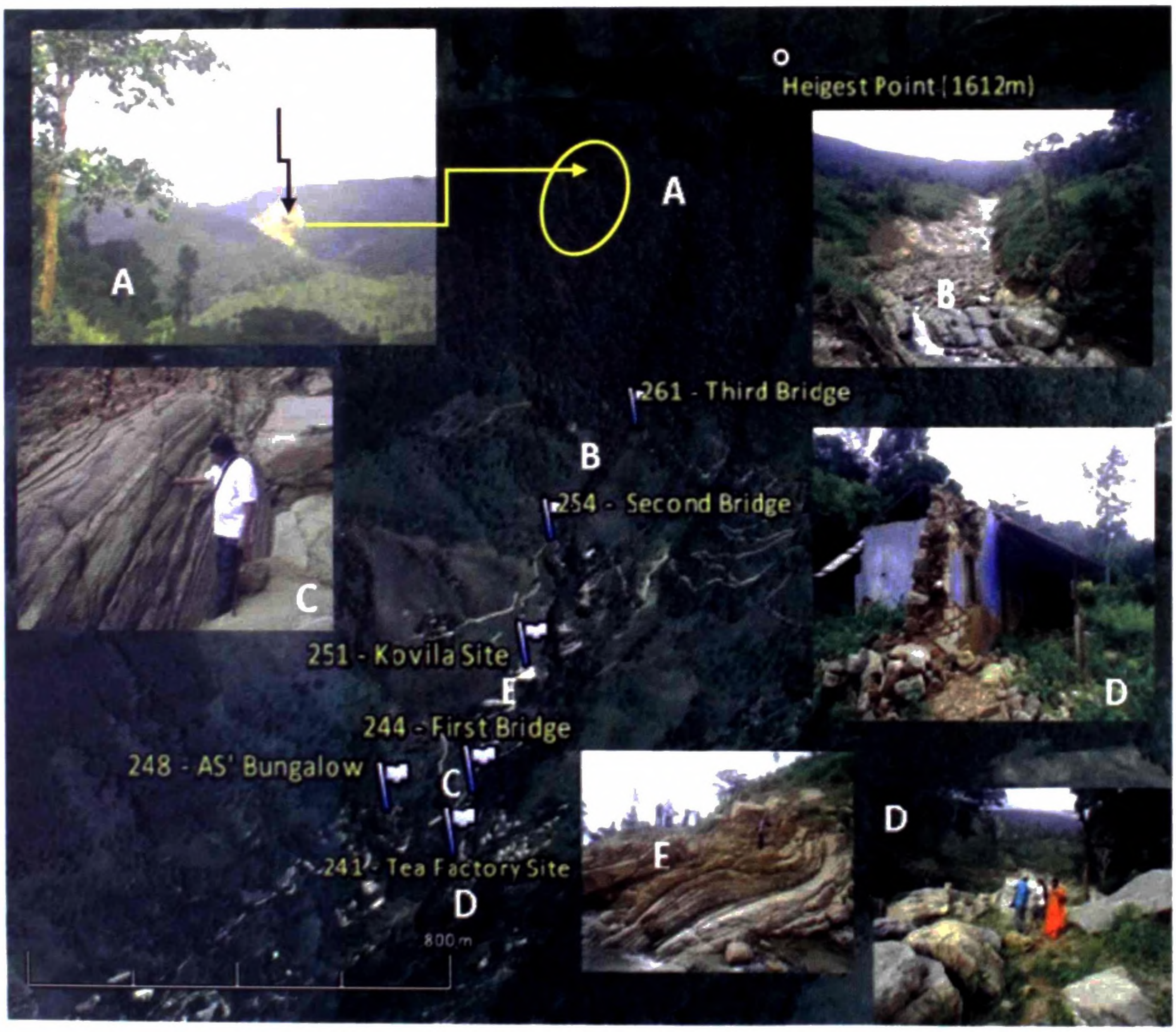

Figure 5: **Nikola Oya landslide area. A. Head of the landslide; B. Middle part of the landslide; C. Appetence of emerged *in situ* rocks and boulders after washout the left bank of the Nikola Oya; D. Damaged houses; it is possible to expect buried lives and property under this debris; E. Folded quartzite band. The numbers denote the GPS points.**

Grain size distribution (Figure 6), shear strength and factor of safety (Fs) are very significant to maintain the soils in moderate to steep slopes. Three soils samples at Nikola Oya basin sites exhibited expansive potential, owing to clay contents well above 20%. A clay content exceeding 32% was identified at the debris flow sites implying an extremely high expansive potential of the soil (Table 1 and Figure 6). High liquid limits at upper catchment (headstreams) make the soils qualify as susceptible to landslides. The value of Fs\1 for the headstream site signifies an inherently unstable slope, and unstable conditions interplay of various physical, geological, pedological and anthropogenic factors.

Table 1. Results of the sieve analysis of selected samples from Nikola Oya

Sieve Size	Percentage Sample 1	Percentage Sample 2	Percentage Sample 3
4mm	10.54%	32.06%	16.85%
2mm	10.04%	14.02%	5.51%
1.7mm	4.81%	4.70%	8.32%
500μm	47.18%	31.86%	59.87%
125μm	25.50%	15.43%	9.42%
90μm	1.90%	1.50%	0.00%
63μm	0.00%	0.40%	0.00%
45μm	0.00%	0.00%	0.00%
Pan	0.00%	0.00%	0.00%

Source: Field investigations, August 2013.

The column ***I*** denotes (Figure 7) the unstable conditions of soil layers of tea planting area, Nikola Oya right bank, because the soils are not *in situ* position. The deposition sequence shows that, these soils should be former debris material. In column ***J*** a weathered quartzite layer is seen, but no proper soil development. Due to layering, breaking up and cracking some plant roots and meso and arthropods are living and help to accelerate the weathering and seepage the water.

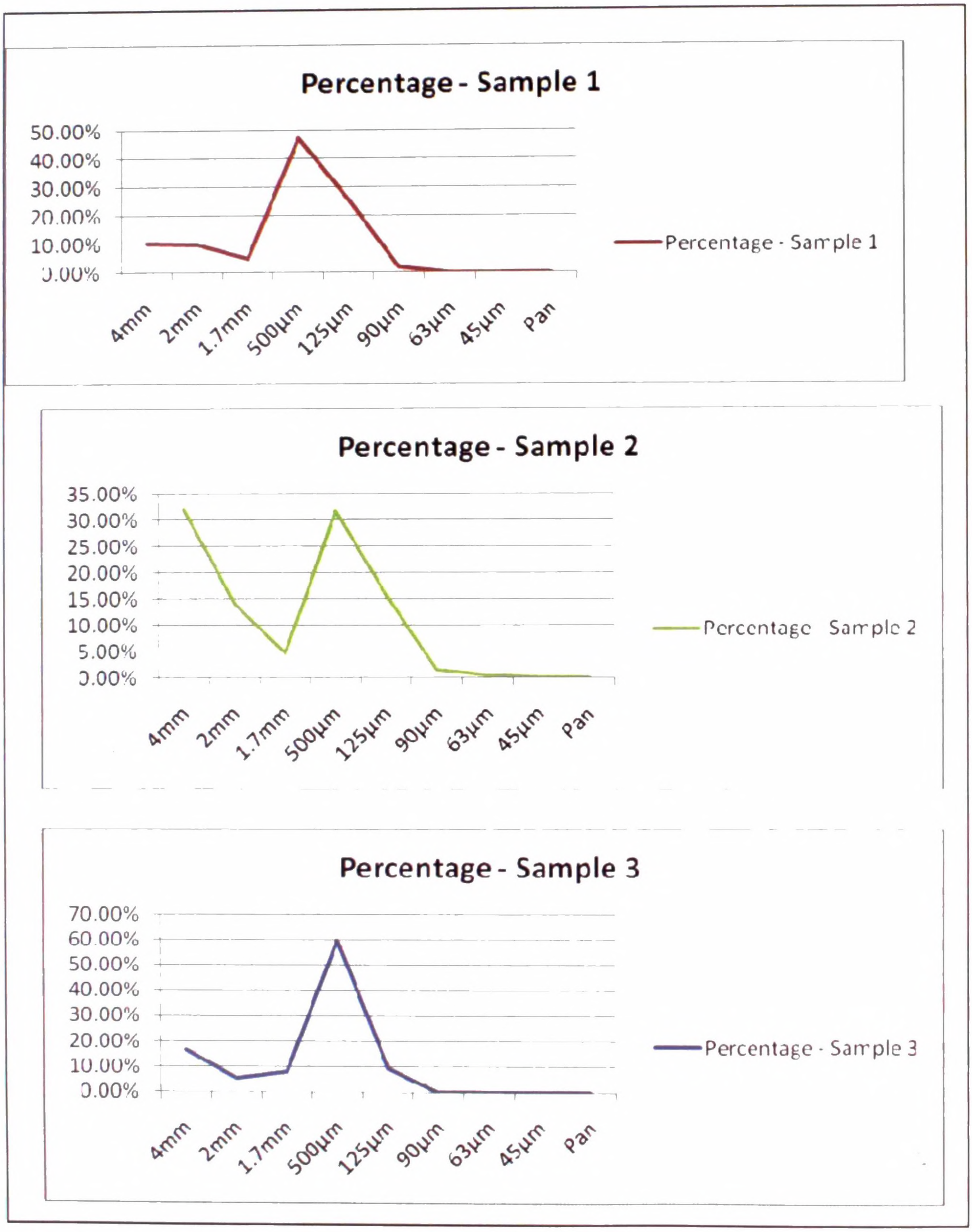

Figure 6 : Three soils samples collected from Nikola Oya (August 2013) indicate that top soils contain considerable amount of clay particles

Such areas also show unstable conditions. The column ***K*** also indicates unstable condition, loose soil with much clay conditions, mainly grassy surfaces. Somewhat compact soil layer is shown in column ***L***, it also shows unstable conditions. Accordingly, many places of the Nikola Oya basin not stable due to former debris flows, weathering of quartzite bands and their locational directions, dip and folding patterns, microbial behavior and damaging of soil nutrient cycles. But, general public or many officials working individual aspects, for *e.g.* geology, weathering, soil, microbial and faunal activity do not consider a landslide prone area as malty-activity based block. For public awareness programs and mitigatory measures, it is necessary to pay attention on all parameters as a unique.

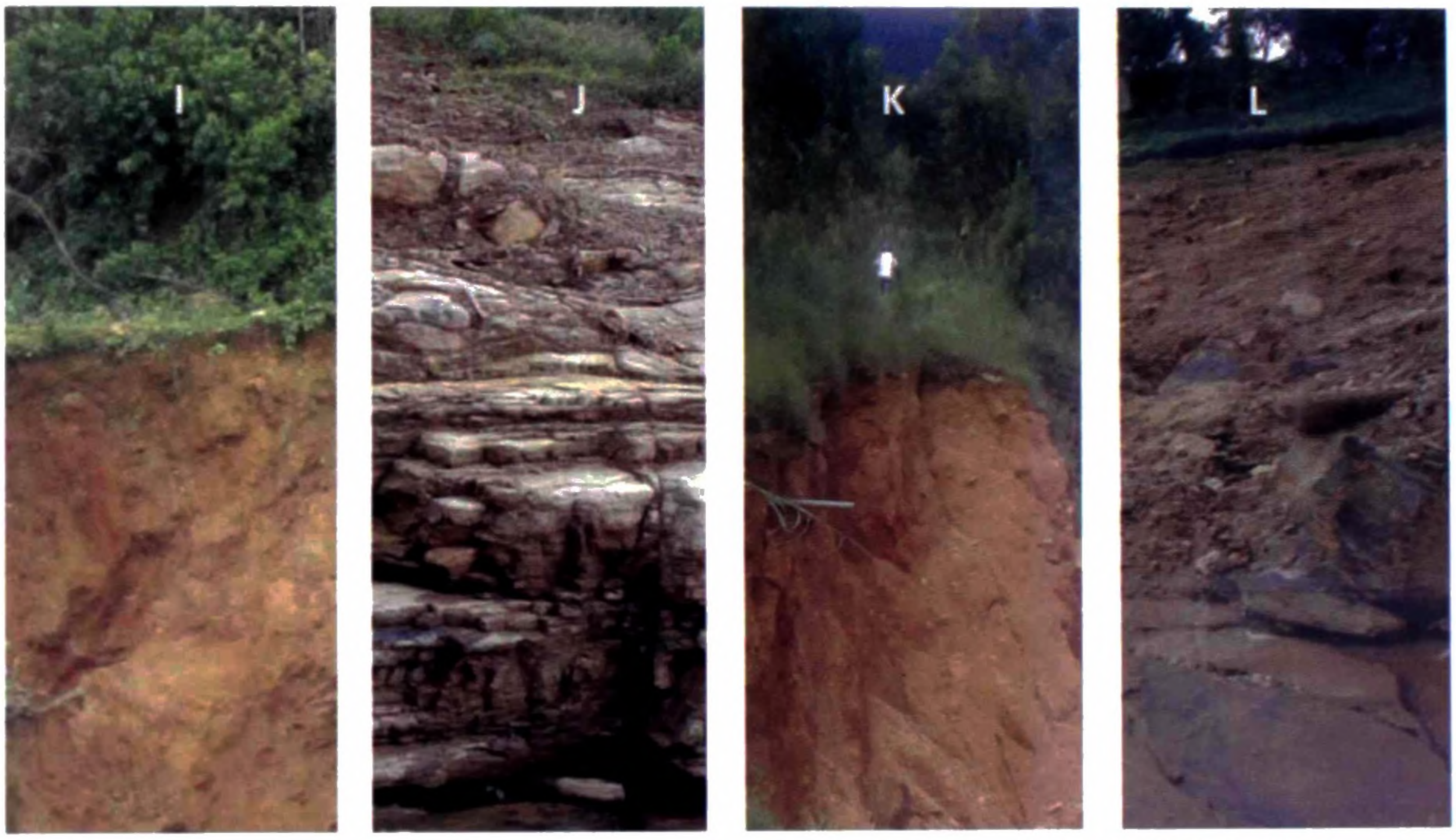

Figure 7: Photos I – L shows the unstable conditions of soil strata along the Nikola Oya basin.

During the debris flow along the stream bed heavy abrasion process continued. By this mean, huge boulders rolling and collision fall to downward with other debris. Accordingly, some places of the stream bed appear gneissic bedrock surfaces and both sides show that there are no soil layers. The banded quartizite layers have broken due to the flowing of debris at this time, and boulders roll further down damaging houses and other properties located along the banks Figure 8.

Geertsema and Pojar (2006) recognize that biophysical diversity at three levels: site, soil, and habitat (ecosystem) diversity on occurring of landslides. Landslides usually change the site conditions at a given location, making conditions drier or wetter, or stonier or muddier, more pervious or less pervious, sunnier, more exposed, *etc.* Changes to site conditions then also lead to changes in soils developing on those sites. Changes to site and soil, and the resultant changes in vegetation contribute to increased habitat diversity which is expressed at the landscape scale. Accordingly, soil and plant biodiversity on landslide at Nikola Oya have some parallels to within habitat, between habitats and regional hierarchy of species diversity.

Figure 8: Photos M – P prove that heavy abrasion process continues during the flowing of debris on bedrock related river beds. The broken rocks scatter in low slopes and damage the houses and other property.

CONCLUSION

Landslides are not a direct result of only physical conditions and human interference. It is highly related with microbial and faunal activity as well as other mega and meso faunal activity. They help to build or damage the nutrient cycles and affect the subsurface soils. During the heavy rain falls, the top soil layer which contain humus and microbial produce clammy soils. Such soils amass the clay material, mainly produced by weathering of minerals in local rocks, always try slipping downward along the moderate slopes. In Sri Lanka, many landslide areas have been subjected to number of times as slope failure places. Most of those places including the Nikola Oya basin are not stable due to former debris flows, regional geology, mineralogy and soil microbiology as well as human interference. Therefore, it is necessary to manage and take mitigaroty measures concerning public awareness programs on influence of the microbial, and in mitigatory measures it is necessary to pay attention on all parameters as a unique.

ACKNOELEGMENT

We thank the Officials of Medawatta Tea Estate at Nikola Oya, Rattota Divisional Secretariat and Officials of the Police Station at Rattota. Also, we acknowledge our Geography Special Third Year students of the Department of Geography, University of Sri Jayewardenepura, and Ms/Msc. (Geography) students, University of Kelaniya for their participation on fieldwork. Also, this study has been completed based on the Research and Development Allowance paid by University (Management Services Circular No: 44 and the Letter of UGC/C/PS/7 - dated 14 March, 2011). Special thanks go to Ms. Dulanjali Wijethilake, 4th Year Student (Faculty of Applied Sciences, University of Sri Jayewardenepura) for helping to undertake sieve analysis on soil samples).

REFERENCES

Cooray P.G. 1984. An Introduction to the Geology of Sri Lanka. Revised Edition, *Ceylon National Museum Publication, Colombo.*

Geertsema, Marten and Pojar, James. Influence of landslides on biophysical diversity- A perspective from British Columbia. *Geomorphology 89 (2007),* 55–69.

Katupotha, J., 1991: The landslide hazards and their impact on environment and society: the experience of Sri Lanka. *Proceedings UCLA International Conference on The Impact on Natural Disasters: Agenda for Future Action, University of California at Los Angeles, USA,* July 10-12, 1991.

Katupolha, J., 1992: Geomorphic surfaces of the river basins along the west and south coasts of Sri Lanka. *A report, 140 pages, 1992 (NARESA).*

Katupotha, J. 1995. Human Responses to Landslide Hazards and Environmental Changes in the Central Hills Country of Sri Lanka. *In. Global environmental change: perspectives of remote sensing and geographic information system / editor, R.B. Singh.* Published: Rotterdam: A. A. Balkema, 1995.

Mugagga F., Kakembo V. & Buyinza M. 2011.A characterisation of the physical properties of soil and the implications for landslide occurrence on the slopes of Mount Elgon, Eastern Uganda. *Journal of the International Society for the Prevention and Mitigation of Natural Hazards.* Vol. 60 (3), 1113-1131.

Zydroń, T and Zawisza, E. 2011: Shear strength investigation of soils in landslide areas. *Geologija. 2011.* Vol. 53. No. 3(75), 147–155.