NATURE BASED LANDSLIDE RISK MANAGEMENT PROJECT IN SRI LANKA

LANDSLIDE RISK MANAGEMENT PLAN FOR TWO PILOT SITES

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Asian Disaster Preparedness Center, SM Tower, 24th Floor, 979/69 Paholyothin Road, Samsen Nai

EXECUTIVE SUMMARY

Landslides are one of the major disasters, Sri Lanka experiences, which result in loss of human lives and considerable damages to economy. The records show a sudden increase in the occurrence of landslides during the recent past presumably due to climate change impacts and human interventions such as inappropriate land use planning. Hence, the importance of undertaking landslide risk mitigation interventions is growing. Risk mitigation measures adopted in Sri Lanka are largely with traditional geotechnical engineering solutions such as slope reinforcing measures, introduction of structures at the toe or across the sliding mass, surface and sub-surface drainage. The application of nature-based and hybrid (engineering in combination with nature based) approaches are still limited in the island nation.

Nature-based solutions or bio-engineering solutions are defined as techniques that use live plants or plant parts to fulfill engineering functions and it is proven as an appropriate, cost effective and nature friendly practice which is appropriate for stabilization of slopes mainly in South/ East Asian region. This is further defined by International Union for Conservation for Nature (IUCN) as “actions to protect, sustainably manage, and restore natural or modified ecosystems, that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits”.

One of the main tasks of “Nature Based Landslide Risk Mitigation Project” is to prepare a comprehensive landslide risk management plan for selected pilot sites. The purpose of the task is to demonstrate the methodology for preparation of a comprehensive landslide risk management plan for an identified vulnerable site so that NBRO and stakeholders will learn the same. For this, ADPC project team has selected two areas in consultation with NBRO. During the project period, a comprehensive strategy was prepared for application of different nature-based solutions. Analysis on risk and effectiveness was conducted for the possible interventions and then the nature-based risk management plans were developed for the suggested two areas.

ACRONYMS

ADB	: Asian Development Bank
AD	: Agriculture Department
ADPC	: Asian Disaster Preparedness Center
CRIP	: Climate Resilience Improvement Project
DCS	: Department of Census and Statistics
DoM	: Department of Meteorology
DMC	: Disaster Management Center
DRM	: Disaster Risk Management
DRR	: Disaster Risk Reduction
DS	: District Secretary
DSD	: Divisional Secretariat Division
FD	: Forest Department
GoSL	: Government of Sri Lanka
GND	: Grama Niladhari Division
GN	: Grama Niladhari
ID	: Irrigation Department
IUCN	: International Union for Conservation of Nature
JICA	: Japan International Cooperation Agency
LHMP	: Landslide Hazard Mitigation Program
MOH	: Ministry of Health
MoDM	: Ministry of Disaster Management
PG	: Provincial Government
NBRO	: National Building Research Organization
RDA	: Road Development Authority
SD	: Survey Department
UDA	: Urban Development Authority
UNDP	: United Nations Development Program
UNCHS	: United Nations Center for Human Settlements (UNHABITAT)
TNGA	: Training needs and gap assessment
WB	: World Bank

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CHAPTER ONE: Introduction

1.1 General

In the recent past, several landslides were reported from many parts of Sri Lanka mainly triggered by heavy rainfall. The data shows a sudden increase in the frequency of occurrences of landslides presumably due to climate change impacts and human interventions such as inappropriate land use planning. The severity of human suffering due to landslides is accompanied by widespread destruction of physical and social productive infrastructure. As a result, the economy of more than ten administrative districts and communities are at a risk of immediate, medium and long-term impacts. Furthermore, environmental assets may get damaged or destroyed and associated services may get disturbed or eliminated in its entirety. Disasters such as landslides are likely to increase considerably in the near future due to the impact of climate change and climate variability resulting in extreme weather conditions.

In this context, the importance of undertaking landslide risk mitigation interventions is growing. Risk mitigation measures adopted in Sri Lanka are largely based on traditional geotechnical engineering solutions such as slope reinforcing measures, introduction of structures at the toe or across the sliding mass, surface and sub-surface drainage. The application of nature-based and hybrid (engineering in combination with nature based) approaches are still limited in the island nation.

Nature-based solutions or bio-engineering solutions are defined as techniques that use live plants or plant parts to fulfill engineering functions and it is proven as an appropriate, cost effective and nature friendly practice which is appropriate for stabilization of slopes mainly in South/ East Asian region. This is further defined by International Union for Conservation for Nature (IUCN) as “actions to protect, sustainably manage, and restore natural or modified ecosystems, that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits”.

IUCN has proposed 8 nature-based solutions (NBS) principles as follows;

1. Embrace nature conservation norms (and principles);

2. Can be implemented alone or in an integrated manner with other solutions to societal challenges (e.g. technological and engineering solutions);

3. Are determined by site-specific natural and cultural contexts that include traditional, local and scientific knowledge;

4. Produce societal benefits in a fair and equitable way, in a manner that promotes transparency and broad participation;

5. Maintain biological and cultural diversity and the ability of ecosystems to evolve over time;

6. Are applied at a landscape scale;

7. Recognize and address the trade-offs between the production of a few immediate economic benefits for development, and future options for the production of the full range of ecosystems services; and

8. Are an integral part of the overall design of policies, and measures or actions, to address a specific challenge.

Having gone through those 8 principles, nature-based solutions in slope stability applications could be justified. Bioengineering techniques improve slope stability by increasing the matric suction of the soil via root water uptake together with the evapotranspiration of their canopy. Further, the root network of plants provides mechanical reinforcement to unstable soil mass. Moreover, such techniques contribute to maintain ecological balance of landslide prone areas.

One of the main tasks of “Nature Based Landslide Risk Mitigation Project” is to prepare a comprehensive landslide risk management plan for selected pilot sites. In this regard, a series of candidate sites with landslide threats were visited. Section 1.2 describes the information on the visited candidate sites.

1.2 Description of candidate sites with landslide threat

Five sites with landslide threats were visited and inspected together with NBRO officials on the days May 16, May 17 and June 13, 2018. Table 1.1 presents the list of sites visited together with their geographical locations.

These five sites were initially selected after a lengthy discussion with NBRO officials on the concept of nature-based landslide mitigation. Applicability of such mitigation in the five chosen areas were considered as positive with the available data at NBRO and their related experience. After analyzing the information gathered from site visits, two pilot sites were selected in accordance with a selection criterion described herein together with consultation of NBRO scientists.

Table 1.1: Summary of sites visited

No.	Location	Geographic coordinates (Kandawala Datum)*		
		X (m)	Y (m)	Z (MSL in m)
1	Near Rathganga Road, Galabada, Rathnapura	166,084.1696	167,572.147	220
2	Beragala Wellawaya Road, between culvert no. 185/7 and 185/6	218,492.222	172,689.518	921

No.	Location	Geographic coordinates (Kandawala Datum)*		
		X (m)	Y (m)	Z (MSL in m)
3	Badulusirigama, Badulla	233,374.1543	197,744.052	790
4	Diyanilla in Walapane, NuwaraEliya	210,554.1262	204,128.676	1453
5	Thanipita in Deniyaya, Mathara	178,372.536	126,094.1941	510

**Geodetic datum in Sri Lanka for latitude, longitude and height*

Four sites located at Ratnapura, Badulla and Nuwara Eliya districts were visited during the two days from 16th May 2018 to17th May 2018. The fifth site which was at Thanipita closer to Deniyaya Matara was visited on 13th June 2018. Following epigraphs describe the characteristics observed at each location.

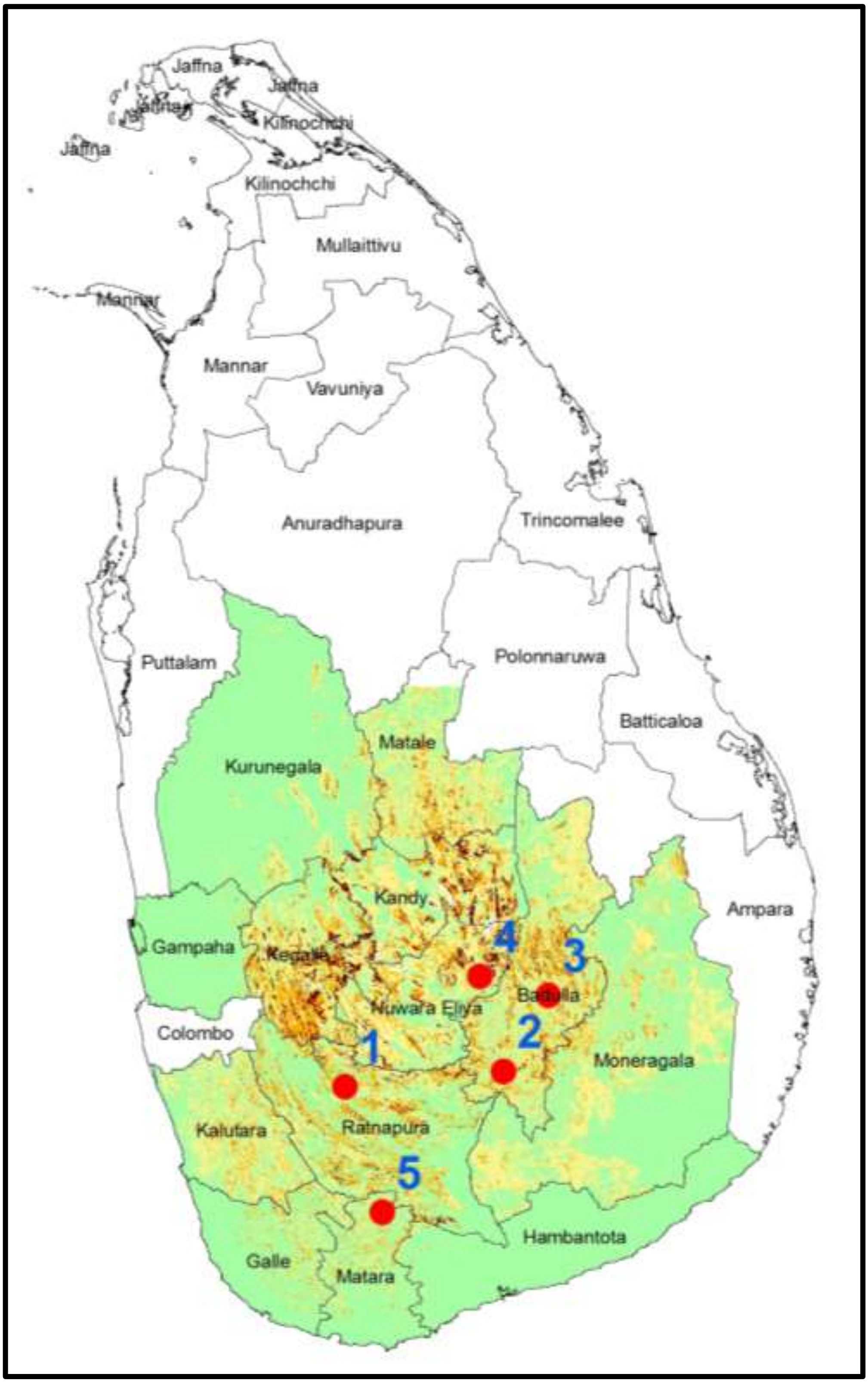


Figure 1.1: Locations of candidate sites

1.2.1 Site No. 1

ID: S-01

Name and Address of the Location:
Galabada-Rathganga Road, Rathnapura

Coordinates

Latitude N	Longitude E	X (m)	Y (m)	Z (m)
6.707467	80.466949	166,084.1696	167,572.147	220

Observations:

According to the information gathered from NBRO scientists at Ratnapura district office, the site has shown ground movements during the last 30 years. A JICA funded project had been initiated at the location and several instrumentations such as piezometers and extensometers too had been installed during the period 2011 – 2012 for monitoring purposes. Large movements were recorded in the year 2014 and 2016. Most probable reason for such movements had been due to the excavation activities near the toe area of the slope for construction and renovation activities of Rathganga road. However, the aforementioned project had come to a standstill and the installed instrumentation has been removed as at present. Figure 1.1 is a Google Earth image, where the affected location is bounded by a red polygon.

Figure 1.2: Google Earth image showing the affected location.

Figure 1.3: Upslope and down slope areas of the failed mass

Figure 1.4: Red line demarcating the Crown area covered with vegetation mainly of *Panicum maximum*

Figure 1.5: Red lines demarcating the affected road section

Figure 1.6: Downslope area of the failed mass

NBRO officers conveyed the ADPC project team that it would be possible to obtain borehole logs of the area, from the contractor (CATIC) who was in-charge of renovation activities of Rathganga Road. Further it was informed that the NBRO had conducted a Ground Probing Radar (GPR) survey at the above location recently.

The Crown area of the failed mass is densely covered with vegetation such as Mangifera indica (Mango) and Caryota urens (Kithul). Scars of ground subsidence are seen scattered around the area. A cemetery is located at the up slope area and is affected by ground movements.

Figure 1.7: Ground subsidence observed at site

1.2.2 Site No. 2

ID: S-02

Name and Address of the location;
Beragala Wellawaya Road, between culvert no. 185/7 and 185/6

Coordinates

Latitude N	Longitude E	X (m)	Y (m)	Z (m)
6.753810	80.941005	218,492.222	172,689.518	921

Observations:

According to the information gathered from NBRO officials, the site experiences slow ground movements. Rock boulders are scattered all around and there is a possible risk of boulders falling onto the main highway (A4) Beragala-Wellawaya. The main road appears to have undergone vertical displacements probably as a result of slow ground movement. The area is covered with mixed vegetation ranging from small bushes to large trees.

Figure 1.8: Vegetated landscape with rock boulders scattered all-around

Figure 1.9: Some vertical displacement observed on the road stretch

1.2.3 Site No. 3

ID: S-03

Name and address of the location:
Badulusirigama, inside the premises of Uva Wellassa University at Badulla

Coordinates

Latitude N	Longitude E	X (m)	Y (m)	Z (m)
6.980315	81.075787	233,374.1543	197,744.052	790

Observations:

The landslide is located inside the premises of Uva Wellassa University. The site had been one of the pilot sites of Technical Corporation for Landslide Mitigation Project (TCLMP) between JICA and NBRO. All the works relevant to the aforementioned project had been completed and the maintenance activities of the site at present is in the process of transferring over to NBRO.

NBRO with the assistance of JICA, had installed sets of horizontal drains and surface drains to contain ground movements. Data on subsurface conditions (BH logs, ground water levels) and slope movement data are available at NBRO.

The site hasn't been landscaped in a proper manner. It is mainly covered with species *"Panicum maximum"* at present.

Figure 1.10: Aerial view of upslope of the landslide and Uva Wellassa University Premises

Figure 1.11: Arial View of the failed mass which is delineated with a red polygon

Figure 1.12: Horizontal drains set up to lower the ground water table and pore pressure

Figure 1.13: Concrete drains built to improve surface water drainage

1.2.4 Site No. 4

ID: S-04

Name and address of the location:
Diyanilla area in Walapane, Nuwara Eliya

Coordinates

Latitude N	Longitude E	X (m)	Y (m)	Z (m)
7.038140	80.869263	210,554.1262	204,128.676	1453

Observations:

The site is a vegetated landscape with tea plants and few other large trees. A vertical displacement was seen on the road stretch (Figure 4.2) as a result of the ground movement. The overburden soil consists of colluvium soils with boulders scattered all around.

Upslope area has cultivated lands and is a highly watered area. Ground movements had been recorded in the year 2007 and 2011, the latter being the most severe movement causing damages to residential households in the surrounding.

Figure 1.14: Vegetated landscape with boulders scattered all-around

Figure 1.15: Vertical displacement observed in the road stretch due to ground movements

Figure 1.16: Cultivated lands in the upslope area

Figure 1.17: A damaged house due to ground movements

1.2.5 Site No. 5

ID: S-05

Name and address of the location:
Thanipita in Deniyaya, Matara

Coordinates

Latitude N	Longitude E	X (m)	Y (m)	Z (m)
6.332442	80.578232	178,372.536	126,094.1941	510

Observations:

The site is a very well vegetated landscape with tea plants and other large trees such as *Artocarpus heterophyllus* (Kos), *Garcinia gummi-gutta* (Goraka), and *Caryota urens* (Kithul). A vertical displacement was seen on the road stretch (Figure 1.17) as a result of slow ground movements. The soil overburden consists of colluvium soils with few boulders scattered around and, in some places, residual soils. This has been classified as a slow-moving landslide.

According to the information gathered from villagers, the ground instabilities in the area had been recorded in the years 1949, 1969 and 1972. A major failure had occurred in May 2003 after heavy rainfalls causing damages to residential households in the surrounding.

Many landslide scars were seen on the unstable ground mass which had occurred during peak rainfall events in the past few years.

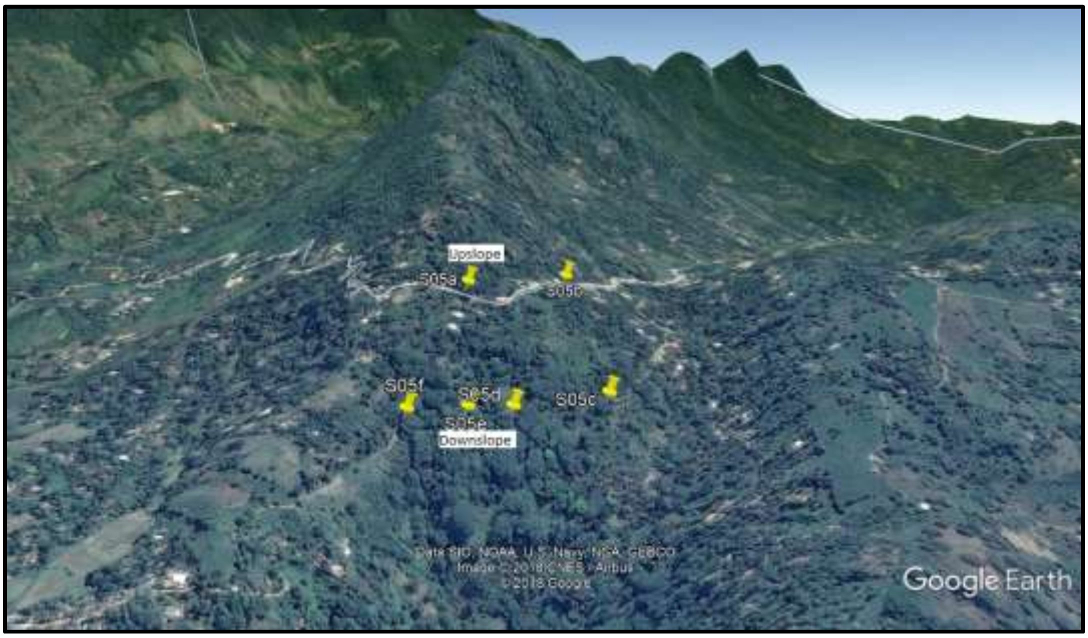


Figure 1.18: Google Earth image of the Unstable slope indicating Upslope and Downslope

Figure 1.19: Slopes covered with thick vegetation consisting of Camellia sinensis (tea) plants and large trees such as *Artocarpus heterophyllus* (Kos), *Garcinia gummi-gutta* (Goraka), and *Caryota urens* (Kithul)

Figure 1.20: A crack on the road stretch marked with the red line

Figure 1.21: A previous landslide scar which had during heavy rainfall in May 2017

Settlement cracks were seen on a residential building due to ground movements (Figure 4.15).

Figure 1.22: Settlement cracks observed on a house due to ground movement

During the site investigations, it was noted that ground water springs are appearing from the middle of the unstable landmass and draining downslope via a series of natural valleys.

NBRO officials conveyed that a mitigation process will be started soon to improve surface drainage by constructing a set of concrete drains. Landslide hazard zonation map on a scale 1:10,000 and a high-resolution Drone image of the area are available at NBRO.

CHAPTER TWO: Site selection criteria and selection of pilot sites

2.1 Description of the selection criteria

Unstable sites with landslide symptoms must be studied in detail considering the factors such as socio-economic, geo-engineering, scientific, risk escalating factors, in order to understand the socio-economic conditions, level of risk and the nature of failure mechanism before implementing nature-based solutions and hybrid solutions. Mostly such solutions would be ideal for shallow & slow-moving landslides and generally would not be very effective for rock fall sites or very deep or rapid moving landslides.

Hence, there is a need for a developing a criterion for shortlisting the sites in order to select the most appropriate location for the implementation of Nature Based Solutions and Hybrid Solutions. The methodology described below is used for site selection for implementing Nature Based Solutions (NBSs) and Hybrid Solutions under the current project.

Seven key criteria are being utilized in short listing of sites for application of NBSs and hybrid solutions. Each of them is assigned with a weightage factor depending on their contribution towards positive implementation of NBSs and hybrid solutions in landslide risk management. The weighting of the criteria is done based on subjective experience and expert judgment within a scale from 0 to 4.1 Table 2.1 indicates weightage factors assigned to each criterion.

Table 2.1: Weightage factors assigned to each criteria

Name of criteria	Weightage Factor
Depth to failure plane	5
Rate of potential movement	5
Slope range & category (in degrees)	5
Suitability for creating a vegetation cover	5
Sustainability/maintenance challenges	3
Geotechnical data availability	3
Probable loss considering the exposure elements at risk within impact zone	5

Depth to failure plane

The criteria have five categories and marks (from 0 to 4) are allocated to each category as shown in the Table 2.2. "Deep" category was specified for the lowest marks since, implementation of nature based solutions are not very effective in such sites. However, nature-based solutions can be used to control the soil erosion rate and to prevent the gullying effect.

Table 2.2: Scores allocated for depth to failure plane

Name of category	Possibility of implementing NBSs	Suggested marks
Surficial (<0.5 m)	Very High	4
Shallow (0.5 – 3 m)	High	3

Medium (3 – 8 m)	Medium	2
Deep (8 - 15 m)	Low	1
Very Deep (>15m)	Very Low	0

Rate of potential movement

Nature based solutions are more favorable for slow moving landslide sites.

Table 2.3: Marks allocated for rate of movement

Name of category	**Possibility of implementing NBSs**	**Suggested marks**
Slow (Creep effect; site observations include tilting of trees)	High	3
Moderate to fast	Very low	0

Slope range and category (in degrees)

Choi and Cheung (2013) mentioned that in Hong Kong vegetation was used as a slope surface cover in the upgrading of existing man-made slopes which are not steeper than 55 degrees. Further, it must be noted that with the increase of slope angle, the soil thickness tends to decrease which is an unfavorable factor for the growth of vegetation. Moreover, as per the Soil Conservation Act of Sri Lanka, perennial crops are not allowed on slopes having more than 60-degree angles and above 1,500m above MSL. Hence, considering the factors described above, marks are suggested for each slope category as shown in table 2.4.

Table 2.4: Marks allocated for slope range

Name of category	**Possibility of implementing NBSs**	**Suggested marks**
Slope category I (>40)	Very Low	0
Slope category II (31-40)	Low	1
Slope category III (17-31)	Medium	2
Slope category IV (11-17)	High	3
Slope category V (0-10)	Very high	4

Suitability for creating a vegetation cover

Factors such as soil thickness, presence of boulders and the climatic conditions of the present ecosystem are considered when allocating marks for each category.

Table 2.5: Marks allocated for planting ability

Name of category	**Possibility of implementing NBSs**	**Suggested marks**
Category I (Greater extent of the site covered with boulders)	Very Low	0
Category II (Soil thickness lower than 0.5 m) and longer dry periods in existence	Low	1
Category III (Soil thickness greater than 0.5 m and ecosystem with average rainfall)	Medium	2
Category IV (Soil thickness greater than 0.5 m and ecosystem with reasonable rainfall)	High	3

Sustainability/ maintenance challenges

More attention must be paid to the possibility of implementing the "build and watch approach" instead of the more common "build and forget approach". If it involves higher maintenance cost or sustainability due to external factors, then application of NBSs are not very conducive, hence, the score can be very low. Further, the possibilities must be looked into whether an economic benefit can be generated from the proposed landslide prevention measure. This has been given a lesser weightage than others in the selection process since the implementation of sustainable approaches could be created if other factors are in favor of NBSs.

Marks can be assigned under these criteria considering the above mentioned factors and grouping them under Very low (0), Low (1), Medium (2), High (3) and Very High (4)

Geotechnical data availability

This parameter could be used as a complementary data when selecting sites for the application of Nature Based Solutions. Hence, the criteria have been given a lesser weightage than others (Table 2.1) since, all sites with landslide threats do not have geotechnical data during early stages of investigations. If relevant geotechnical data are available, then a factor of safety relevant to present condition can be calculated, and marks can be assigned as follows;

Table 2.6: Marks allocated for factor of safety considering the current state of stability of the slope

Name of Criteria	**Possibility of implementing NBSs**	**Suggested marks**
Category I (1-1.1)	Very Low	0

Category II (1.1-1.3)	Low	1
Category III (1.3-1.5)	Medium	2
Category IV (>1,5)	High	3

Probable loss considering the exposure elements at risk within the impact zone/sensitivity considering socio-economic, environmental, cultural aspects

Scores can be assigned under this criteria considering the magnitude of loss considering the exposure elements within the impact zone (the size of the community, number of residential building units, commercial institutes etc.) and grouping them under Very low (0), Low (1), Medium (2), High (3) and Very High (4)

Method of calculating the Final Score for each site

The scores allocated under each sub category must be multiplied by the corresponding weightage factor shown in Table 2.1. The Final score can then be finalized by taking the weighted average.

$$Final\ Score = \frac{\sum_{i=1}^{n}[W_i * S_i]}{\sum_{i=1}^{n} W_i}$$

n – no. of criteria
W – Weight assigned to each criterion
S – Marks assigned to each criterion

The final score is based on a scale of 4.0. The site with the highest score against a threshold value of 2.0 is considered as suitable for the implementation of NBSs and hybrid solutions.

2.2 Selection of two pilot sites

Table 2.7 summarizes the total scores assigned to the five sites as per the selection criteria described above. Accordingly, the highest score was obtained by the site at **Badulusirigama in Badulla** followed by the site at **Galabada in Ratnapura**. Hence, the two sites were selected as the Pilot Sites under this project for the preparation of a comprehensive landslide risk management plan adopting nature-based solutions.

Table 2.7: Total marks allocated to five sites

	Location	Name of Criteria							Total Score (out of 4)
		Depth to failure plane (5)*	Rate of movement (5) *	Slope range & category (in degrees) (5)*	Suitability for creation of a vegetation cover (5) *	Sustainability/ maintenance challenges (3)*	Geotechnical data availability (3)*	Amount of exposure elements at risk (5)*	
1	Near Rathganga Road, Galabada, Rathnapura	Medium (2)**	Slow (3)**	Slope category IV (15°-35°) (3)**	Category IV (3)**	Medium (2) **	Medium (2) **	High (3) **	2.65
2	Beragala Wellawaya Road, between culvert no. 185/7 and 185/6	Deep (1) **	Slow (3)**	Slope category IV (15°-35°) (3)**	Category I (0) **	Low (1) **	Very low (0) **	Medium (2) **	1.55
3	Badulusirigama, Badulla	Deep (1) **	Slow (3)**	Slope category IV (15°-35°) (3)**	Category IV (3)**	High (3) **	High (3) **	High (3) **	2.68

4	Diyanilla in Walapane, NuwaraEliya	Deep (1) **	Slow (3)**	Slope category IV (15°-35°) (3)**	Category IV (3)**	Low (1) **	Very low (0) **	Medium (2) **	2.03
5	Thanipita in Deniyaya, Mathara	Deep (1) **	Slow (3)**	Slope category III (35°-45°) (2)**	Category IV (3)**	Low (1) **	Very low (0) **	Medium (2) **	1.87

* Weightage factor
** Marks allocated

CHAPTER THREE: Overview and socio-economic survey conducted at two pilot sites

The information generated through a socio-economic survey is expected to provide valuable inputs to develop a long-term landslide risk management plan, which could be implemented by the relevant agencies to minimize the impacts of landslide risk in future.

3.1 Overview of Badulusirigama site in Badulla district

The landslide at Badulusirigama is located within the premises of Uva Wellassa University in Badulla District. With respect to administrative boundaries, the area belongs to Badulla Divisional Secretariat and lies within Rambukpotha and Hindagoda Grama Niladhari Divisions.

Figure 3.1: Aerial view of upslope of the landslide and Uva Wellassa University Premises

At present, a network of surface and subsurface drains was constructed in order to improve surface drainage of water, minimize infiltration of storm water and lower the ground water level in order to arrest any further ground movements. NBRO has been performing continuous monitoring of the activity of the landslide using extensometers, inclinometers, strain gauges and ground water level monitoring gauges.

Figure 3.2: Arial View of the failed mass which is delineated with a red polygon

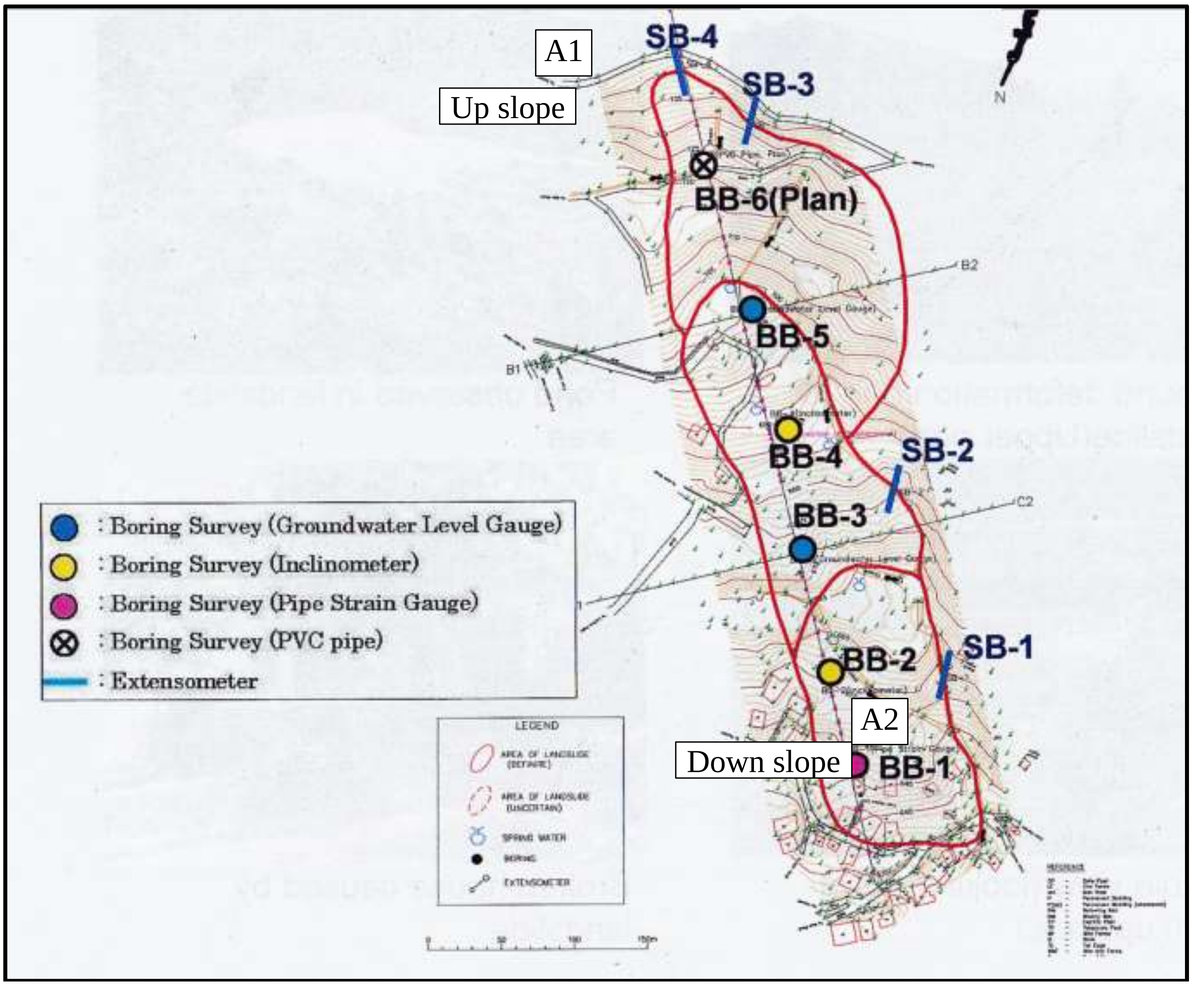


Figure 3.3: Layout plan of installed slope monitoring instrumentation (Countermeasures for Badulusirigama-JICA, 2015)

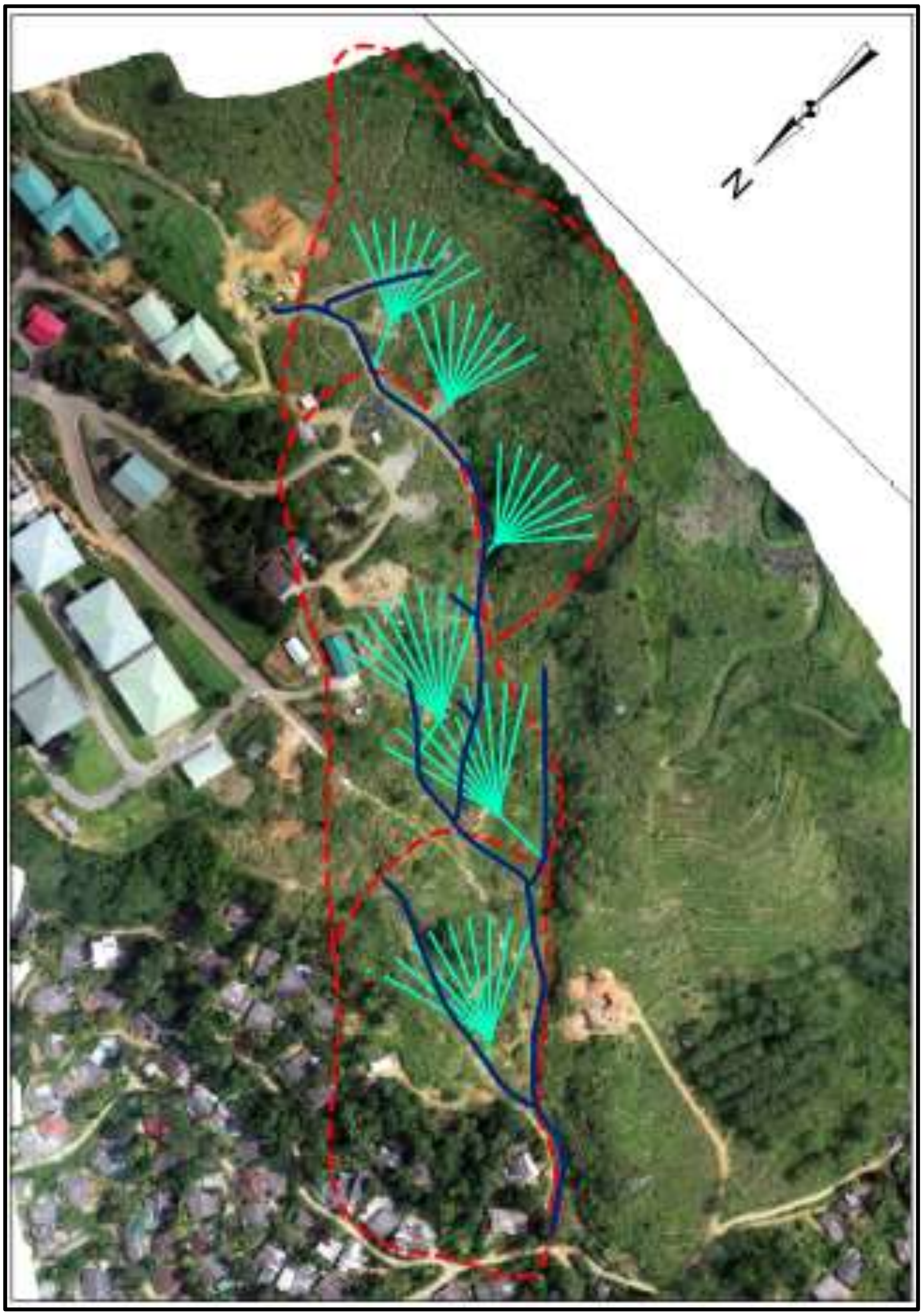


Figure 3.4: Drone image of the site.
landslide foot print (red dotted lines), surface drainage network (dark blue lines) and subsurface drainage network (light green lines)

Figure 3.5: Horizontal drains set up to lower the ground water table and pore pressure

Figure 3.6: Concrete drains built to improve surface water drainage

The approximate dimensions of the slide constitute a width of 120m, a length of 500m and a depth of 9m~13m. The landslide had moved slowly and sporadically in the rainy seasons of 2007, 2011 and 2012. Such ground movements had posed a threat to the community living near the toe of the landslide.

3.2 Overview of Galabada site in Ratnapura

The site is located in Ratnapura district belonging to Galabada Grama Niladhari Division. The site is owned by Galaboda Tea Estate which is under Hapugastenna Plantation, Finlay group. The land was previously used for Tear plantation.

The landslide has a width of 50-55m and a length of 135 m. Large movements were recorded in the year 2014 and 2016. Currently a JICA funded project had been initiated at the location and several instrumentation such as piezometers & extensometers has been installed.

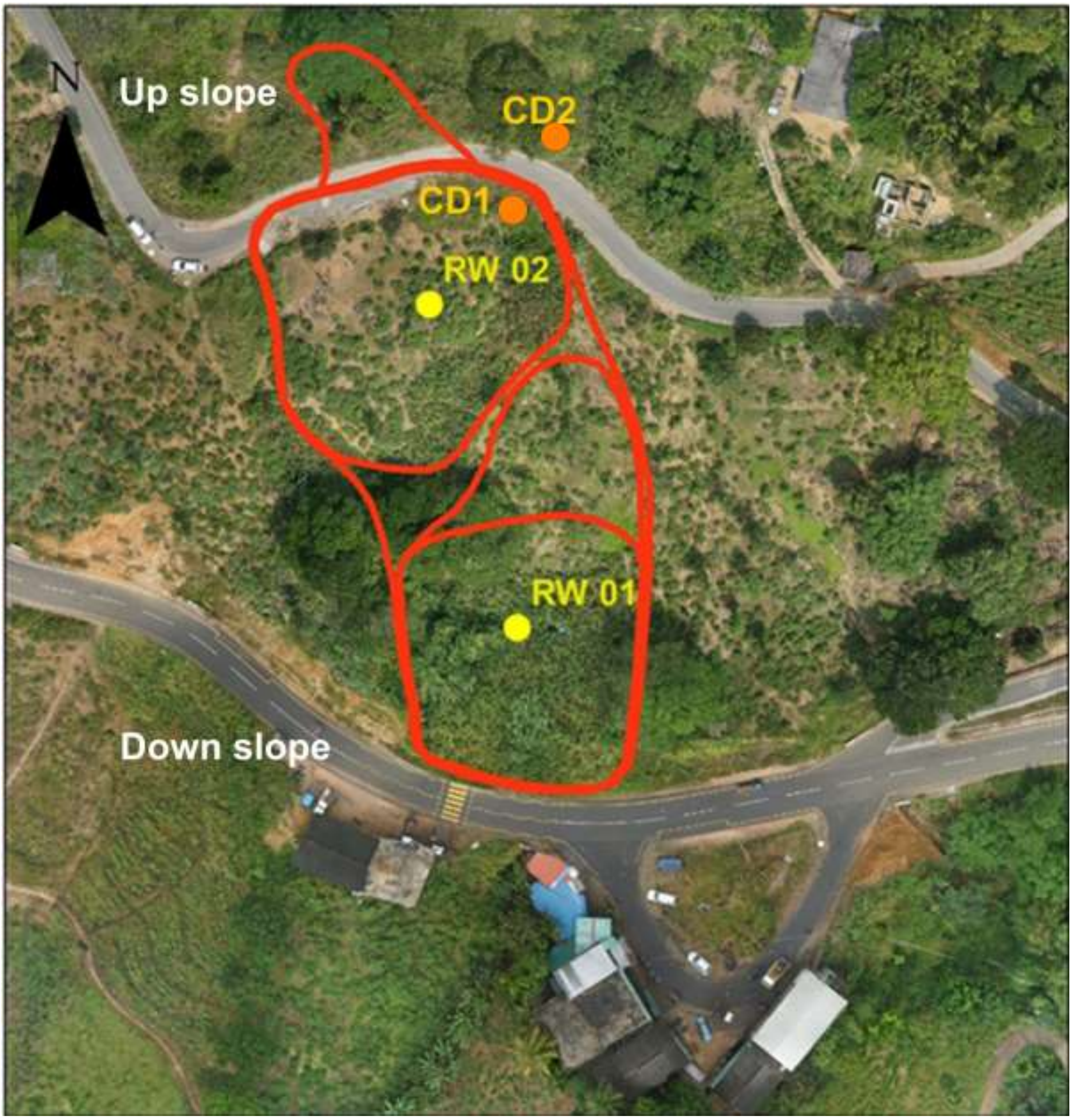


Figure 3.7: Drone image of Galabada site

Red lines indicate the landslide foot print. RW 01 & RW 02 are two bore holes drilled in 2018 and CD1 and CD2 are two boreholes drilled in 2010.

Figure 3.8: Overall view of the landslide area

Figure 3.9: Downslope area bordering the main road

The crown area of the failed mass is densely covered with vegetation such as *Mangifera indica* (Mango) and *Caryota urens* (Kithul trees). Rest of the area is covered with plant species such as *Camellia sinensis* (Tea), *Macaranga peltata* (Kanda), *Areca catechu* (Puwak) and *Cymbopogan nardud* (Citronella grass).

Scars of ground subsidence are seen scattered around the area. A cemetery is located at the up slope area and is affected by ground movements.

3.3 Socio-economic survey

A socio-economic survey was carried out to identify the current vulnerabilities of the community and the degree of exposure of elements (buildings, inhabitants, properties, economic activities, public services etc.) to landslide hazard of the selected two areas.

The necessary data for the site at Badulusirigama in Badulla were obtained from the Data Base maintained by NBRO since all the data were available on the digital platform. For the site at Galabada, Rathnapura, a house by house questionnaire survey was conducted to gather the required data.

The type of information and data analyzed during this stage are:
a. General information;
b. demographic profile of the households;
c. land use and characteristics of the housing units;
e. whether construction guidelines followed to build the house;
f. disaster impacts;
g. knowledge on disaster preparedness;
h. knowledge on disaster risk reduction measures.

3.3.1 Highlights of socioeconomic survey conducted at Badulusirigama site in Badulla

The vulnerable land area to landslide hazard was identified using NBRO Landslide Hazard Zonation Map and after studying the Geotechnical nature of the failure mechanism. Accordingly Figure 3.10 shows the land area vulnerable to landslide hazard in purple colour which is marked as “Subsidence” on the landslide hazard map. All the elements which falls in the given region were selected. Afterwards an analysis on socioeconomic aspects and physical characteristics of building units was carried out. The necessary data for the analysis were obtained from the Database maintained by NBRO. The results generated are presented in following epigraphs

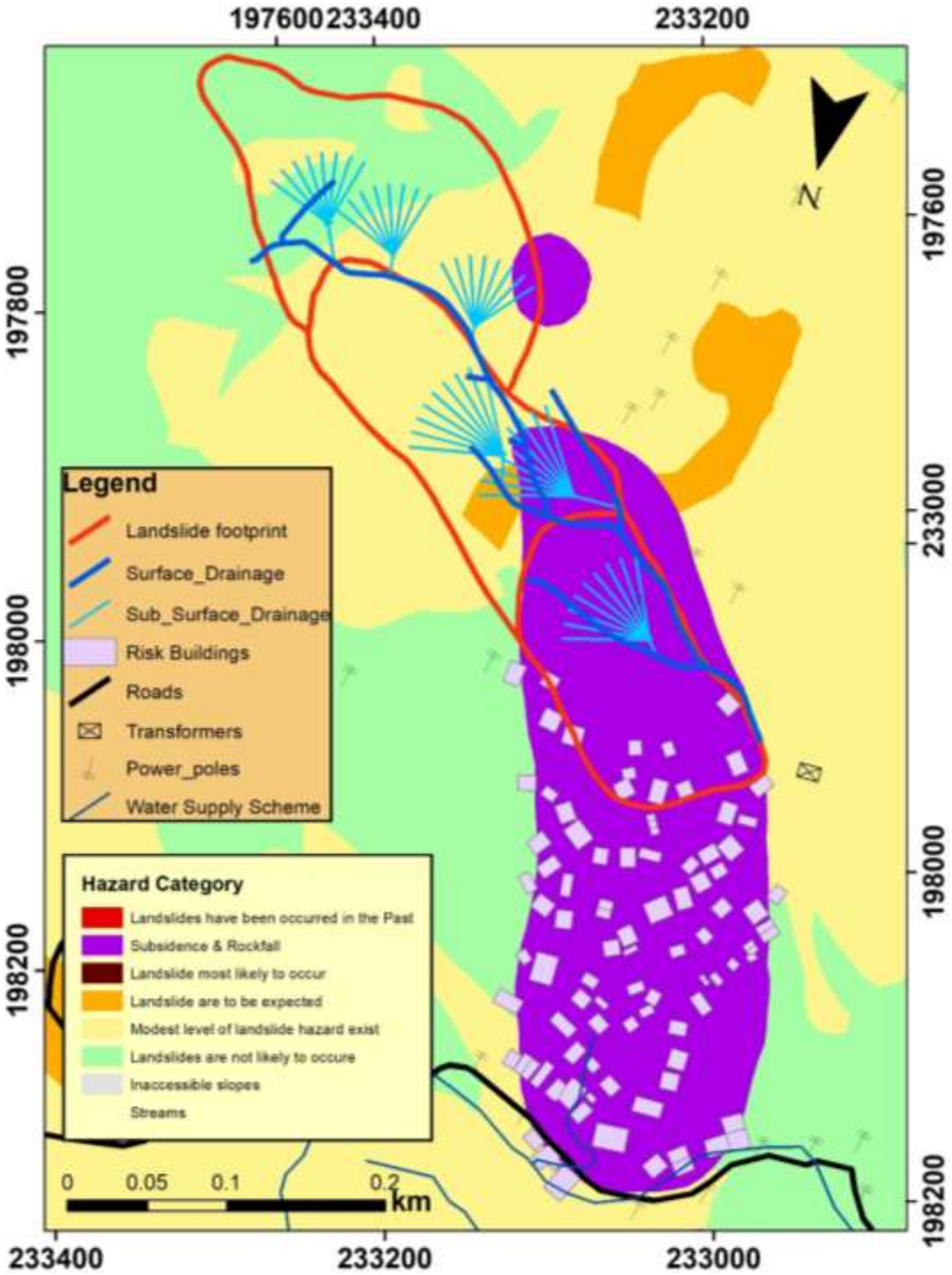


Figure 3.10: Map showing the spatial distribution of elements at risk in the study area overlaid on the landslide hazard zonation map

Table 3.1: Summary of elements at risk

Elements at Risk	Quantity
Total Number of buildings	95
Number of residents/occupants	355
Road length (minor and major roads) (km)	1
Power supply facilities (No. of High tension line towers)	4
Water supply facilities (Transmission pipe length in m)	400
Vulnerable land extent (total area in sq. km)	0.08

Main Findings of the building survey

1. Majority of head of households (56%) are male headed. About 73% of the heads are 50 years and older.
2. Major portion of the heads are engaged in Government sector employment.
3. 68% of the housing units are residential while 24% are Line Houses
4. Majority of them have been constructed during the period 1980-1990 where government organizations have acted as designer of the house.
5. Majority of the structures consist of Load Bearing Walls and Small Bricks were the major material of construction.
6. Major portion of the housing units consist of;
   - cement floors
   - foundations mainly of rubble works
   - Wood roof structures with asbestos as the roofing material
   - Have a systematic drainage system
7. 69% of the units are located on a terrain with gentle slope while 31% of the units are located on steep slopes.
8. No landslide signs were observed in 58% of housing units, however cracks on buildings, stagnation of water and subsidence were observed in some units.
9. 71% of the respondents reported that they had not received any instruction on disaster preparedness.
10. Most families prefer to relocate within the current GN division.

Results are presented in detail in Annex I.

3.3.2 Highlights of socioeconomic survey conducted at Galabada site in Ratnapura

The vulnerable land area to landslide hazard was identified using NBRO Landslide Hazard Zonation Map and after studying the Geotechnical data extracted from the investigation done by JICA in the year 2018. Accordingly Figure 3.11 shows the land area vulnerable to landslide hazard delineated by a red dotted line. All the elements which falls in the given area were selected. Afterwards an analysis on socioeconomic aspects and physical characteristics of building units was carried out. The necessary data for the analysis were obtained by conducting a house by house questionnaire survey at site. The results generated are presented in following epigraphs.

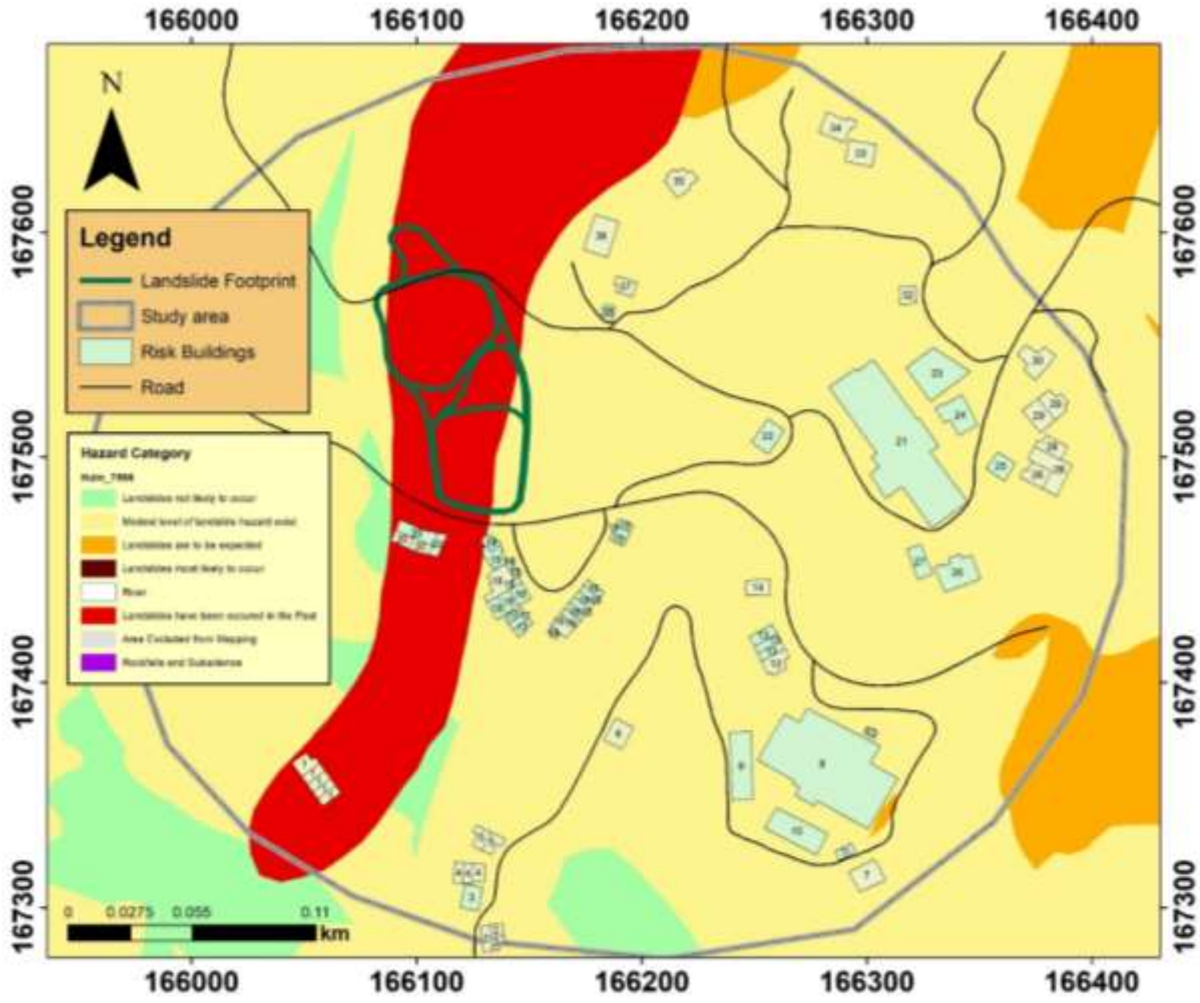


Figure 3.11: Map showing the spatial distribution of elements at risk in the study area overlaid on NBRO landslide hazard zonation map

Table 3.2: Quantitative measure of elements at risk

Elements at Risk	**Quantity**
Total number of building units	73
Number of residential buildings	33
Number of residents/ occupants	117
Number of commercial building units	25
Number of industrial building units	13
Number of building units which house institutions	2
Road length (km) Major Roads Minor Roads	 0.51 2.22
Number of Power supply facilities (High Tension line length in m)	403
Vulnerable land extent (total area in sq. km)	0.15

Main Findings of the building survey

1. Majority of head of households (75%) are male headed. About 46% of the heads are of 40-50 age group while 39% are 50 years and older.
2. Major portion of the heads are engaged in Private sector employment.
3. 54% of the housing units are Line Houses while 35% are Residential Units.
4. Majority of them have been constructed before year 1990 where mainly masons have acted as the designer of the house.
5. Majority of the structures consist of Load Bearing Walls and Cement Blocks was the major material that had been used in construction.
6. Major portion of the housing units consist of
   - cement floors
   - foundations mainly of rubble works
   - Wood roof structures with asbestos as the roofing material
   - Do not have a systematic drainage system

7. 75% of the units are located on a rolling terrain while the rest on steep slopes.
8. No landslide signs were observed in 68% of housing units, however cracks on buildings were observed in some units.
9. 56% of the respondents reported that they had not received any instruction on disaster preparedness.
10. Most families prefer to relocate within the current GN division

Results are presented in detail in Annex II.

CHAPTER FOUR: Laboratory testing program to evaluate root tensile strength

4.1 Introduction

One of the project task is to carry out a laboratory testing program to obtain geotechnical parameters for application in to a computer model to assess the degree of stability change upon introduction of vegetation.

Root tensile strength is an indicator of the reinforcement potential offered by the particular plant species. The reinforcement provided by the roots is fully utilized at the time of rupture. Hence, in order to evaluate the potential of plant species to prevent shallow mass movements, the root tensile capacity must be assessed.

The following epigraphs describe the methodology adopted in determining the root tensile strength.

4.2 Materials and Methods

Plant species for testing were short listed based on the level of knowledge acquired from the Plant Manual. Accordingly, seventeen plant species were selected to obtain tensile strength of its roots. The root tensile strengths of the collected plant species were measured through laboratory experiments.

For each selected plant species, approximately 10 undamaged roots with an average diameter of 2 to 50 mm, and a minimum root length of 0.15 m were selected. To collect the roots, a few individual, medium-size plants, growing in the same microenvironment (same habitat, similar landscape position), were dug out using the dry excavation method. The roots were manually collected by careful excavation, and also by cutting the roots on exposed profiles (Figure 4.1). After excavation, the roots were individually stored in a plastic bag to preserve their moisture content. The collected root samples were immediately transported to the laboratory; however, the tested roots probably had slightly different moisture contents.

Figure 4.1: Root sample collection for laboratory tests

Root tensile strength tests were conducted in the laboratory using Dynamometer universal tensile and compression test machine (Model LW 6527, WC DILLON & Co Inc, USA) (Figure 4.2). This device combines three functions: (1) traction force generation, (2) measuring load and displacement, and (3) data acquisition. Clamping is the most critical issue when measuring root strength. Roots with fleshy root epithelia could not be tested due to clamping problems, as the samples slipped without breaking. Also, direct mounting of roots causes grip damage to the roots. In this experiment, we wrapped cotton textile bandage around the griping ends of the roots to increase the grip and to minimize the damage to the roots.

Figure 4.2: Root tensile strength testing using Dynamometer

The initial root length was set to 150 mm. The root diameter was measured at both ends and the middle was measured using Vernier calipers or a micrometer.

4.3. Results and Discussion

The following formula was used to calculate the tensile strength:

$$T_r = \frac{F_{max}}{\pi\left(\frac{D^2}{4}\right)}$$

where F_{max} is the maximum force (N) needed to break the root and D is the mean root diameter (mm) before the break.

Root cohesion which is needed for design and analysis of the stability of slopes was obtained from the formula given. It was obtained from the study carried out by Schwarz et al. (2010);

$$Cr = 0.48 * Tr * (RAR)$$

$$\mathrm{RAR} = \frac{A_r}{A} = \frac{\sum_{i=1}^{n} \pi d_i^2/4}{A}$$

d – diameter of the root
A – effective soil cross section area

This increment in cohesion value is used in stability assessments to evaluate the vegetation effect and was applied in function of the plants' root zone.

As the next step, an average value of root cohesion for the entire slope, $\bar{c}_r$ was calculated considering the spacing between each plant row as suggested by Mahannopkul & Jotisankasa (2019). They have applied the formula for testing vetiver plants:

$$\bar{c}_r = \frac{c_r l_r}{l_r + l_s}$$

l_r – width of the plant row
l_s – spacing between each plant row (width of the non-reinforced zone)

Table 4.1 presents the results of root tensile testing. The table includes root tensile strength for each plant species. Root cohesion and the variation of root cohesion with different spacing patterns was calculated as a pilot study using the information from literature.

The tensile strength vs root diameter relationship for the tested plant species which included some from Kandyan Home Garden system were analyzed (Figure 4.3). The results indicated that root tensile strength generally decreases with increasing root diameter as reported in several studies. This approach of finding root cohesion values could be very useful to rank plant species according to their slope stability improvement potential.

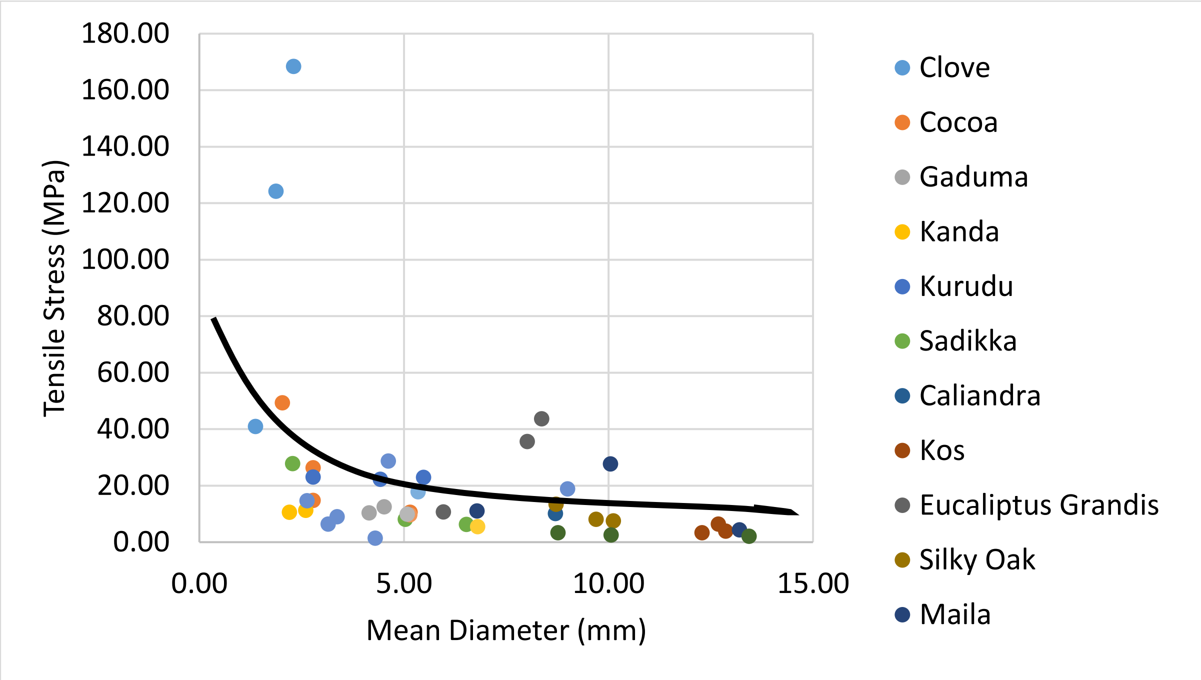


Figure 4.3: Graph showing the relationship between root tensile strength and its diameter

Table 4.1: Results of root tensile testing

Scientific name	Common name	Test No.	Tensile stress (Mpa)	Mean Diameter (mm)	Remarks	Age	RAR	Root cohesion	Width of row	Average root cohesion in MPa for different spacing (m)			
			Tr	D				Cr (Mpa)	lr	2.00	1.50	1.00	0.50
Eugenia caryophyllus	Clove	Test_01	40.90	1.37	Breakage	20 years	0.01	0.20	0.50	0.04	0.05	0.07	0.10
		Test_02	124.21	1.87	Slippage	20 years	0.01	0.60	0.50	0.12	0.15	0.20	0.30
		Test_03	168.38	2.30	Breakage	20 years	0.01	0.81	0.50	0.16	0.20	0.27	0.40
Theobroma cacao	Cocoa	Test_01	10.56	5.15	Slippage	20 years	0.01	0.05	0.50	0.01	0.01	0.02	0.03
		Test_02	26.30	2.78	Breakage	20 years	0.01	0.13	0.50	0.03	0.03	0.04	0.06
		Test_03	49.27	2.03	Breakage	20 years	0.01	0.24	0.50	0.05	0.06	0.08	0.12
		Test_04	14.79	2.78	Slippage	20 years	0.01	0.07	0.50	0.01	0.02	0.02	0.04
Trema orientalis	Gaduma	Test_01	12.48	4.52	Breakage	25 years	0.01	0.06	0.50	0.01	0.01	0.02	0.03
		Test_02	10.35	4.15	Breakage	25 years	0.01	0.05	0.50	0.01	0.01	0.02	0.02
Macaranga peltata	Kanda	Test_01	11.30	2.60	Breakage	1 year	0.01	0.05	0.50	0.01	0.01	0.02	0.03
		Test_02	10.52	2.20	Breakage	1 year	0.01	0.05	0.50	0.01	0.01	0.02	0.03
Cinnamomum verum	Kurudu (cinnaman)	Test_01	22.87	5.48	Breakage	3 years	0.01	0.11	0.50	0.02	0.03	0.04	0.05
		Test_02	23.01	2.78	slippage	3 years	0.01	0.11	0.50	0.02	0.03	0.04	0.06
		Test_03	22.19	4.42	Breakage	3 years	0.01	0.11	0.50	0.02	0.03	0.04	0.05
Myristica fragrans	Sadikka (Nutmeg)	Test_01	27.75	2.28	Breakage	15 years	0.01	0.13	0.50	0.03	0.03	0.04	0.07
		Test_02	6.26	6.53	Slippage	15 years	0.01	0.03	0.50	0.01	0.01	0.01	0.02

Scientific name	Common name	Test No.	Tensile stress (Mpa)	Mean Diameter (mm)	Remarks	Age	RAR	Root cohesion	Width of row	Average root cohesion in MPa for different spacing (m)			
			Tr	D				Cr (Mpa)	Ir	2.00	1.50	1.00	0.50
		Test_03	8.04	5.03	Slippage	15 years	0.01	0.04	0.50	0.01	0.01	0.01	0.02
Calliandra calothyrsus	-	Test_01	10.09	8.70	5		0.01	0.05	0.50	0.01	0.01	0.02	0.02
Artocarpus hetarophyllus	Kos	Test_01	3.38	12.28	Sliped		0.01	0.02	0.50	0.00	0.00	0.01	0.01
		Test_02	3.85	12.87	Sliped		0.01	0.02	0.50	0.00	0.00	0.01	0.01
		Test_03	6.33	12.68	Sliped		0.01	0.03	0.50	0.01	0.01	0.01	0.02
Eucaliptus grandis	-	Test_01	43.65	8.37	3		0.01	0.21	0.50	0.04	0.05	0.07	0.10
		Test_02	35.66	8.02	3.5		0.01	0.17	0.50	0.03	0.04	0.06	0.09
		Test_03	10.73	5.97	4		0.01	0.05	0.50	0.01	0.01	0.02	0.03
Grevillea banksii	Red silky oak, Dwarf silky oak	Test_01	13.41	8.72	Sliped		0.01	0.06	0.50	0.01	0.02	0.02	0.03
		Test_02	7.46	10.12	Sliped		0.01	0.04	0.50	0.01	0.01	0.01	0.02
		Test_03	8.12	9.70	Sliped		0.01	0.04	0.50	0.01	0.01	0.01	0.02
Bauhinia racemosa	Maila	Test_01	4.38	13.20	Sliped		0.01	0.02	0.50	0.00	0.01	0.01	0.01
		Test_02	11.06	6.79	11		0.01	0.05	0.50	0.01	0.01	0.02	0.03
		Test_03	9.73	5.12	12.5		0.01	0.05	0.50	0.01	0.01	0.02	0.02
		Test_04	27.73	10.05	Sliped		0.01	0.13	0.50	0.03	0.03	0.04	0.07

Scientific name	Common name	Test No.	Tensile stress (Mpa)	Mean Diameter (mm)	Remarks	Age	RAR	Root cohesion	Width of row	Average root cohesion in MPa for different spacing (m)			
			Tr	D				Cr (Mpa)	lr	2.00	1.50	1.00	0.50
Camellia sinensis	Tea	Test_01	2.12	13.43	Sliped		0.01	0.01	0.50	0.00	0.00	0.00	0.01
		Test_02	2.51	10.07	11		0.01	0.01	0.50	0.00	0.00	0.00	0.01
		Test_03	3.31	8.77	13		0.01	0.02	0.50	0.00	0.00	0.01	0.01
Azadirachta indica	Kohomba	Test_01	17.79	5.35	13.5		0.01	0.09	0.50	0.02	0.02	0.03	0.04
Clidermia hirta	Kata-kalu boowitiya	Test_01	9.63	5.14	11.5		0.01	0.05	0.50	0.01	0.01	0.02	0.02
Osbeckia sp.	Heen-boowitiya	Test_01	9.85	5.08	12		0.01	0.05	0.50	0.01	0.01	0.02	0.02
Lantana camara	Hinguru	Test_01	5.51	6.80	12		0.01	0.03	0.50	0.01	0.01	0.01	0.01
Coffea	Cofee	Test_01	18.86	9.00	Breakage		0.01	0.09	0.50	0.02	0.02	0.03	0.05
		Test_02	8.99	3.37	Slippage		0.01	0.04	0.50	0.01	0.01	0.01	0.02
		Test_03	6.42	3.15	Slippage		0.01	0.03	0.50	0.01	0.01	0.01	0.02
		Test_04	28.67	4.62	Breakage		0.01	0.14	0.50	0.03	0.03	0.05	0.07
		Test_05	14.69	2.63	Breakage		0.01	0.07	0.50	0.01	0.02	0.02	0.04
		Test_06	1.38	4.30	Breakage		0.01	0.01	0.50	0.00	0.00	0.00	0.00

CHAPTER FIVE: Results of geotechnical assessments conducted at the selected two pilot sites

4.1 Badulusirigama site in Badulla

5.1.1 Geological and Topographical features

Bedrock geology of the site constitutes of Quartzofeldspathic gneiss. Highly weathered rock and colluvium lies on top of bedrock. Colluvium layer has a depth of 9-13m. The area has a gentle valley type slope which ranges between 10-15 degrees (Nishikawa & Balasooriya, 2016).

5.1.2 Previous failure surfaces

JAICA team of investigation had identified three main failure surfaces at a maximum depth of 9-10m from the existing ground level (Figure 5.6). All three surfaces move along the interface between Colluvium Soil layer and Highly Weathered Rock layer. The proposed failure surfaces were supplemented with slope movement data which were extracted from the Site. (Nishikawa & Balasooriya, 2016) (Countermeasures for Badulusirigama-JAICA, 2015)

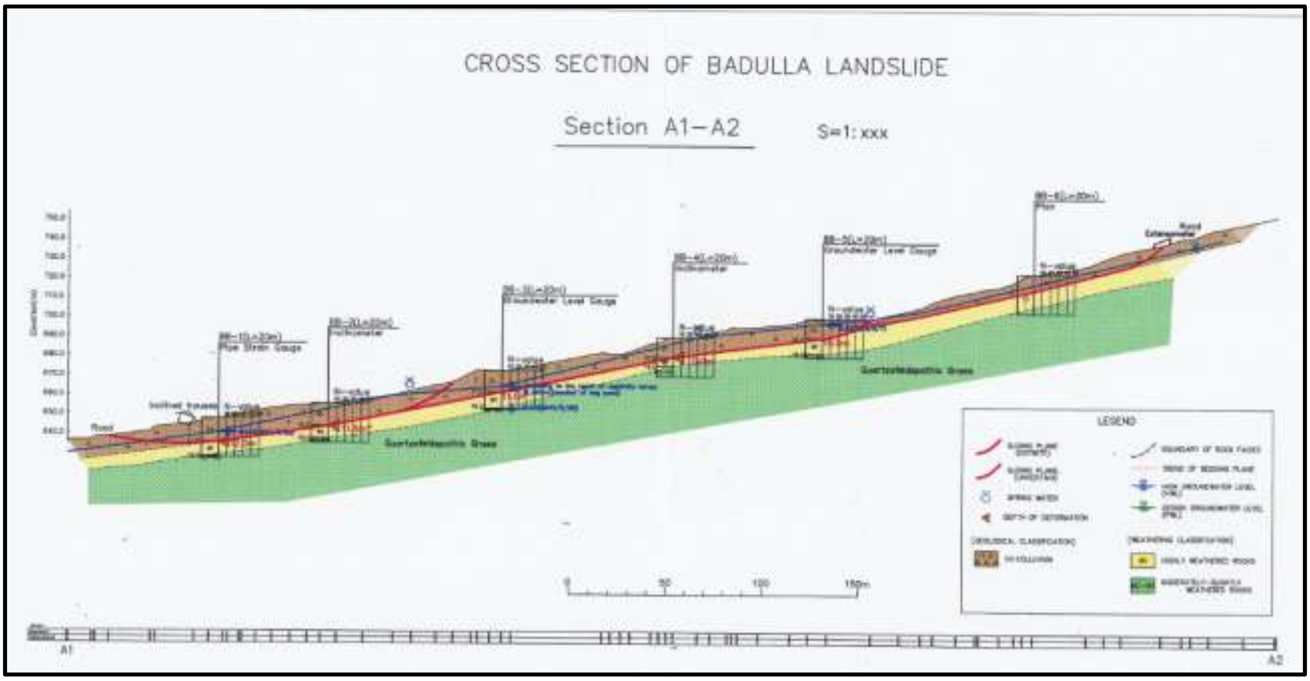


Figure 5.1: Cross section of Badulla Landslide along its main axis (Countermeasures for Badulusirigama-JAICA, 2015)

5.1.3 Review of slope monitoring data

Slope monitoring reports compiled by NBRO from December 2014 to April 2018 were reviewed to study the nature of slope movement. Data on slope activity were recorded from four types of different equipment, namely; 4 no. extensometers, 2 no. inclinometers, 1 no pipe strain guage, 3 no. groundwater level gauges.

The obtained data showed considerable activity during period up to the end of year 2015.1 A series of counter measures, which included a network of surface and subsurface drains, were constructed during the period from June 2016 to July 2017.

As per the report by NBRO, after the implementation of said countermeasures there has been a reduction in slope movement as indicated by data from extensometers, inclinometers and strain guage. Groundwater level has also been decreased. The standard average water level recorded in dry season has dropped approximately by 5m.

However at present, the site has areas with exposed bare soil formations and there is a potential for gullying in areas in between where surface drains have been built. *Panicum maximum* (a local invasive grass) bushes have grown up naturally and in an uncontrolled manner covering up a major portion of the site. There could be a risk of soil erosion occurring in some slope segments. This in turn could pose a threat to the population of 320 people living near the toe area of the landslide. Therefore, an engineered vegetation cover is of utmost importance in this site to minimize soil erosion and rainwater infiltration into the unstable soil mass.

5.1.4 Stability assessment

The conditions of the slope was simulated in Geo Studio modules considering both Finite Element and Limit Equilibrium approaches to check the possible shallow failures. Spencer method was adopted to calculate the factor of safety with a fully specified slip surface method. The shallow slip surface was assumed to be varied between 2.5 – 3.0 m which is typical for shallow landslides in Sri Lanka. This depth was selected based on previous experiences of NBRO and as well as considering the values reported in the literature.

The analysis was conducted under three cases;
1. Slope without any mitigation measures,
2. Modified slope with subsurface drains and
3. Modified slope with application of a hybrid system (Sub-surface drains + vegetation).

Information on the sub surface profile were extracted from the investigations done by JAICA team of investigation and the test results available at NBRO. Different strength properties assigned for each subsurface layer is summarized in table 5.1.

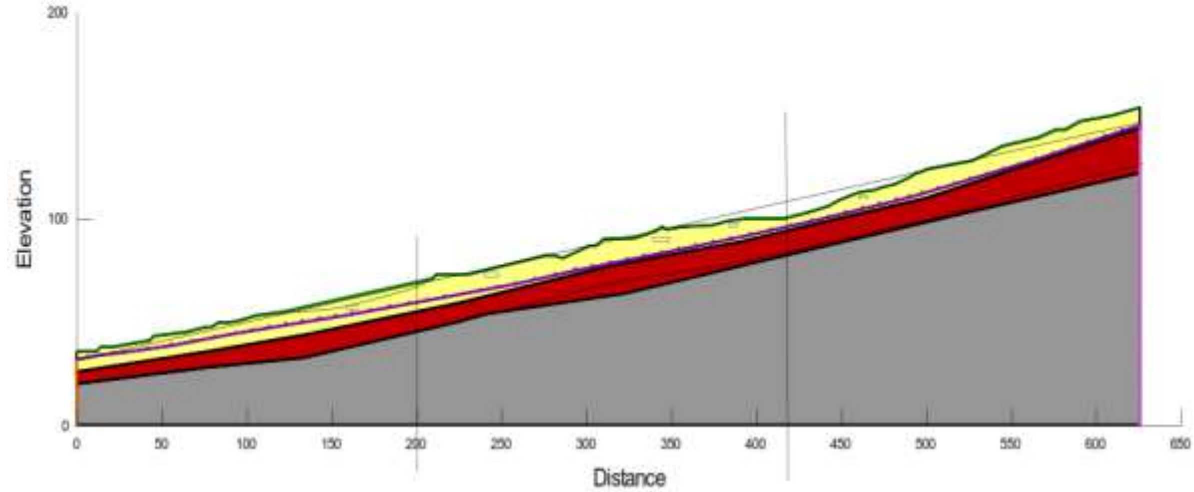


Figure 5.2: Idealized subsurface profile

Table 5.1: Geotechnical parameters assigned for each subsurface layer

Layer	Colour code	Cohesion (kPa)*	Phi (deg)*	Phi b (deg)**	Unit weight (kN/m^2)
Colluvium		7	12	10	15
Completely weathered rock (soil)		7	14	-	16
Mod. Weathered Rock		20	40	-	19

*Monitoring Report No. 08 Published by Jica and NBRO studies

**Kankanamge et.al (2018)

The subsurface profile shown in figure 5.3 was divided into three zones after studying the results of the geophysical investigations carried out by JAICA team of experts. Figure 5.3 shows the division of zones. In the stability analysis, each zone was modelled separately.

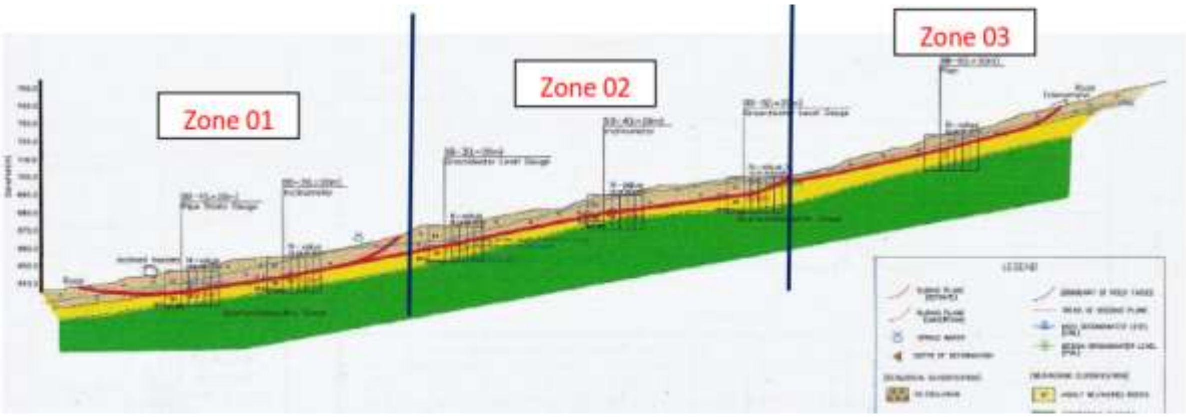


Figure 5.3: Division of three zones for stability analysis

The slip surfaces for respective zones were assumed to be at a depth of around 3m to 5 m.

Results and Discussion

Case 1: Slope without any mitigation measures

Table 5.2: Factor of safety of different zones when there are no mitigation measures

Zone	FoS under existing conditions
01	1.001
02	0.959
03	0.913

From the stability analysis conducted, it is evident that the Zone 03 has the lowest safety margin indicated by a factor of safety value of less than one. The safety criteria of the other two zones are also not satisfactory as the FoS value is slightly greater than one which is not acceptable. Therefore, appropriate mitigation measures need to be applied in order to improve the safety margins of the entire slope.

Case 2: Modified slope with subsurface drains

Under this case, the slope was analyzed by introducing subsurface drains drilled at different levels and having length of approximately between 30- 40 m. The angle of inclination of these drains are maintained between 6 degrees and 9 degrees with respect to the horizontal.

The new safety margins of the slope and the percentage increase of the FoS are summarized in the Table 5.3.

Table 5.3: Factor of safety improvement after drainage improvement

Zone`	FoS before drainage improvement	FoS after drainage improvement	Percentage increase of FoS
01	1.001	1.180	17.9
02	0.959	1.137	18.6
03	0.913	1.140	24.9

Table 5.3 indicates that stability has increased upon the introduction of subsurface drainages. The highest increase of factor of safety is on zone 3.

Case 3: Modified slope with hybrid solutions (Subsurface drainage + vegetation)

The effect of vegetation was incorporated to slope stability by calculating soil cohesion due to presence of roots which is defined as root cohesion. This value was treated as an additional cohesion provided to the soil layers.

<u>Calculation of root cohesion and its variation due to different spacing patterns</u>

Step 1:
The following formula was used to calculate the tensile strength:

$$T_r = \frac{F_{max}}{\pi\left(\frac{D^2}{4}\right)}$$

where F_{max} is the maximum force (N) needed to break the root and D is the mean root diameter (mm) before the break.

Step 2:
Root cohesion which is needed for design and analysis of the stability of slopes was obtained from the formula given. It was obtained from the study carried out by Schwarz et al. (2010);

$$Cr = 0.48 * Tr * (RAR)$$

$$\mathrm{RAR} = \frac{A_r}{A} = \frac{\sum_{i=1}^{n} \pi d_i^2/4}{A}$$

d – diameter of the root
A – effective soil cross section area

This increment in cohesion value is used in stability assessments to evaluate the vegetation effect and was applied in function of the plants' root zone.

Step 3:
As the next step, an average value of root cohesion for the entire slope, $\bar{c}_r$ was calculated considering the spacing between each plant row as suggested by Mahannopkul & Jotisankasa (2019). They have applied the formula for testing vetiver plants:

$$\bar{c}_r = \frac{c_r l_r}{l_r + l_s}$$

l_r – width of the plant row
l_s – spacing between each plant row (width of the non-reinforced zone)

For this pilot analysis, Eugenia caryophyllus species which is commonly known as Clove was used. Its properties were given in the table below.

Table 5.4: Properties of the Clove root

Crop name	Scientific name	Age (yrs)	Average root cohesion (MPa) for different spacing (m)			
			2.0	1.5	1.0	0.5
Clove	Eugenia caryophyllus	20	0.038	0.048	0.064	0.096

The shear strength parameters of Colluvium soil layer was adjusted accordingly due to presence of Clove roots. The amended values are given in table 5.5.

Table 5.5: Revised geotechnical parameters upon application of vegetation (Clove)

Layer	Colour code	Cohesion (kPa)	Phi (deg)	Phi b (deg)*	Unit weight (kN/m^2)
Colluvium after vegetation		22	12	10	15
Colluvium		7	12	10	15
Completely weathered rock (soil)		7	14	-	16
Mod. Weathered Rock		20	40	-	19

The soil layer "Colluvium after vegetation" was created by considering the average root depth zone of Cloves which is around 2m to 3m. The variation of factor of safety upon introduction of subsurface drainages and vegetation (hybrid solution) is given in table 5.6.

Table 5.6: Variation of factor of safety after applying subsurface drainages with vegetation (Hybrid solution)

Zone`	FoS before drainage improvement	FoS after drainage improvement	FoS after drainage improvement and applying vegetation	Percentage increase of FoS after applying the hybrid solution
01	1.001	1.180	1.464	46.3
01 (with surcharge)	1.001	-	1.760	75.8
02	0.959	1.137	1.261	31.5
03	0.913	1.140	1.367	49.7

This analysis shows that the factor of safety values could be increased by introducing vegetation coupled with subsurface drainages.

However, it is to be noted that in this pilot study an approach is proposed to quantify the effects of vegetation on the slope stability. Geotechnical values related to soil cohesion used above are based on assumptions. Further investigations needs to be carried out in order to achieve a better characterization of the contribution of plant roots in increasing soil cohesion.

5.2 Galabada site in Ratnapura

5.2.1 Geological and Topographical features

The top soil layer is made up of dark brown, yellowish brown and light brown clay with fine to coarse sand. Its thickness ranges from 0.9 m to 1.3 m below the existing ground level. Next layer consists of completely weathered rock which includes yellowish brown clay with coarse to fine sand and some mica. Weathered rock layer is continued up to 30 m of depth from the existing ground level. Borehole drilling has been stopped at 30 m of depth and bed rock has not been encountered (Investigation at Galabada Landslide - JAICA, 2018). The borehole locations are shown in Figure 3.6.

The area has a gentle slope which ranges from 10-12 degrees.

5.2.2 Failure surfaces

JICA team of investigation had identified two blocks of unstable soil masses (Figure 5.17).

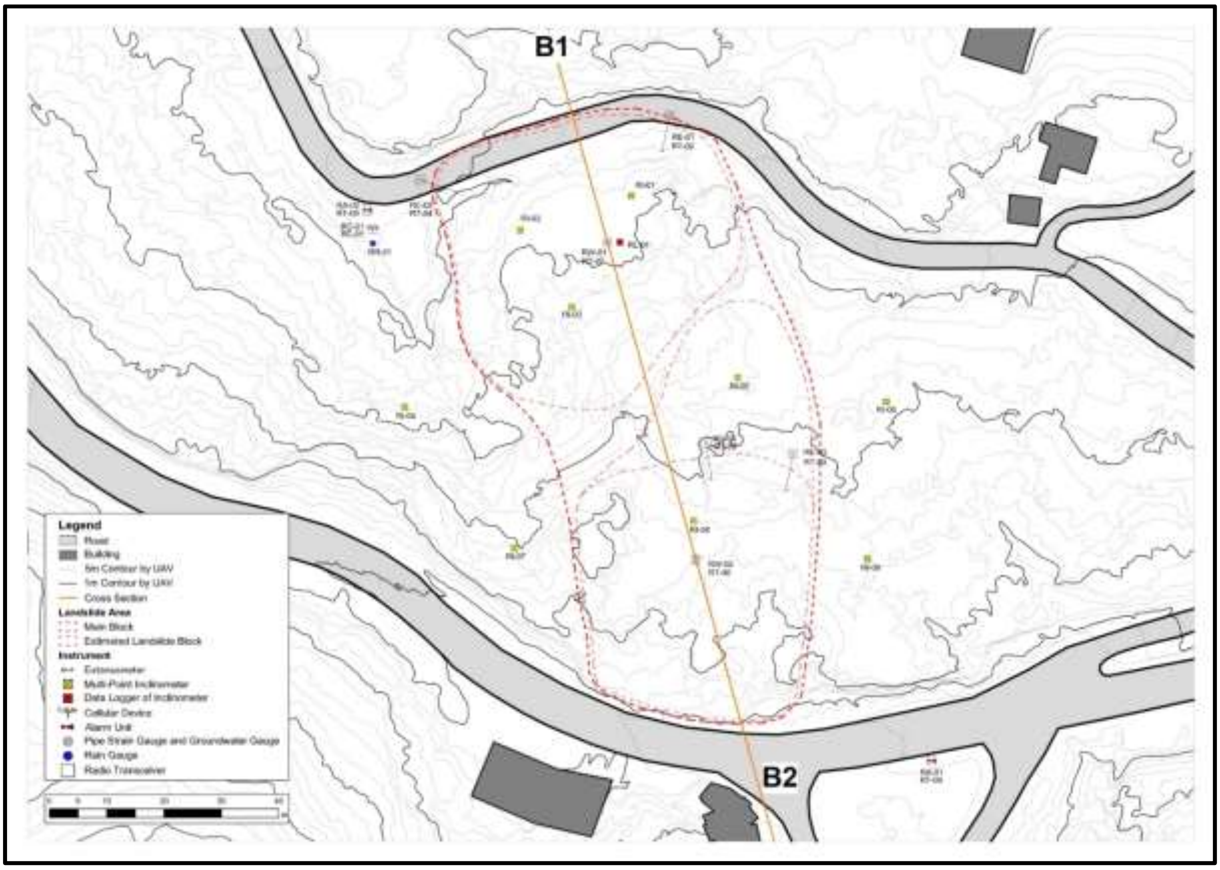


Figure 5.4: Spatial distribution of possible failure plains in plan view. Red thick dotted line presents the main landslide block. Red thin line represents estimated subdivisions of the main block. (Investigation at Galabada Landslide - JAICA, 2018)

5.2.3 Review of slope monitoring data

National Building Research Organization (NBRO) in collabaration with OSASI Technos Inc based in Japan have set up a landslide monitoring system at site. The system includes extensometers, strain guages, water level meters and a rain guage. It also includes a siren device to alert the community in the event of a failure. The data has been recorded by instruments since December 2018.

As per the data recorded in the two strain guages (upslope & downslope), it is understood that the failure plane is at a depth around 10m in the upslope area and 4-5m in the down slope area. This information was used in the stability analysis carried out for this site.

5.2.4 Stability assessment

A stability analysis was carried out using Spencer method and assuming the sub surface profile indicated in figure 5.4.

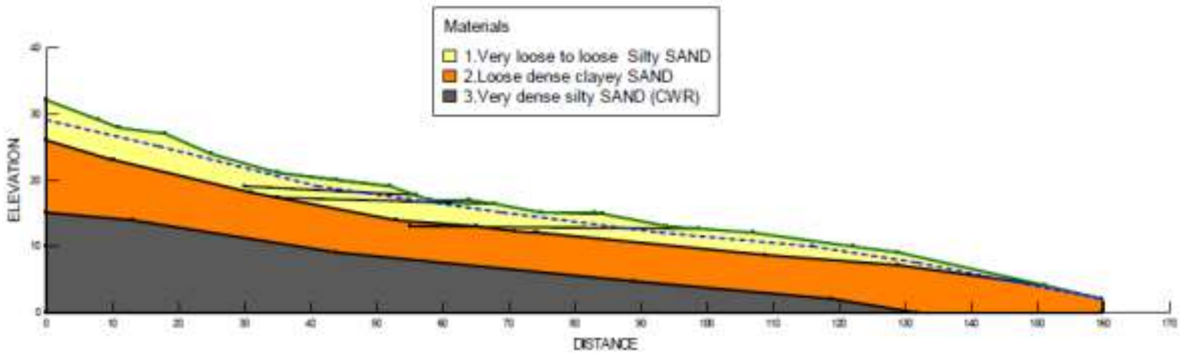


Figure 5.4: Subsurface profile of the slope. Galabada in Ratnapura

The slope was analyzed by assuming the presence of three layers as indicated in Table 5.7.

Table 5.7: Geotechnical parameters of different layers

Layer	Cohesion (kPa)	Friction angle (°)
1. Very loose to loose silty SAND	1	20
2. Medium dense clayey SAND	2	21
3. Very dense silty SAND (CWR)	10	35

The stability margin of the slope, under existing conditions and without any mitigation measures is indicated in Figure 5.5.

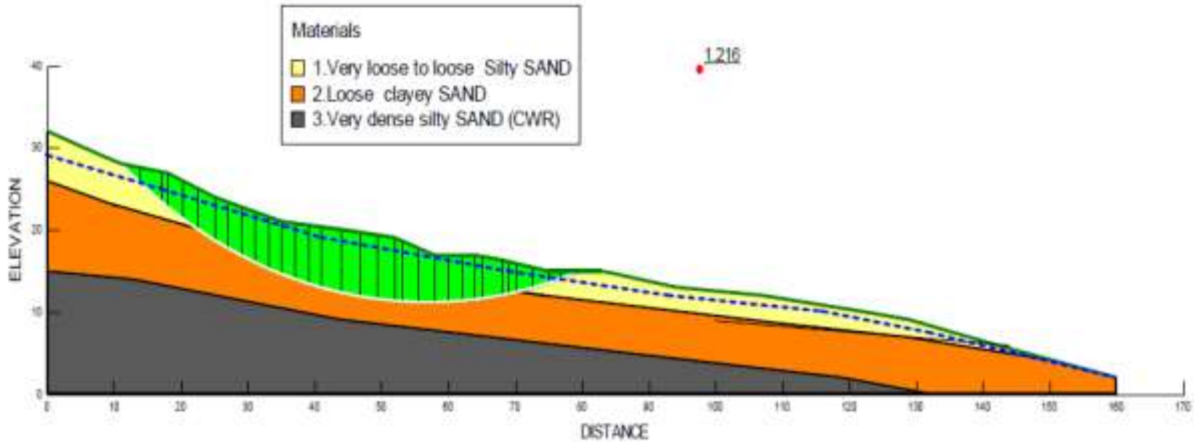


Figure 5.5: Stability condition of the existing slope

The failure plane is at a depth of around 9 – 10.0 m, which indicates the failure is of deep seated type. The current computed factor of safety is around 1.2. This analysis more or less simulate the existing slope conditions, as per the monitoring data and general observations made during site inspections.

Introduction of subsurface drainage *(Engineering measure to increase the current factor of safety)*

A subsurface drain was introduced to lower the water table. The location and the length of the drain was selected based on the information on seepage conditions of the site.

The stability conditions after the introduction of the subsurface drain is presented in figure 5.6.

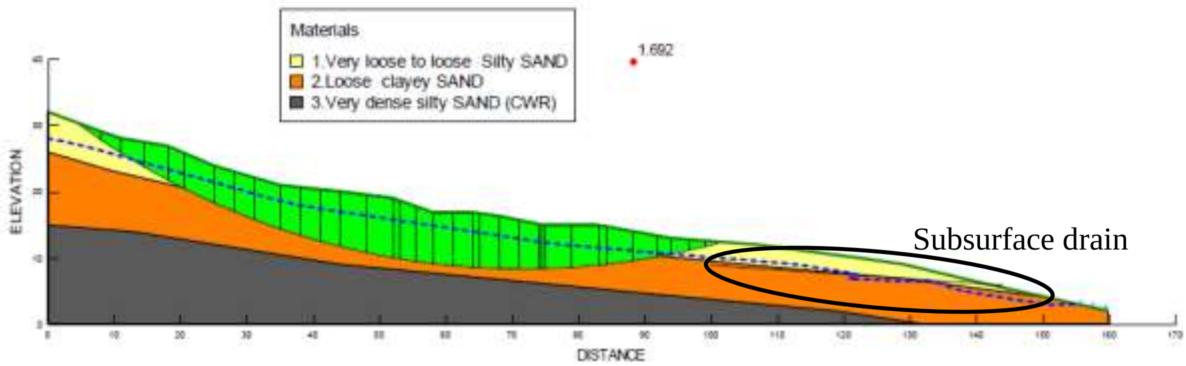


Figure 5.6: Stability conditions after the introduction of the subsurface drain

The factor of safety has been increased to a value of 1.692 which was around 1.216 previously. But still the critical failure surface is deep seated. However, it can be decided that subsurface and surface drainage improvement will be a good measure to rectify this deep seated slide.

Application of bio – engineering measures

During site inspections, it was observed that the landslide area is prone to water logging. In addition, surface erosion was a critical concern that must be addressed in terms of proper means. Washing out of surface soil in fallow areas of the body of the landslide was observed. Accumulation of water at relatively low level areas of the soil mass also leads to slope instabilities by increasing the weight of the sliding mass, as well as increasing the pore water pressures through infiltration.

In this context, plant species which have higher rates of evapotranspiration capacities can be introduced in water logging areas as they can remove water from soil at comparatively higher rates. Grasses or small shrubs like species can be planted to control the surface erosion. This type of vegetation would help to keep the soil particles intact.

Further tress such as “Kumbuk” could be introduced along the toe area of the slope, as they will serve as a toe support in the long term.

CHAPTER SIX: Draft Landslide Risk Management Plan for the Badulusirigama site in Badulla

6.1 Introduction

The landslide area was divided into three zones considering its morphology. They are upper section (zone 1), middle section (zone 2) and lower section (zone 3). The proposed plan is developed accordingly, focusing on the individual characteristics of these zones. Each zone is assigned a separate theme.

6.2 Description of the proposed plan

Zone 1 – GRASSLAND:
This is the upper most area of the landslide. The delineated zone has an approximate area of 1.45 hectares. It is proposed to have a "Grassland" on this zone considering that the crown area should be loaded lightly while minimizing the soil erosion. Proposed grass types are presented in Table 6.2.

Zone 2 – BOTANICAL GARDEN:
Area under zone 2 is the middle part of the landslide and has an approximate area of 1.55 hectares. This zone being a close proximity to the Uva Wellassa University lecture halls and labs, can make it easy accessible by the university students and staff. Hence, it is proposed to have a botanical garden with native and exotic species that would enrich the plant biodiversity. University academics and students can make use of this space to spend their leisure time or even to carry out research and development activities.

Zone 3 – COMMUNITY INTEGRATION AREA/ KANDYAN HOME GARDEN:
This zone consists of the lower section of the landslide. It has an approximate area of 1.40 hectares. The area lies close to Badulusirigama village which is located in the downslope area of the landslide. This zone will be more attractive if it can be used as a Kandyan Home Garden which is a Sri Lankan traditional system of perennial cropping with the help of the community living in the downslope which in turn could support their socio-economic needs.

Figure 6.1 shows the proposed preliminary zonation plan.

6.3 Measures to be undertaken before the implementation of the plan

Prior to the implementation of the proposed plan above, following shall be carried out in the earlier stage;

- Carry out a GPR survey to find the thickness of soil in areas where horizontal surface drainage pipes has been inserted into the ground. This data will be beneficial when determining the exact locations for the identified tree and grass species with in the zones described above hence the obstruction of drainage pipes due to root systems can be avoided.

- Carry out a testing campaign to determine the current nutrient levels (at least 10 samples evenly distributed around the site). This will help quantify the additional nutrient level which needs to be supplied externally.

Figure 6.1: Preliminary zonation plan with descriptions

Figure 6.2 shows the layout of the existing surface and subsurface drainage network overlaid on the proposed zonation map. Figure 6.3 shows the elevation profile across the section A’-A covering the three zones.

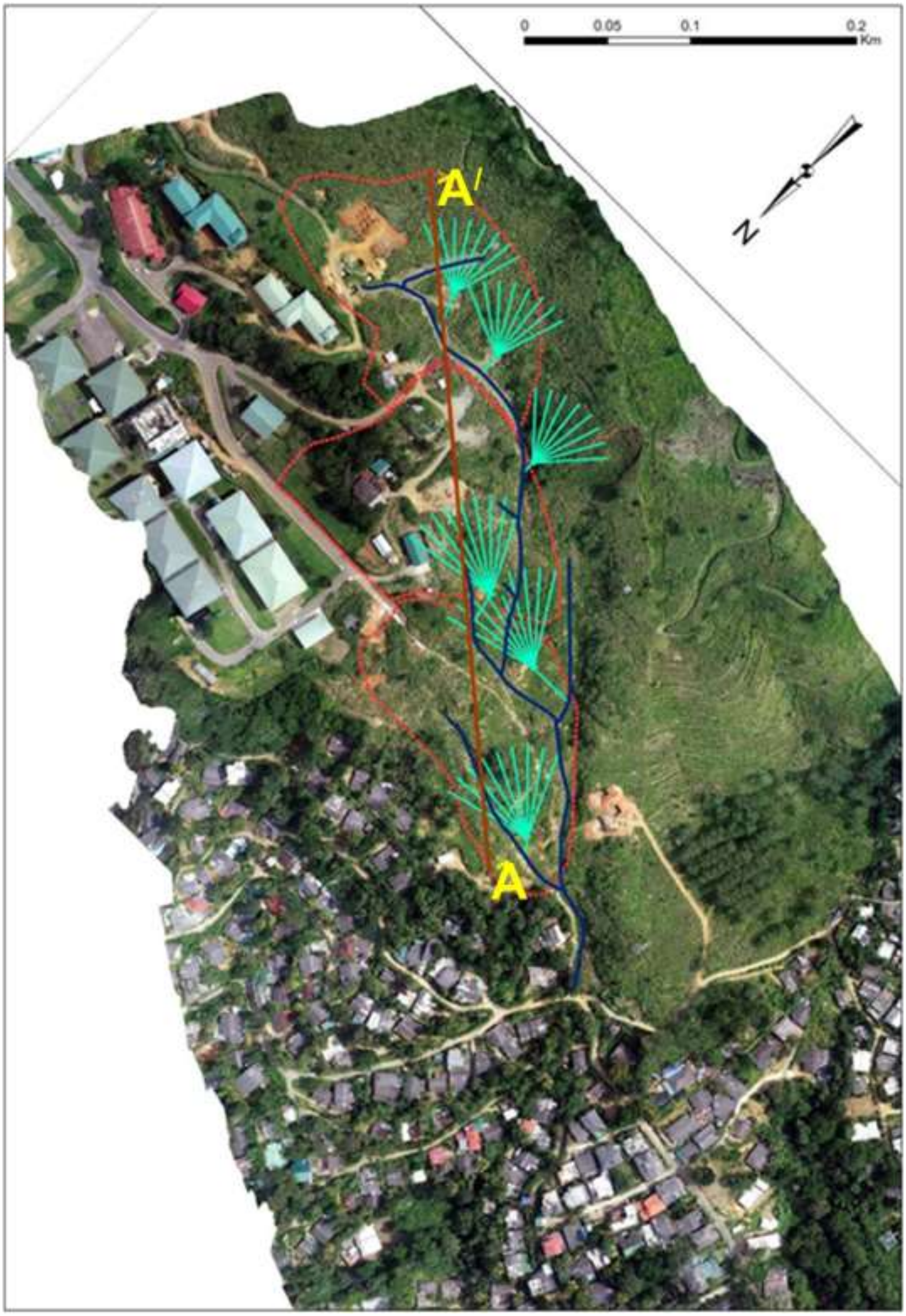


Figure 6.2: Layout plan of the existing surface and subsurface drainage network (marked in dark blue and cyan) overlaid on the proposed zonation map

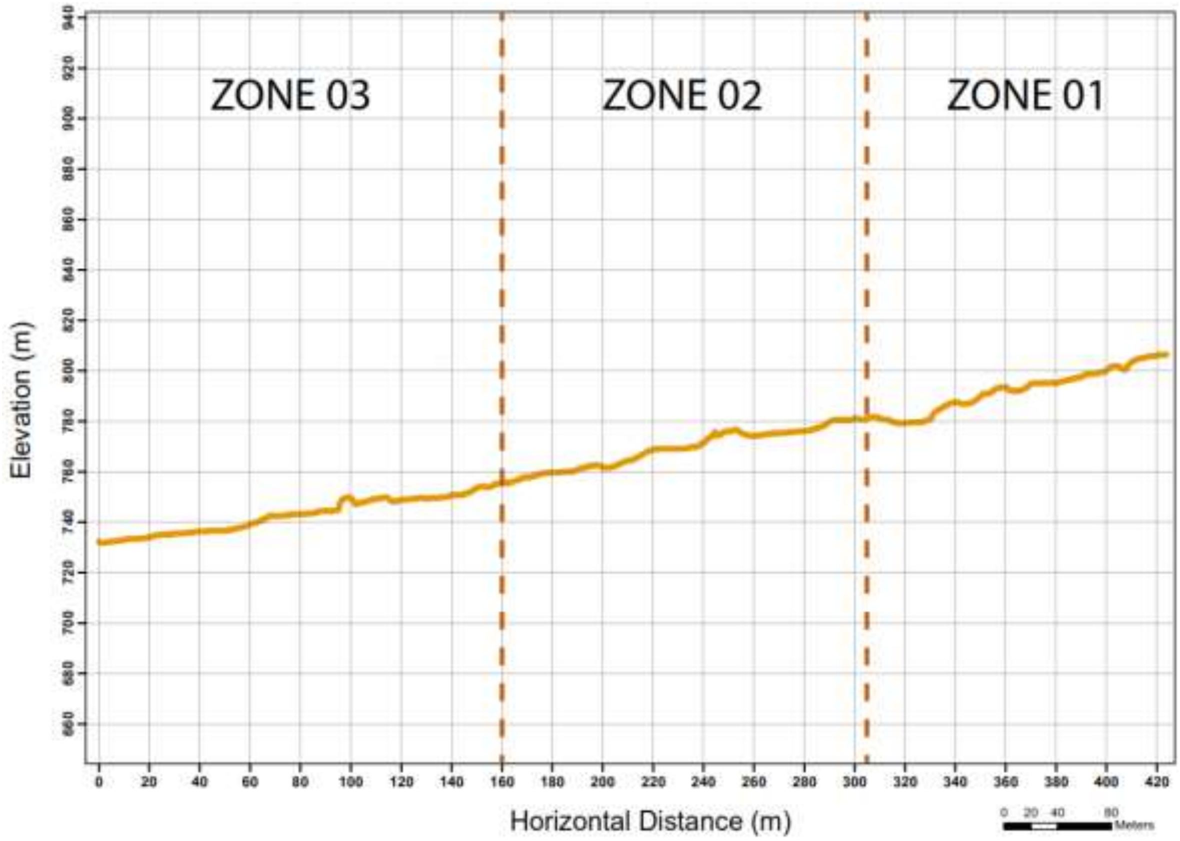


Figure 6.3: Elevation profile along the line A-A' indicated on figure 6.2

An average gradient for each of the three zones were calculated based on the above elevation profile and is given on table 1.

Table 6.1: Average gradients of each zone

Zone No	Average gradient in degrees
Zone 1	15.5°
Zone 2	10.3°
Zone 3	7.13°

The next epigraphs describe in detail the proposed plan for each zone with appropriate candidate plants. In addition, the table presents the strengths (pros) and weaknesses (cons) observed under each zone at present conditions.

6.4 Details of the proposed plan to be implemented under zone 1

Observations		Candidate plants	Proposed configuration	Anticipated benefit
Pros	**Cons**	**Scientific name (Common Name)**		
Direct exposure to sunlight	Low soil fertility Low moisture in soil Propagation of invasive species	Chrysopogon nardus (Citronella grass) Cymbopogon citratus (Lemmon grass) Chrysopogon zizanioides (Vetiver grass)	Species shall be planted following contour lines. Internal surface cascade drains shall be provided following natural (seasonal) drainage paths. These cascade drains can be used as footpaths in moving within the proposed plantation of grasses.	Production of citrus/palm oil from the harvested grasses. (Time duration for one harvest level is around 18 months) Can be managed by Department of Export Agriculture of the University

Candidate plants for Zone 1

Candidate plant	Photo	Hydrological significance	Root characteristics	Ecological significance	Economic value
Chrysopogon nardus (Citronella grass)		Low to moderate evapotranspiration	Dense fibrous root penetrate to moderate depth	Native grass for erosion control and soil improvement	Essential oil
Cymbopogon citratus (Lemmon grass)		Low to moderate evapotranspiration	Dense fibrous root penetrate to moderate depth	Introduced grass for erosion control and soil improvement	Essential oil

Chrysopogon zizanioides (Vetiver grass)		Moderate evapotranspiration	Dense fibrous root penetrate to deep	Grass for erosion control and soil improvement	Essential oil

6.5 Details of the proposed plan to be implemented under zone 2

Observations		Candidate plants	Proposed configuration	Anticipated benefit
Pros	**Cons**	**Scientific name (Common Name)**		
Availability of spring water Easy possibility to observe beautiful mountain ranges and scenic beauty	Low soil fertility Propagation of invasive species Unauthorized people tapping spring water from drainage pipes obstructing its free flow	Macaranga peltata (Kanda) Trema orientalis (Gadumba) Wendlandia bicuspidata (Rawana Idala) Murraya paniculata (Etteriya) Michelia champaca (Ginisapu) Brachiaria mutica (Buffalo grass)	Tress shall be planted as clusters so as to make shaded areas. Footpaths and benches will be constructed with lightweight construction materials.	University academics and students can make use of this space to spend their leisure time or even to carry out R&D activities.

Candidate plants for Zone 2

Candidate plant	Photo	Hydrological significance	Root strength characteristics	Ecological significance	Economic value
Macaranga peltata (Kanda)		High evapotranspiration	Taproot system up to 2m. VH type roots. *(Tensile strength values: 11.30MPa, 10.52MPa)*	Native forest species in secondary forest, pioneer.	Low value timber or fuel wood.
Trema orientalis (Gadumba)		High evapotranspiration	Taproot system up to 2m. VH type roots. *(Tensile strength values: 12.48MPa, 10.35MPa)*	Native forest species in secondary forest, pioneer.	Low value timber or fuel wood.
Wendlandia bicuspidata (Rawana Idala)		Low to moderate evapotranspiration	Tap root system up to 2m.	Native forest species in secondary forest, pioneer.	Forest species

Candidate plant	**Photo**	**Hydrological significance**	**Root strength characteristics**	**Ecological significance**	**Economic value**
Murraya paniculata (Etteriya)		Good evaporator	Taproot system up to 1.0m; H type roots.	Native tree, not a pioneer species.	
Michelia champaca (Ginisapu)		High evapotranspiration	Taproot system up to 2.0m; VH type roots	Introduced as a timber and shade tree neutralized	High value timber tree
Brachiaria mutica (Buffalo grass)		Ground cover			

6.6 Details of the proposed plan to be implemented under zone 3

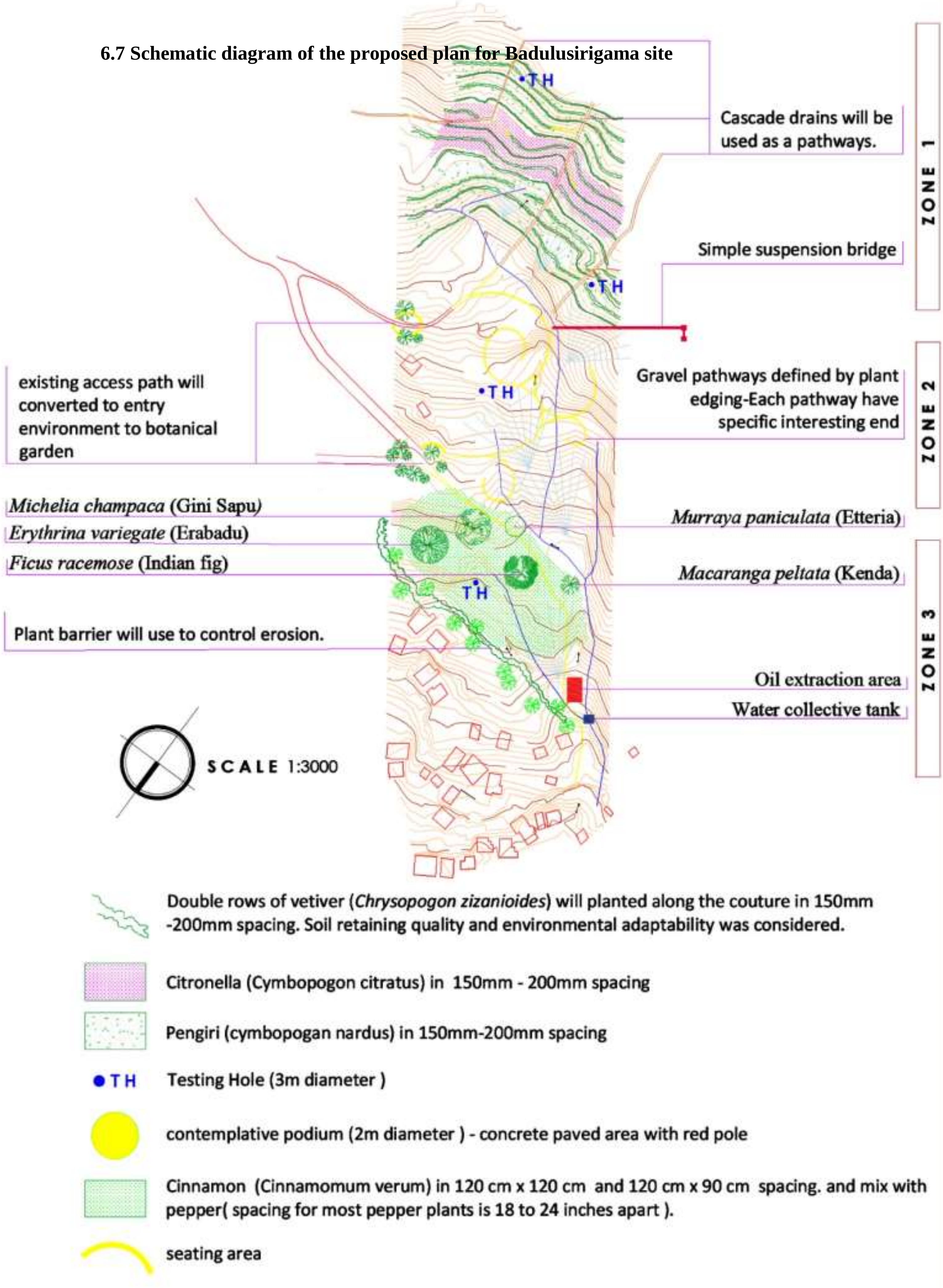
Observations		Candidate plants	Proposed configuration	Anticipated benefit
Pros	**Cons**	**Scientific name (Common Name)**		
Availability of spring water Close proximity to Badulusirigama village	Low soil fertility Propagation of invasive species	Eugenia caryophyllus (Clove) Cinnamomum verum (Cinnamoum) Gliricidia sepium (Gliricidia) for growing Piper nigrum (Pepper) Brachiaria mutica (Buffalo grass)	Species shall be planted following contour lines. Internal surface cascade drains shall be provided following natural (seasonal) drainage paths. These cascade drains can be used as footpaths Community living downslope will be involved in this activity in consultation with university authorities.	Harvests from these economic crops can generate a secondary income for the villagers.

Candidate plants for Zone 3

Candidate plant	Photo	Hydrological significance	Root strength characteristics	Ecological significance	Economic value
Eugenia caryophyllus (Clove)		High evapotranspiration	Taproot system up to 2m. VH type roots. *(Tensile strength values: 40.90MPa)*	Native forest species in secondary forest, pioneer.	Low value timber or fuel wood.
Cinnamomum verum (Cinnamoum)		High evapotranspiration	Taproot system up to 2m. VH type roots. *(Tensile strength values: 22.87MPa, 23.01MPa, 22.19MPa)*	Native forest species in secondary forest, pioneer.	Low value timber or fuel wood.
Gliricidia sepium (Gliricidia)		High evapotranspiration	Taproot system upto 2.0m. VH type roots.	Introduced and neutralized as an agricultural crop	Multipurpose (fodder, firewood, shade, fencing)

Brachiaria mutica (Buffalo grass)		Ground cover			

6.7 Schematic diagram of the proposed plan for Badulusirigama site



Notes

ZONE 1

- No vehicle access to the site
- Soil improving method will be determined after conducting nutrition tests
- Minimum ground modification
- Rhythmic motion of the plants will create the contemplative feeling among visitors

ZONE 2

- Slight ground shaping will be conducted to arrange plant beds.to manage high level of diversity edible plants and flowering plants will be used to attract fauna.
- Seating will be provided for small group gathering.
- Space is not allocated for night time functioning. Lighting will be provided for security reasons only
- Soil depth must be calculated before introducing plants to prevent damage to sub surface drains

ZONE 3

- Mainly cloves and cinnamon are proposed to give benefits to a group of selected villagers.
- Access given from village.

6.8 Draft Work Plan

Work Plan is divided into three segments;

1. Measures to be undertaken before the implementation of the plan;
2. Civil and bio engineering works;
3. Monitoring, inspection and maintenance.

6.8.1. Measures to be undertaken before the implementation of the plan

No.	Task name
1	**GPR survey to establish soil thickness at selected locations**
	Determining the required GPR survey lines
	Carrying out of GPR survey
	Analysis and presentation of report on soil thickness
2	**Soil nutrient level checks**
	Determining the sampling points
	Obtaining of required samples
	Carrying out of soil nutrient laboratory checks
	Analysis and presentation of report on present nutrient levels
	Determination of additional nutrition amounts to be added

6.8.2. Civil and bio engineering work

No.	Task name
1	**Site preparations**
	• Slope clearance and trimming operations
	• Retention of selected tree species, trimming if necessary, providing cover and support
2	**Plant nursery development and maintenance**
	• Nursery establishment
	• Construction of Nursery beds
	• Nursery production of selected grass types
	• Nursery production of trees and shrubs in poly-bags and poly-pots
	• Nursery production of hardwood plants
	• Compost and mulch production
	• Extraction of plants from Nursery and planting at site
3	**Civil engineering work**
	• Allow lump sum for pegging out of boundaries, footpaths, other alignments, location of plant species etc. using appropriate surveying equipment, including minor re-adjustment on site if necessary
	• Excavation and backfill to improve slope shapes in a few places and to make open storm water drainage ditches leading to natural drainage lines or planned drainage outlets (exact patches & strips to be decided on site)
	• Construction of Irrigation & water supply lines
	• Construction of 1.2m wide, gravel footpaths, using gravel existing at site, as per drawing and instructions on site
	• Construction of plastered brick masonry seating or Supply and installation of ready-made cement seating structures
	• Installation of outdoor LED lighting fixtures supplied by TT, including supply & laying of cabling
4	**Bio-engineering work**
	• Soil Filling, leveling and compaction where necessary (not more than 50% compaction in planting areas)
	• Supply and laying of topsoil as necessary in lawn and planting areas
	• Planting of Vetiver, Citronella and lemon grass including soil improvement as required for healthy growth.

	• Planting of small to medium tree species including soil improvement as required for healthy growth; Rate will increase or decrease according to size of tree
	• Supply and laying of ground cover grass including soil improvement as required for plant growth

6.8.3 Monitoring Inspection and Maintenance

Parameters to be monitored:
Daily precipitation
Ground water level
Soil suction levels
Moisture levels
Slope movement

Set of instrumentation:
Rain guage
Standpipe/ Water level meter
Suction sensor/ tensiometer
Moisture sensor
Strain guage

Monitoring Plan:

Data shall be obtained from two locations, namely, locations with nature based solutions and locations with out. This is for the purpose of comparing the two sets of data in order to assess the improvements gained from implementing nature based solutions. Testing holes indicated in the schematic diagram are used to set up the instrumentation devices.

Suction sensor/ tensiometer and moisture sensor shall be installed at different depth levels considering the depth of plant roots zone. Suggested depth levels for each zone are;
Zone 1: 0.5m and 1m
Zone 2: 1m and 2m
Zone 3: 1m and 2m

Strain guages shall be installed at a depth between 1.5m to 2m in order to monitor the shallow slope movement in each of the three zones.

Further it is better to monitor the discharge rate of water from subsurface drainage outlets regularly in order to see any disturbances to its flow.

Monitoring Sequence:

Hourly measurements of precipitation
Daily measurements from suction sensor/ tensiometer and moisture sensors

Groundwater level shall be monitored daily during rainy seasons and once a week during dry periods.

Analysis of Acquired data:

Data from monitoring instruments shall be analyzed once a month or every after fifteen days to assess the effectiveness of nature based solutions.

Inspection and maintenance

No.	Task name
1	**1 year's full maintenance during the Defects Liability Period**
	Allow for all labour, plant materials, equipment and necessary fertilizers and all costs and expenses in connection with maintenance during the Defects Liability Period, for a period of 12 months commencing upon the issuance of Engineer's Completion Certificate. There shall be an experienced chief gardener and another skilled gardener full-time on 7 days per week to ensure satisfactory maintenance.

6.9 Preliminary Budget

	Task	Sub-tasks	Unit	Rate	Quantity	Cost(SLR)
1.	Site preparations	• Slope clearance and trimming operations	Sqr	810.00	6,370	5,159,700
		• Retention of selected tree species, trimming if necessary, providing cover and support	Sqr	2,230.00	2,120	4,727,600
2.	Civil engineering work	• Allow lump sum for pegging out of boundaries, footpaths, other alignments, location of plant species etc. using appropriate surveying equipment, including minor re-adjustment on site if necessary	LS			400,000
		• Excavation and backfill to improve slope shapes in a few places and to make open storm water drainage ditches leading to natural drainage lines or planned drainage outlets (exact patches & strips to be decided on site)	M3	500.00	1,500	750,000
		• Construction of Irrigation & water supply lines	M	900.00	2,000	1,800,000
		• Construction of 1.2m wide, gravel footpaths, using gravel existing at site, as per drawing and instructions on site	M2	4,000.00	1,200	4,800,000
		• Construction of plastered brick masonry seating or Supply and installation of ready-made cement seating structures	Ft	800.00	30	24,000
		• Installation of outdoor LED lighting fixtures supplied by TT, including supply & laying of cabling	LS			1,500,000
3.	Bio-engineering work	• Soil Filling, leveling and compaction where necessary (not more than 50% compaction in planting areas)	M3	2,000.00	100	200,000
		• Supply and laying of topsoil as necessary in lawn and planting areas	M3	4,500.00	100	450,000
		• Planting of Vetiver, Citronella and lemon grass including soil improvement as required for healthy growth.	No	500.00	750	300,000
		• Planting of small to medium tree species including soil improvement as required for healthy growth; Rate will increase or decrease according to size of tree	No	10,000.00	20	200,000
		• Supply and laying of ground cover grass including soil improvement as required for plant growth	M2	1,000.00	15,000	15,000,000
		• Nursery establishment	PS			

4.	Plant nursery development and maintenance	• Construction of Nursery beds				
		• Nursery production of selected grass types				
		• Nursery production of trees and shrubs in poly-bags and poly-pots				1,000,000
		• Nursery production of hardwood plants				
		• Compost and mulch production				
		• Extraction of plants from Nursery and transportation				
5.	Post execution inspection and maintenance	**1 year's full maintenance during the Defects Liability Period** Allow for all labour, plant materials, equipment and necessary fertilizers and all costs and expenses in connection with maintenance during the Defects Liability Period, for a period of 12 months commencing upon the issuance of Engineer's Completion Certificate. There shall be an experienced chief gardener and another skilled gardener full-time on 7 days per week to ensure satisfactory maintenance.	Month	250,000.00	12	3,000,000
6.	Monitoring and Instrumentation	• Automatic rain guage	No	75,000.00	1	75,000
		• Stand pipe	No	50,000.00	3	150,000
		• Strain guage	No.	45.000.00	6	270,000
		• Suction sensors/Tensiometer	No.	300,000.00	6	1,800,000
		• Moisture sensor	No.	35,000.00	6	210,000
		• Installation of sensors	LS			1,000,000
		• Monitoring for one year period	LS			400,000.00
	Sub Total					43,216,300
	Contingencies (15%)					6,482,445
	Total excluding taxes					49,698,745

	Task	Sub-tasks	Unit	Rate	Quantity	Cost(SLR)
1.	Remunerations for supervisory staff	• Civil engineers	m/m	225,000.00	12	2,700,000
		• Geotechnical engineer/ engineering geologists	m/m	225,000.00	12	2,700,000
		• Agricultural engineers	m/m	225,000.00	8	1,800,000
		• Agronomists	m/m	175,000.00	8	1,400,000
		• Botanists	m/m	175,000.00	8	1,400,000
		• Landscape architects	m/m	200,000.00	5	1,000,000
		• Technical officer	m/m	140,000.00	12	1,680,000
		• Work supervisor	m/m	75,000.00	12	900,000
	Total					13,580,000

CHAPTER SEVEN: Draft Landslide Risk Management Plan for Galabada site in Ratnapura

7.1 Introduction

The site is located in Ratnapura district belonging to Galabada Grama Niladhari Division. The land forms a part of Galabada Estate and is owned by Hapugasthenna Plantation Company of Finlay Group.

7.2 Description of the proposed plan

The landslide area is divided into three zones considering its morphology. The upslope area being the crown of the landslide is delineated as zone 1. The zone between the two roads are assigned as the zone 2. The down slope part of the landslide area is designated as zone 3.

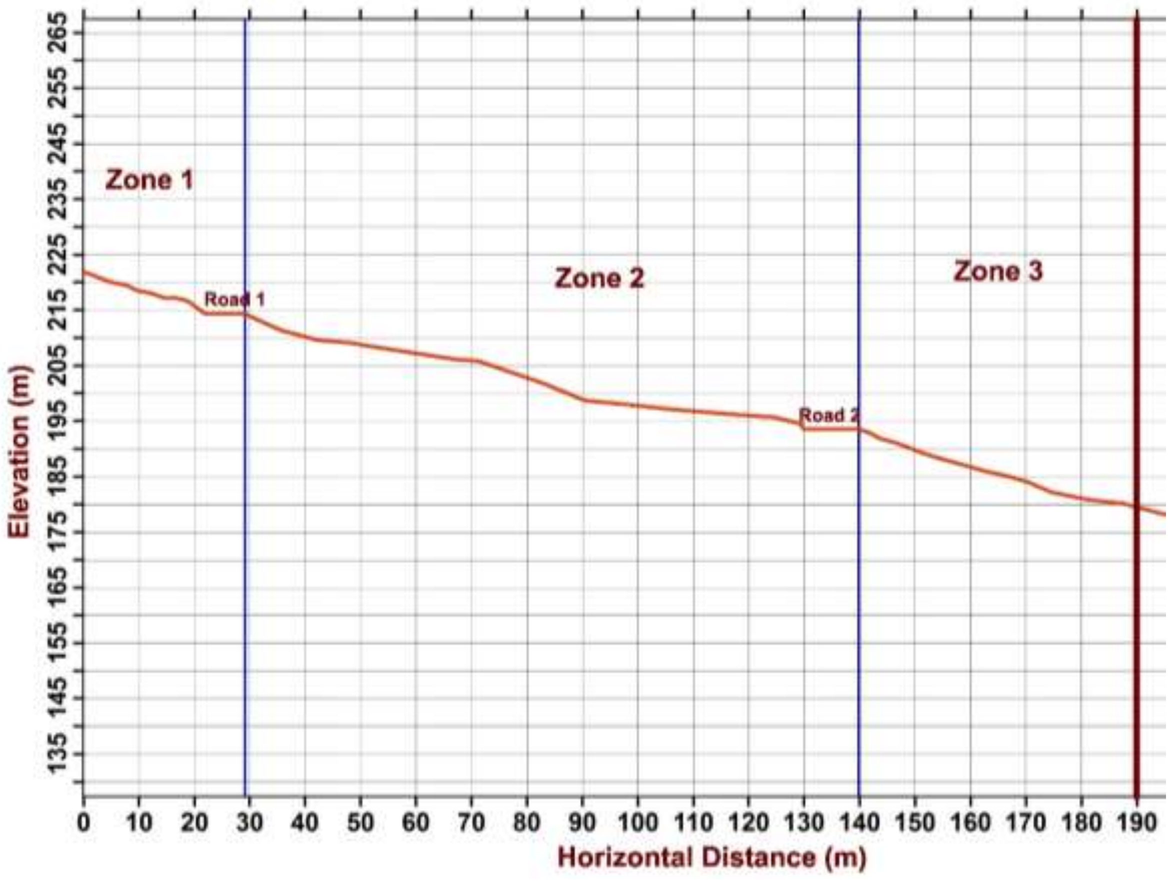


Figure 7.1: General elevation profile along the B-B’ indicated on figure 7.2

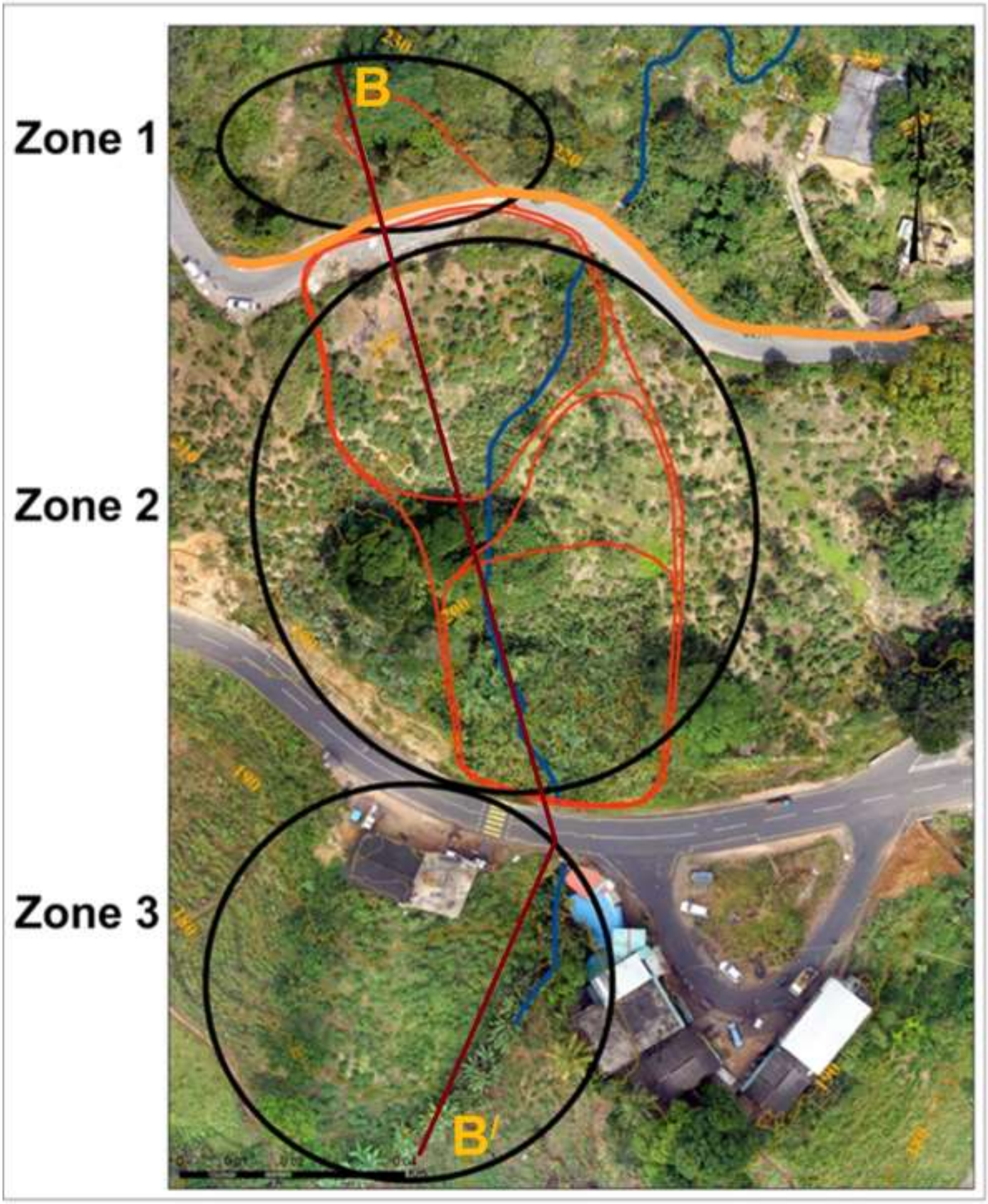


Figure 7.2: Preliminary zonation plan

7.3 Measures to be undertaken before the implementation of the plan

Prior to the implementation of the proposed plan above, it is recommended to carry out a testing campaign to determine the current nutrient levels (at least 10 samples evenly distributed around the site). This will help quantify the additional nutrient level which needs to be supplied externally.

7.4 Details of the proposed plan to be implemented under Zone 1

Observations	Proposed Modification
Zone 1: There are tall trees such as *Mangifera indica* (Mango) and *Caryota urens* (Kithul). A cemetery is located upslope.	This area shall be lightly loaded. Hence the existing tall trees must be trimmed in order to reduce the weight and the negative effect coming from wind. A cut off drain (Figure 7.3) is proposed to intercept water coming from upslope area and will be diverted along the road to the existing network which is located to the east of the landslide area. Vetiver grass is recommended to be planted on the slope. The grass has an extensive root network and a good survival ability.

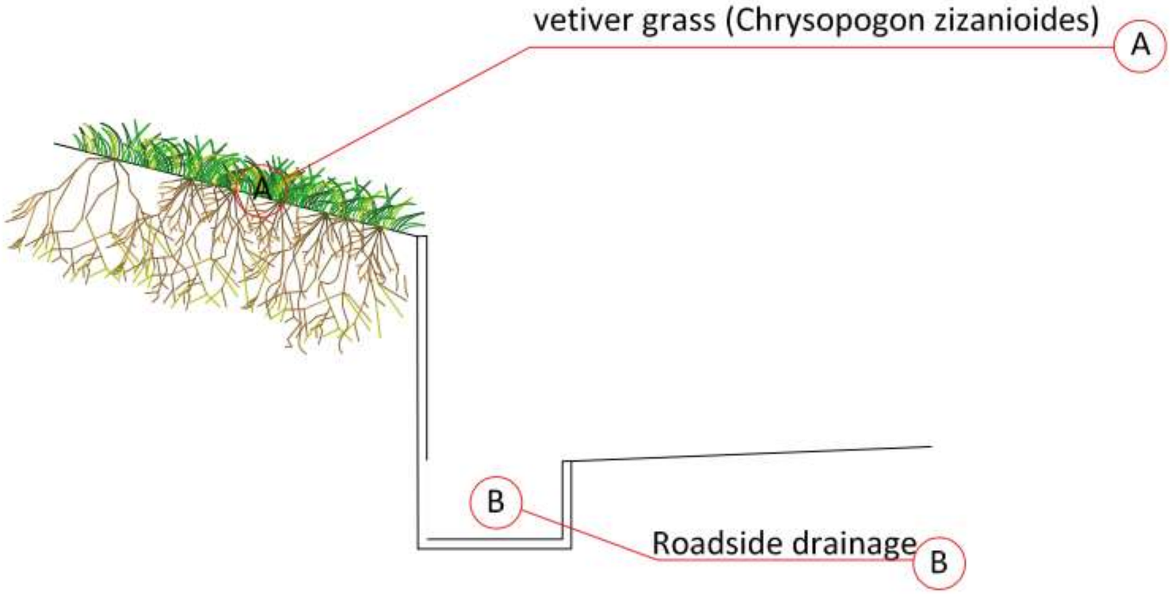


Figure 7.3: Schematic diagram of the proposed cut off drain

Candidate Plants for Zone 1

Candidate plant	Photo	Hydrological significance	Root characteristics	Ecological significance	Economic value
Chrysopogon nardus (Citronella grass)		Low to moderate evapotranspiration	Dense fibrous root penetrate to moderate depth	Native grass for erosion control and soil improvement	Essential oil
Chrysopogon zizanioides (Vetiver grass)		Moderate evapotranspiration	Dense fibrous root penetrate to deep	Grass for erosion control and soil improvement	Essential oil

7.5 Details of the proposed plan to be implemented under Zone 2

Observations	Proposed Modification
Zone 2: Uneven ground surface. Water logging area at the bottom part of the zone. <u>Main plant species</u> (Camellia sinensis) Tea plants (Tripsacum andersonii) Gautamala grass	A network of surface drains (cut offs and cascade drains) to dispose safely the running water without passing through the unstable ground mass. Reshaping of the slope and re-growing of Tea plants (tensile strength: 2.12MPa, 2.51MPa, 3.31MPa) together with Gautamala grass as it is a good soil binder and organic matter builder. Further, since the site has developed to a good monitoring station, this would be an ideal location for monitoring the dynamics in a tea plantation.

Candidate Plants for Zone 2

Candidate plant	Photo	Soil type	Stabilization method	Root system
Camellia sinensis (Tea)		Light (sandy) and medium (loamy) soils and prefers well drained soil.	Ground covers and soil stabilizers	Taproot primary to 3 meters deep
Tripsacum andersonii (Guatemala grass)		Can grow on a wide range of soils (including podsols, ultisols, oxisols, peats, acid sulfate soils and very acid coastal marine sands)	Moderate evapotranspiration	Roots are shallow

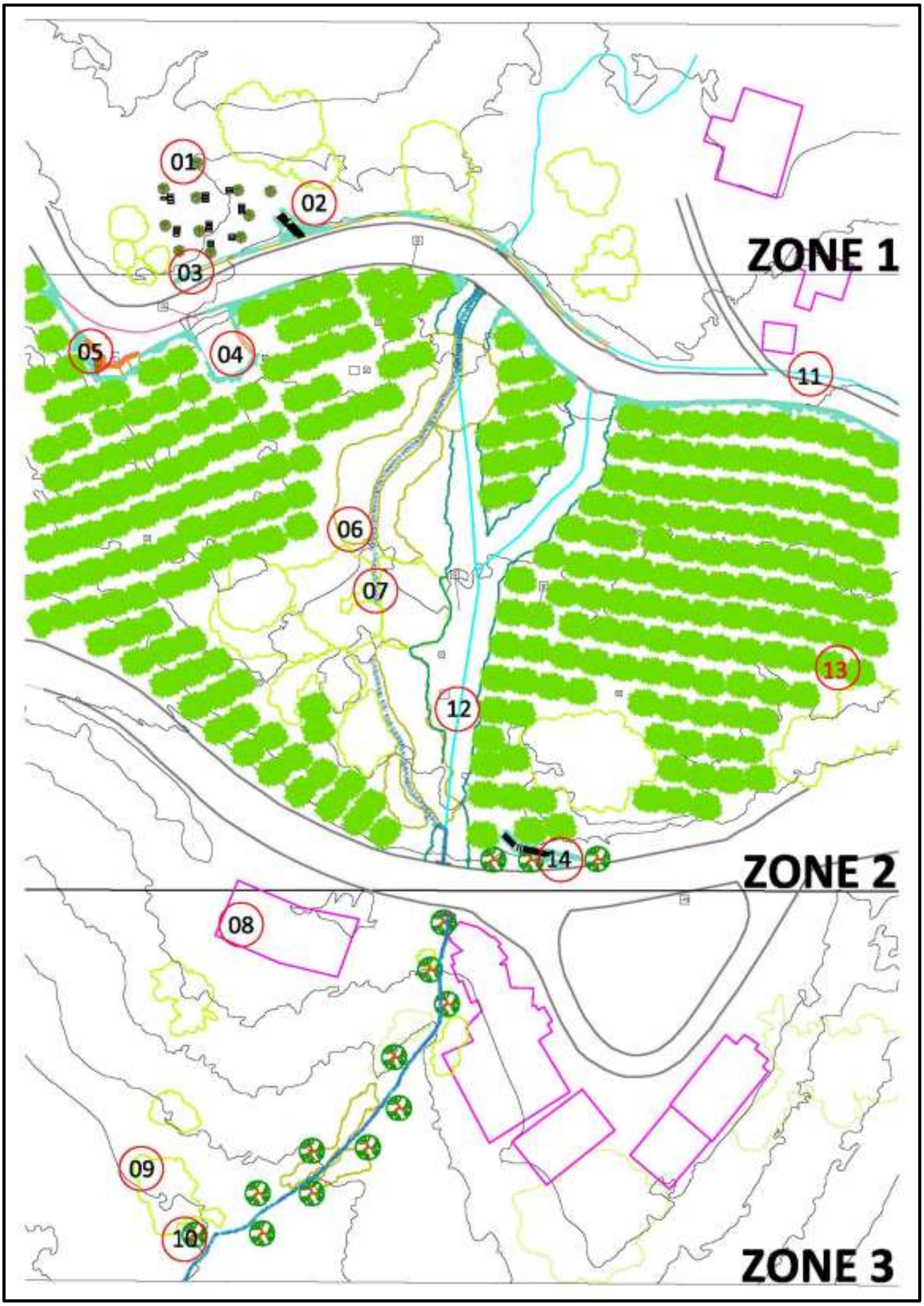
7.6 Details of the proposed plan to be implemented under Zone 3

Observations	Proposed Modification
Zone 3: Appearance of spring water during rainy seasons from the downslope area.	A network of subsurface drainage network to lower the ground water level to a safer margin. A system of deep rooted large trees covering the toe of the slope. Ideal to use 2-3 year old plants (root ball/ nursery bags) for quick establishment.

Candidate Plants for Zone 3

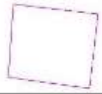
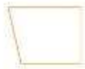
Candidate plant	Photo	Soil type	Stabilization method	Root system
Termiinalia arjuna (Kumbuk)		light (sandy), medium (loamy) and heavy (clay) soils and prefers well-drained soil	Ground anchor	Taproot

7.7 Schematic diagram of the proposed plan for Galabada in Ratnapura



Legend

1. Aesthetically well managed cemetery with light weight flowering trees.
2. Entrances to the cemetery
3. vetiver grass planted on the top of the slop to central erosion and add stability.
4. Adjoining paved area to the viewing deck, to give the glimpses of tea trails through the tea plantation.
5. Raised viewing deck with sanitary facilities and sank bar.
6. Existing guatemala grass patch alongside of the runoff path.
7. Existing water runoff path
8. Existing Building
9. Existing major vegetation patch
10. Kumbuk (Terminalia arjuna) trees alongside the water flow path.
11. Roadside drains
12. Cascade drains along the natural contours.
13. Tea plantation
14. Access to the tea plantation.

	Cascad drains
	vetiver grass (Chrysopogon zizanioides)
	Tea plantation.
	Existing major vegetation patch
	Kubuk (Terminalia arjuna) trees
	Existing guatemala grass patch
	Proposed guatemala grass patch
	Existing Building
	Proposed hard landscape
	Existing water logging area
	culvert
	Proposed lighting
	Proposed light weight flowering trees

7.8 Draft Work Plan

Work Plan is divided into three segments;

- Measures to be undertaken before the implementation of the plan;
- Civil and bio engineering works;
- Monitoring, inspection and maintenance.

7.8.1 Measures to be undertaken before the implementation of the plan

No.	Task name
1	**Soil nutrient level checks**
	Determining the sampling points
	Obtaining of required samples
	Carrying out of soil nutrient laboratory checks
	Analysis and presentation of report on present nutrient levels
	Determination of additional nutrition amounts to be added

7.8.2 Civil and bio engineering work

No.	Task name
1	**Site preparations**
	• Slope clearance and trimming operations
	• Retention of selected tree species, trimming if necessary, providing cover and support
2	**Plant nursery development and maintenance**
	• Nursery establishment
	• Construction of Nursery beds
	• Nursery production of selected grass types
	• Nursery production of trees and shrubs in poly-bags and poly-pots
	• Nursery production of hardwood plants
	• Compost and mulch production
	• Extraction of plants from Nursery and planting at site

3	**Civil engineering work**
	• Pegging out of boundaries, footpaths, other alignments, location of plant species etc. using appropriate surveying equipment, including minor re-adjustment on site if necessary
	• Excavation and backfill to improve slope shapes in a few places and to make open storm water drainage ditches leading to natural drainage lines or planned drainage outlets (exact patches & strips to be decided on site)
	• Construction of Cascade drain – Concrete (shape regular) Section 1m long x 0.65m x 0.75m
	• Construction of Line drain – Concrete (shape regular) Section 1m long x 0.6m x 0.65m
	• Construction of RC Retaining wall Section 1m x1.1m x 3m
	• Construction of horizontal drains 90mm dia long drains with perforated type 1000 PVC pipes and geotextile wrapping. Rate shall include for drilling and associated work and disposal of driled material away from the site as directed by the Engineer.
	• Construction of Irrigation & water supply lines
	• Construction of paved area – Interlock pavings; To approved design cement interlock paving slabs and to slope not exceeding 15° from horizontal on and including 15mm thick quarry dust layer, 300mm thick aggregate base course (100% proctor compaction to be achieved) on guage 500 polythene sheet and edges finished with 50mm wide edge kerbs and grooves filled with seived sand as per detail drawing. 110x220x80mm thick interlocking paving blocks
	• Construction of plastered brick masonry seating or Supply and installation of ready-made cement seating structures
	• Installation of outdoor LED lighting fixtures, including supply & laying of cabling
4	**Bio-engineering work**
	• Soil Filling, leveling and compaction where necessary (not more than 50% compaction in planting areas)
	• Supply and laying of topsoil as necessary in lawn and planting areas
	• Planting of Vetiver, Citronella and lemon grass including soil improvement as required for healthy growth.
	• Planting of small to medium tree species including soil improvement as required for healthy growth; Rate will increase or decrease according to size of tree
	• Supply and laying of ground cover grass including soil improvement as required for plant growth

7.8.3 Monitoring Inspection and Maintenance

Parameters to be monitored:
Daily precipitation
Ground water level
Soil suction levels
Moisture levels
Slope movement

Set of instrumentation:
Rain guage
Standpipe/ Water level meter
Suction sensor/ tensiometer
Moisture sensor
Strain guage

Monitoring Plan:

Data shall be obtained from two locations, namely, locations with nature based solutions and locations with out. This is for the purpose of comparing the two sets of data in order to assess the improvements gained from implementing nature based solutions.

Suction sensor/ tensiometer and moisture sensor shall be installed at different depth levels considering the depth of plant roots zone. Suggested depth levels for each zone are;
Zone 1: 0.5m and 1m
Zone 2: 1m and 2m
Zone 3: 1m and 2m

Monitoring Sequence:

Hourly measurements of precipitation
Daily measurements from suction sensor/ tensiometer and moisture sensors
Groundwater level shall be monitored daily during rainy seasons and once a week during dry periods.

Analysis of Acquired data:

Data from monitoring instruments shall be analyzed once a month or every after fifteen days to assess the effectiveness of nature based solutions.

Inspection and maintenance

No.	Task name
1	**1 year's full maintenance during the Defects Liability Period**
	Allow for all labour, plant materials, equipment and necessary fertilizers and all costs and expenses in connection with maintenance during the Defects Liability Period, for a period of 12 months commencing upon the issuance of Engineer's Completion Certificate. There shall be an experienced chief gardener and another skilled gardener full-time on 7 days per week to ensure satisfactory maintenance.

7.9 Preliminary Budget

	Task	Sub-tasks	Unit	Rate	Quantity	Cost(SLR)
1.	Site preparations	• Slope clearance and trimming operations	Sqr	810.00	575	465,750
		• Retention of selected tree species, trimming if necessary, providing cover and support	Sqr	2,230.00	290	646,700
2.	Civil engineering work	• Allow lump sum for pegging out of boundaries, footpaths, other alignments, location of plant species etc. using appropriate surveying equipment, including minor re-adjustment on site if necessary	LS			200,000
		• Excavation and backfill to improve slope shapes in a few places and to make open storm water drainage ditches leading to natural drainage lines or planned drainage outlets (exact patches & strips to be decided on site)	M3	1,000.00	30	30,000
		• Cascade drain – Concrete (shape regular) Section 1m long x 0.65m x 0.75m	M	21,000.00	300	6,300,000
		• Line drain – Concrete (shape regular) Section 1m long x 0.6m x 0.65m	M	16,000.00	200	3,200,000
		• Construction of RC Retaining wall Section 1m x1.1m x 3m	M	60,000.00	25	1,500,000
		• Construction of horizontal drains 90mm dia long drains with perforated type 1000 PVC pipes and geotextile wrapping. Rate shall include for drilling and associated work and disposal of drilled material away from the site as directed by the Engineer.	M	6,500.00	250	1,625,000
		• Construction of Irrigation & water supply lines	M	900.00	300	270,000
		• Construction of paved area – Interlock pavings; To approved design cement interlock paving slabs and to slope not exceeding 15° from horizontal on and including 15mm thick quarry dust layer, 300mm thick aggregate base course on guage 500 polythene sheet and edges finished with 50mm wide edge kerbs and grooves filled with seived sand as per detail drawing. 110x220x80mm thick interlocking paving blocks	M2	4,000.00	300	1,200,000
		• Construction of plastered brick masonry seating or Supply and installation of ready-made cement seating structures	Ft	800	20	16,000

		• Installation of outdoor LED lighting fixtures supplied by TT, including supply & laying of cabling	LS			1,000,000
3.	Bio-engineering work	• Soil Filling, leveling and compaction where necessary (not more than 50% compaction in planting areas)	M3	2,000.00	40	80,000
		• Supply and laying of topsoil as necessary in lawn and planting areas	M3	4,500.00	40	180,000
		• Planting of Vetiver, Citronella and lemon grass including soil improvement as required for healthy growth.	No	500.00	650	325,000
		• Planting of small to medium tree species including soil improvement as required for healthy growth; Rate will increase or decrease according to size of tree	No	10,000.00	80	800,000
		• Supply and laying of ground cover grass including soil improvement as required for plant growth	M2	1,000.00	2,500	2,500,000
4.	Plant nursery development and maintenance	• Nursery establishment	PS			
		• Construction of Nursery beds				
		• Nursery production of selected grass types				
		• Nursery production of trees and shrubs in poly-bags and poly-pots				1,000,000
		• Nursery production of hardwood plants				
		• Compost and mulch production				
		• Extraction of plants from Nursery and transportation				
5.	Post execution inspection and maintenance	**1 year's full maintenance during the Defects Liability Period** Allow for all labour, plant materials, equipment and necessary fertilizers and all costs and expenses in connection with maintenance during the Defects Liability Period, for a period of 12 months commencing upon the issuance of Engineer's Completion Certificate. There shall be an experienced chief gardener and another skilled gardener full-time on 7 days per week to ensure satisfactory maintenance.	Month	200,000.00	12	2,400,000
6.	Monitoring and	• Suction sensors/Tensiometer	No.	300,000.00	6	1,800,000
		• Moisture sensor	No.	35,000.00	6	210,000
		• Installation of sensors	LS			1,000,000

	Instrumentation	• Monitoring for one year period	LS			400,000.00
	Sub Total					27,148,450
	Contingencies (15%)					4,072,268
	Total excluding taxes					31,220,718

	Task	**Sub-tasks**	**Unit**	**Rate**	**Quantity**	**Cost(SLR)**
1.	Remunerations for supervisory staff	• Civil engineers	m/m	225,000.00	12	2,700,000
		• Geotechnical engineer/ engineering geologists	m/m	225,000.00	12	2,700,000
		• Agricultural engineers	m/m	225,000.00	8	1,800,000
		• Agronomists	m/m	175,000.00	8	1,400,000
		• Botanists	m/m	175,000.00	8	1,400,000
		• Landscape architects	m/m	200,000.00	5	1,000,000
		• Technical officer	m/m	140,000.00	12	1,680,000
		• Work supervisor	m/m	75,000.00	12	900,000
	Total					13,580,000

REFERENCES

Australian Geomechanics Society, (2000). Landslide risk management concepts and guidelines, s.l.: Australian Geomechanics Society, Sub-Committee on Landslide Risk Management

Baets, S. D., Poesen, J., Reubens, B., Wemans, K., Baerdemaeker, J. D., & Muys, B. (2008) Root tensile strength and root distribution of typical Mediterranean plant species and their contribution to soil shear strength. Plant Soil (305), 207-226

Choi, K. Y. and Cheung, R. W. M. (2013). Landslide disaster prevention and mitigation through works in Hong Kong. Journal of Rock Mechanics and Geotechnical Engineering. (5). Pp. 354-365. http://dx.doi.org/10.1016/j.jrmge.2013.07.007

Cofie, P. (2000). Mechanical properties of tree roots for reinforcement models. Wageningen: Wageningen University. The Netherlands

Countermeasures for Badulusirigama-JAICA (2015) Japan International Cooperation Agency

ELS Construction (Pvt) Ltd, (2017). Pilot Project for Landslide and Rockfall Mitigation Works in Badulla, NuwaraEliya and Matale. Lot 1-Badulusirigama in Badulla District. Project Completion Report

Elia, G., Cotecchia, F., Pedone, P., Vaunat, J., Vardon, P. J., Pereira, C., Springman, S. M., Rouainia, M., Esch, J. V., Koda, E., Josifovski, J., Nocilla, A., Askarinejad, A., Stirling, R., Helm, P., Lollino, P. and Osinski, P. (2017). Numerical modelling of slope-vegetation-atmosphere interaction: an overview. Quarterly Journal of Engineering Geology and Hydrogeology. DOI: https://doi.org./10.1144/qjegh2016-079

Endo, T. (1980). Effect of tree roots upon shear strength of soil. Japan Agricultural Research Quarterly, XIV (2)

Feedipedia (2019). Gautemala Grass. https://www.feedipedia.org/node/365

Fell, R., Ho, K. K. S., Lacasse, S. & Leroi, E., (2004) A framework for landslide risk assessment and management. London, International Conference on Landslide Risk Management

Geoslope, (2018). Stability Modelling with Geostudio. Calgary, Canada: GEO-SLOPE International Ltd

Greenwood, J. R., Norris, J. E., & Wint, J. (2004). Assessing the contribution of vegetation to slope stability. Geotechnical Engineering - Institution of Civil Engineers, 157 (GE4), 199-207

Investigation at Galabada Landslide - JAICA (2018) Japan International Cooperation Agency

IUCN, 2018. International Union for Conservation of Nature. Commision on Ecosystem Management. Available at: https://www.iucn.org/commissions/commission-ecosystem-management/our-work/nature-based-solutions. [Accessed November 2018]

Leung, F. T., Yan, W. M., Hau, B. C., & Tham, L. G. (2015). Root systems of native shrubs and trees in Hong Kong and their effects on enhancing slope stability. Catena (125), 102-110

Mahannopkul, Krairoj, and Apiniti Jotisankasa. "Influence of root suction on tensile strength of Chrysopogon zizanioides roots and its implication on bioslope stabilization." Journal of Mountain Science 16, no. 2 (2019): 275-284

Nishikawa, T. & Balasooriya, R., 2016. Evaluation of Landslide Monitoring Data for Badulla Site in Sri Lanka. Colombo, National Building Research Organization

Pallewattha, M., Indraratna, B., Heitor, A., & Rujikiatkamjorn, C. (2019). Shear strength of a vegetated soil incorporating both root reinforcement and suction. Transportation Geotechnics(18), 72-82

Schwarz, M., Preti, F., Giadrossich, F., Lehmann, P., Or, D. (2010). Quantifying the role of vegetation in slope stability: A case study in Tuscany (Italy). Ecological Engineering. Vol. 36. pp: 285-291 DOI: 10.1016/j.ecoleng.2009.06.014