ASSESSING THE EFFECTIVENESS OF BIOTECHNICAL SLOPE STABILIZATION METHODS IN LANDSLIDE PRONE AREAS

MICHAEL VLADIMIR

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ABSTRACT

This research was conducted in Kasika village with a main aim of assessing the effectiveness of the different biotechnical slope stabilization methods in landslide prone areas. The study was triggered by the increasing challenge of slope instability in the area which led to loss of lives and destruction of community infrastructure such as roads, the study aimed at coming up with sustainable and environmentally friendly measures of stabilizing the slopes in the area. The study was conducted basing on three objectives that is to evaluate the slope susceptibility of the slopes to landslides in the landslide prone areas , to determine the factor of safety of the slope before failure and to assess the effectiveness of the biotechnical slope stabilization techniques. The study used (Analytical Hierarchy Process)AHP to come up with the landslide susceptibility map and morgenstern price method of slices to determine the factor of safety of the slope before failure under saturated and normal soil conditions. The study found out that the endangered slope was unstable and prone to landslides and recommended the use of the biotechinical slope stabilization method of brush layering with bamboo live cuttings(Oldenia Alpina) to stabilize the slope.

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DECLARATION

I VLADIMIR MICHAEL do hereby declare that this report contains information about the research we are carrying out in fulfillment of the requirement of the Final year project and is my very own authentic work and the content of this document has never been submitted to any institution. It contains my very consequence discoveries from my research activity while at Uganda Christian University.

I hence pronounce that it will be utilized to survey the degree of my abilities advancement and proficient over the semester period.

SIGNED : ………………………………………………………………………………………….

DATE : …………………………………………………………………………………………..

APPROVAL

This is to certify that Mr. Vladimir Michael conducted this research under supervision and the report was submitted with the approval of the authorized supervisor.

Signature : ……………………………………………………………………………………………

Date : ……………………………………………………………………………………………

DR. MAKABAYI BRIAN

RESEARCH SUPERVISOR

UGANDA CHRISTIAN UNIVERSITY

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CHAPTER ONE: INTRODUCTION

1.0 Background and Introduction

Landslides refer to the downward movement of rocks ,debris or soil along the slope due to gravity (Xingmin ,2024). There are various factors like precipitation,slope angle , aspect , curvature, landuse , human activities and lithology among others that influence landslide occurence in landslide prone areas (Mersha et al., 2020). In the Rwenzori mountains , Kasese district, landslides are recurring due the presence of triggering factors such as heavy rainfalls and flooding of streams and rivers (Geoengineer.org, 2022). For example, a 2021 study revealed that over 76% of households in the Ibanda Sub County, kasese district had experienced landslides in the past five years with the frequency of these events peaked during the rainy seasons, from March to May and September to November, correlating with heavy rainfall patterns. Key causes included deforestation, steep slopes, and soil erosion. Over the past decade, landslide occurrences have noticeably increased, attributed to climate change and intensified rainfall (Ainomugisha, 2021).

These landslides threaten infrastructure especially along road networks as well as agricultural land and the natural environment (Quevedo R.P. et al, 2023).

Kasika village in Kasese which is traversed by hilly and mountainous terrain is especially prone to slope instability most especially in the rainy seasons .These slope failure pose significant threats to both transportation infrastructure and the local ecosystem (Richard et al.,2022 and CGTN Africa, 2022).

With slope instability being a recurring challenge in this region a comprehensive analysis is crucial to understand the factors driving landslides and identify effective slope stabilization measures. Infastructure development such as Road construction disrupt the natural balance of a slope, triggering landslides. The soil and rock's geotechnical properties, such as cohesion, shear strength, and permeability, are crucial for determining slope likelihood to failure through calculating the factor of safety of the identified slopes to know how strong the slope is to movement. Therefore, accurate knowledge of soil and rock characteristics is essential for predicting slope failures and identifying vulnerable areas (Abramson, L.W. et al., 2002).

Given the frequent occurrence of slope failures in Kasika and other similar landscapes this research aims to mainly focus on the spatial relationship of the landslide causative factors and how they lead to slope failure hence, creating a landslide susceptibility map that locates endangered community infrastructures such as roads in Kasika village and evaluate the effectiveness of the different slope stabilization techniques along them and provide a sustainable biotechinical slope stabilization technique that can resist slope movement and has the ability to adapt to the varying environmental and climatic changes.

1.1 Problem Statement

Landslides refer to the downward movement of rocks ,debris or soil along the slope due to gravity(Xingmin ,2024).

In 2022, due to heavy rains in Kasika , Rukoki subcounty, Kasese region a landslide happened that killed 15 people ,left 6 injured and 18 feared to be missing (Richard, 2022). More recently, in May 2024, multiple landslides in the district occurred in various sub counties claiming 13 lives over the span of a week due to the heavy rains (Monitor team,2024). These incidents highlight the ongoing vulnerability of the area to such natural disasters.

These slope failures impact infrastructures such as roads leading to road blockages according to (CGTN Africa, 2022) in this area , cause damage to road surfaces, disruptions to transportation and increased risks to road accidents.

Current traditional stabilization techniques such as soil hardening , retaining walls are climatically unadaptable and environmentally intrusive, thus the need for methods that are environmentally friendly and climatically adaptable.

Therefore, this research seeks to locate endangered community infrastructures such as roads in Kasika village and determine the suitable factor of safety of these endangered slopes before failure and provide a biotechnical soil stabilization technique with the ability to adapt to the varying environmental and climatic changes.

1.2 Objectives of the study

1.2.1 Main Objective

To assess the effectiveness of biotechnical slope stabilization techniques for slope stabilization in landslide prone areas.

1.2.2 Specific Objectives

1. To evaluate the slope susceptibility of slopes to landslides in landslide prone areas.
2. To determine the suitability of the factor of safety of the slope before failure

3. To assess the effectiveness of biotechnical slope stabilization techniques for slope stabilization in landslide prone areas.

1.3 Research questions

1. What are the key factors that contribute to the susceptibility of slopes to landslides in the study area?
2. How suitable is the Factor of Safety of the endangered slope before failure?
3. How effective are biotechnical slope stabilization techniques in enhancing slope stability in landslide-prone areas?

1.4 Geographical scope

Kasika Village with coordinates 0°11'N 30°05'E is located in Rukoki Sub-county which is part of Kasese District in Western Uganda with DMS(Degree Minute Seconds) coordinates of 0°07'15.60" N and 30°00'27.97" E (Latitude.to,2024).

Kasika village is one of the administrative units within Kigoro Parish,Rukoki Sub-county. This village is suited in the hilly region of the rwenzori mountains with varying elevations and the terrain including steep slopes and valleys.

Kasika experiences a tropical climate with distinct rainy and dry seasons . The rain seasons are two that is May and August to November (Citizenreport, n.d.).

1.5 Justification

Landslide susceptibility mapping with AHP assigns weights to landslide causative factors enabling weighted overlay analysis on geospatial data to assess their influence on landslides and accurately identify high risk areas (landslide prone areas) (Mersha et al, 2020).

For slope stability analysis of the identified endagered slopes, the limit equilibrium principle which focuses on balancing the forces that resist movement to the forces that cause movement will be used to determine the factor of safety of the slope using morgenstern price method that accounts for both force and moment equilibrium allowing for accurate susceptibilty analysis of the endangered slope to landslides (Abramson L.W. et al.,2002).

Biotechnical slope stabilization methods intergrate indigenous vegetation with structural measures to enhance slope stability by improving soil cohesion and increasing the resistance to slope movement . The limit equilibrium principle is employed to assess the stability of these reinforced slopes by evaluating the balance between driving and resisiting forces along the potential failure surface. This approach allows for the calculation of the factor of safety, providing a quantitative measure of slope stability after reinforcement (Gray D.H. et al.,1992). The incorporation of indigenous species of plants ensures that the slope stabilised is adaptable to the local environment and climatic conditions of the place hence providing a sustainable and resilient solution for slope stbilisation in landslide prone areas (Gray D.H. et al.,1992).

CHAPTER TWO: LITERATURE REVIEW

2.1 Landslides

Landslides are simply the downward movement of rocks , debris or soil along the slope due to gravitation forces (Xingmin, 2024).

These landslides are caused by several causative factors such as landuse and landcover, human activities, lithology ,heavy rainfalls , the nature of the slope angle , curvature of the slopes, aspect of the slopes , the distance from the stream and faults among other factors (Mersha et al, 2020).

2.2 Landslide Susceptibility Mapping with the Analytical Hierarchy Process.

Landslide susceptibility mapping is a schematic method used to identify areas in a region that are more prone to landslides through analysising the various geospatial data on the factors that cause landslides as these can be either geological like faults , rock types , soil types among others, hydrological causing factors such as distances from the stream , river , flooding among others, and other environmental factors such as land cover and even anthropogenic activities like farming among others . Basically,this process utilises the data and advanced techniques like Bayesian probabilities , multi criteria analytical decision making tools like the Analytical Hierachy Process (AHP) to assess the likelihood of landslides occurences in specific regions , helping in disaster risk reduction and landuse planning (Geological Survey Ireland ,n.d.).

While conducting landslide susceptibility mapping , the landslide causing factors to be used in the GIS(Geographical infromation systems) system should be directly relevant to the landslides in that region. These landslide causative factors should be should work in a way that they have clear relationship with landslides , should be able to be well represented across the study area, should be measurable using various scales and non redundant that is not cause overlapping effects in the final analysis. This will ensure that the final model's accuracy that is the landslide susceptibility map will be accurate and reliable in predicting or analysing landslides (Kumar et al.,2016).

Under the various techiniques used for landslide susceptibility mapping, this research will utilise the AHP process to assign weights to the landslide reclassified maps on how they influence landslides in the area. AHP is basically a multi criteria decision making tool that was introduced by Saaty in 1980 and is widely used in various decision making fields such as site selection , suitability analysis and Landslide susceptibility Mapping (LSM). It incorporates both subjective and objective factors in decision making following principles of decomposition , comparative judgement and sysnthesis of priorities. This method basically breaks down complex decisions into a hierachy assigning weights through pairwise comparions. These comparisons are influenced by expert knowledge which is subjective ensuring a comprehensive evalution of the landslide causing factors and hoe much they actually influence the landslides of that specific region (Tavana et al.,2023 and Kumar et al.,2016).

AHP softwares are used instead of the manual calculations of the AHP decion making because they significantly enhance the decision making process compared to the manual methods through streamling the complex process thus reducing the related biases and inconsistencies created by the user. Basically, it simplifies the pairwise comparisons through handling the large datasets efficeintly providing visual aids for better understanding. Softwares like Transparent choice are highly recommended due to their user friendly interfaces , robust algorithms and ability to facilitate collaboration among the different stakeholders involved. The AHP tools help in organising criteria heirachically , performing sensitivity analyses and ensuring that all voices are heard ultimately leading to more informed and consensus driven decisions (TransparentChoice, 2024).

During the study , raster maps will be carried out for each causative factor selected and reclassified on how they actually cause landslides and these reclassified maps of the landslides will be weighted on how they influence the landslides in the area according to expert judgement using AHP and later weighted on a cell by cell basis using the weighted overlay process in the GIS environment in the software. A landslide susceptibility map will then be produced assigning numerical values to indicate susceptibility with higher values representing greater risk. To classify these values , a natural break classifier can be employed dividing the landslide susceptibility map into five distinct susceptibility levels that is very highly susceptible, highly suscpetible , moderately susceptible , low suscpetibilty and very low risk to susceptibility to landslides (Kumar et al.,2016).

Before validation , landslide inventory mapping is done to show where the past landslides happened in the study area and this is achieved through field observations in fieldwork surveys , historical records and from satellite imagery from google earth among other satellite plattforms. A polygon vecto map is created in the GIS softwares environment showing the past landlsides in the area according to their magnitude and these mapped slides are rasterised and used as the future landslides during the validation of of the landlside suscpetibility map to check how accuratlety the landlside susceptibilty map was able to accurately map out areas that are actually prone to landslides from areas that are not prone to landslides(mapping prone landslides areas from arreas not prone to landslides with no false alarms). Validation of the landslide susceptibilty map is done to ensure that the landslide susceptibility map accurately identifies landslide prone areas with less false alarms. This involves comparing different the landslide susceptibility map and the landslide inventory map with a Receiver Operating Curve (ROC) that plots success rate curves, prediction rate curves which are used to assess the models accuracy heavily relying on training data. While creating the Receiver Operating curve(ROC) , it compares both the true positive rate against the false positive rate at various thresholds (Kumar et al.,2016 and Mersha et al.,2020). The True positive rate represents the portion of the actual landslide correctly predicted by the landslide susceptibility map while the false positive rate represents the portion of non landslide areas that were incorrectly predicted by the landslide prone areas. An Area Under the Curve(AUC) value of 0.7 to 0.8 indicates acceptible performance and values above 0.9 indicate outstanding performance(Mersha et al.,2020).

2.3 Slope Stabilization Techniques

Slope stabilisation in landslide prone areas is a crucial aspect for geotechinical engineering as it aims at minimising the risk of slope failure. Many techniques are employed based on the characteristics of the slope , soil type and severity of the the landslide risk. Today, modern slope stabilisation methods focus on reinforcing the slope such as the the soil type , improving drainage systems and using both natural and engineered structures to prevent landslides. The key techniques employed include retaining walls , soil nailing , drainage control and biotechinical stabilisation that uses vegetation which can work either independently or in combination with other techniques to enhance the stability of endagered slopes (Abramson L.W. et al.,2002).

2.3.1 Retaining walls:

Retaining walls are among the most commonly used structural methods to stabilise slopes. They function through providing support to slopes that would slide under weight of the earth. Retaining walls are comprised of concrete , aggregates, stone or other materials and are designed in the following forms for example gravity walls, cantilevered walls , anchored walls depending on the specific requirements of the slope to be stabilised and the site conditions. However, retaining walls are vulnerable to water pressures and poor drainage during very extreme weather conditions such as heavy rains(Abramson L.W. et al.,2002).

2.3.2 Soil nailing :

Soil nailing is an insitu reinforcement techinique that involves placing steel rods these are referred to as the nails into the slope being stabilised to increase its strength. These rods are grouted into place and and work by providing tensile strength , which prevents the soil from shifting or slipping. In most cases, soil nailing is done together with retaining walls or alone when stabilising endagered slopes to failure. However , soil nailing is majorly effective in unsaturated soils as the water interactions weakens the bonds between the soil and the nails leading to slope failure (Abramson L.W. et al.,2002).

2.3.3 Drainage Systems:

Proper drainage is essential in slope stabilisation as infiltrated water is a major cause of slope failure. The installation of of surface drains , subsurface drains among others increases the wa ter pressure within the soil thereby increasing the slope susceptibility to failure. Some of the techniques employed under drainage systems include: horizontal drains, drainage blankets , trench drains which prevent the accumulation of water in the soil that can trigger slope failures. Though effective at reducing the amount of water infilitrating the soils, drainage systems are very vulnerable to sediment build up which becomes more pronounced with heavy rainfalls hence require frequent maintainance (Abramson L.W. et al.,2002).

2.3.4 Vegetation and Biotechnical stabilisation methods:

Planting vegetations across the slopes can be effective in natural stabilisation methods. The roots of these plants help bind the soil , reducing the risk of erosion and landslides. Biotechinical stabilisation techniques which combine vegetation with structural elements governed by engineering principles are used to reinforce slopes naturally while improving the ecological sustainability of the slope endangered. For example, using trees , shrubs and grasses like ventiver grass to reinforce endagered slopes and these methods are effective at stabilising shallow landslides (Abramson L.W. et al.,2002).

2.3.5 Terracing and bench construction:

Terracing involves the cutting of the slope into benches to reduce the slope's gradient minimising erosion. This technique also redistributes the weight of the slope across a larger area and provides pathways for water to be duveted away from the endagered slope safely. This diversion of the water prevents water from pooling and trigerring landslides such as mudflows/. bench construction on the otherhand is often used together with drainage systems to enhance the effectiveness of this method (Abramson L.W. et al.,2002).

2.3.6 Rock Bottling and Shotcrete:

For the case of rocky slopes, rock bottling is employed to stabilise fractured rock masses through the installation of long steel bolts into the rockface to be stabilised. Shotcrete on the other hand is a spray applied concrete that can also be used to cover unstable rock masses or soil through providing a protective layer . These techniques are often used when stabilising steep rocky slopes preventing rock falls (Abramson L.W. et al.,2002).

2.3.7 Reinforced earth structures:

Reinforced earth techniques involve placing materials such as steel strips or geogrids into the soil to improve its strength. This method ensures that areas where large volumes of earth are in need of stabilisation especially highway projects railways are stabilised effectively. The advantage of reinforced earth structures is that they are flexible and can accommodate ground movements making them more suitable for landslide prone areas (Abramson L.W. et al.,2002).

2.3.8 Anchored walls and Ground Anchors:

Anchored walls use tensioned steel cables or rods that are drilled through stable ground behind a slidding mass of soil. These cables provide additional support to prevent the movement of the slope. Ground anchors are a similar method involving the use of steel cables drilled deep into stable strata and then tensioned to hold the unstable slope in place (Abramson L.W. et al.,2002).

These techniques above are often combined to provide an efficeint an effective slope stabilisation in areas prone to landslides. However the choice of the method for slope stabilisation highly depends on the specific characteristics of the site , the type of landslide risk, and also the economic considerations (Abramson L.W. et al.,2002).

The types of slope stability Analysis:

There are different ways of carrying out slope stability analysis that is the total stress and effective stress approach.

The total stress approach which corresponds with claysoils under short term loading where pore water pressure is not dissipated. The effective stress approach corresponds to to long term stability analysis in which drained conditions prevail. Natural slopes and slopes with residual soils should be analysed with the effective stress method by considering the maximum water level under severe precipitation. This is very important for areas that receive intense rainfall (Abramson L.W. et al.,2002).

2.4 Factor of safety

The factor of safety according to the limit equilibrium of slope stability analysis refers to the ratio of the ultimate shear strength that is the forces that resist sliding of the slope materials to the shear stress that is the forces that cause slope movement for a slope. In the limit equilibrium principle , the factor of safety is assumed to be the same across the slip surface of failure. When analyzing the slope under moments for rotational slip surfaces the factor of safety is given as :

$F=M_r/M_d$ where M_r is the sum of moments of the slope resisting slope movement and M_d is the sum of moments of the slope causing the slope failure (Abramson L.W. et al.,2002).

When analysing slopes with the forces equilibrium which is applied when the slopes have transitional slope failures :

$F=F_r/F_d$ where f_r id the sum of all the forces that resist slope movements and F_d is the the sum of all forces that drive slope movements for the slope.

A slope is considered to be unstable according to the limit equilibrium principle is suggested to have a factor of safety of less than 1 and for a slope to be considered stable the factor of safety is supposed to be greater than 1 for the slope to be considered stable from failure (Abramson L.W. et al.,2002).

The shear strength mobilised along the slope surface is dependent on the normal effective stress acting on the failure slip surface. The shear strength of the slope is given by the following formula as for the limit equilibrium principle:

$T=T_f/F$

Where F is the factor of safety of the slope, T_f is the shear strength , $T_f=C + a \tan b$ where C is the cohesion , a is the effective normal stress and b is the internal angle of friction of the slope (Abramson L.W. et al.,2002).

Laboratory tests to determine the shear strength of the endangered slopes to failure. To practically determine the the cohesion , effective normal stress , the unit weight of the soil , the internal angle of friction of the soil of the slope to be stabilised , laboratory tests are performed that is the shear box test for the angle of friction and cohesion of the slope materials , proctor tests are performed to determine the unit weight of the soil . these tests are designed to simulate the real world conditions under which the soils and the rocks of the endangered slope are subjected to stress and deformation allowing engineers to assess the key geotechnical properties of the slope (Abramson L.W. et al.,2002).

Direct shear tests: These tests are performed to determine the shear strength parameters of the soil that is the cohesion and the angle of friction . The soil sample is placed in a shear box and normal loads are applied to induce normal stresses and a failure envelope is drawn from which cohesion (the intercept on the shear stress axis) and the friction angle (that is the slope of the failure envelope) are acquired (Abramson L.W. et al.,2002).

Triaxial compression tests: For this test, a cylindrical soil sample is placed in a chamber where its subjected to controlled confining pressures. This test provides more comprehensive data for the soil as it allows for controlling the drainage conditions (consolidated-drained , consolidated- undrained or unconsolidated undrained). from the results, Mohrs circles of stress can be plotted to determine the effective normal stress and the shear strength parameters including friction angle and cohesion (Abramson L.W. et al.,2002).

The causes of slope failure: So its very important to understand the things that cause the slopes to fail to better anticipate when failure can occur . Slope stability analysis depends on the balance of the shear strength properties of the slope and the shear stress parameters of the slope and consider them to be in a state of equilibrium.

Instability can arise in the slopes incase the shear strength parameters that prevent slope movement decrease or the shear stress parameters that drive the slope to failure increase.

There several processes that can lead to reduced shear strength of slope materials and include several processes such as increasing pore water pressure from rising ground waters or heavy rainfalls, cracking , swelling in clays , the development of slickensides , decomposition of clayey rock fills, creep under sustained loads , strain softening , weathering and cyclic loading. Water and clay materials often play critical roles in these processes . shear stress can increase due to added loads on the slope, water pressure in cracks , increased soil weight from water infiltration , excavation at the base of the slope , rapid drawdown of water levels and earth quake shakes (seismic activity). slope failures usually happen due to multiple causative factors and rarely due to one single factor . Therefore , its essential to consider all potential factors when designing or repairing slopes to ensure long term stability (Abramson L.W. et al.,2002).

Meaningful soil strength analysis can only be applied if the shear strengths applied are appropriate for the specific soils and conditions . Over the last 70 years, much has been learned about soil shear strength through positive and negative experiences with slope stability. The amassed data on soil strength is substantial. The discussion below focusses on the principles governing soil strength , key issues in evaluating strength and useful strength correlations for practise . this aims to establish a frame work for studying shear strength at specific sites (Abramson L.W. et al.,2002).

Granular material like sand , gravel share similar strength characteristics as these materials have high permeability and are typically fully drained in the field lacking cohesion. This means the effective stress shear strength envelope passes through the origin of the Mohr stress diagram. The primary factors affecting the shear strength include the soil density , grain size distribution , boundary conditions and particle breakage during shear which is influenced by confining pressure , mineral type and particle characteristics.As the confining pressure increases, granular soil strength envelope curve, and their secant friction angles decreases due to greater particle breakage. This is because higher inter particle forces lead to more breakage which consumes less energy than rolling or sliding . Consequently , as confining pressures increases , the shearing resistance the shearing resistance doesn't increase proportionally. For well graded materials , the strength of the materials increases confining pressure, reflecting significant particle breakage (Abramson L.W. et al.,2002).

The density of granular materials quantified usung relative density , plays a major role in strength . higher densities result in higher values of shear strength. Additionally , well graded soils typically have higher shear strengths values compared to uniformly graded soils because smaller particles fill gaps between larger ones creating denser and stronger packing. However , issues like segregation during fill placement can occur (Abramson L.W. et al.,2002).

2.5 Biotechinical methods of slope stabilization:

Bioengineering techniques utilize vegetation and natural materials to stabilise slopes , prevent erosion and enhance soil strength. They are cost effective , environmentally friendly and promote ecological restoration of the slopes. Biotechinical stabilisation methods are particularly useful in landslide prone areas and also erosion. Brush layering is a slope stabilisation technique that involves placing live cuttings of woody plants in shallow trenches or layers along the slope. These cuttings sprout roots and shoots improving soil cohesion and increasing the slope's resistance to failure. Despite its widespread use , quantifying the exact contribution of brush layering to slope stability has received limited attention. This study aims to fill that gap by developing a model based on the limit equilibrium principle and evaluating the factor of safety (FS) of slopes stabilised with brush layering. Brushlayering is essentially an older version of reinforced earth techniques. The method involves placing live cuttings or brush pieces at the bottom of small benches excavated into a slope. The best time for brush layering is during the dormant season to ensure proper sprouting and root development (Bischetti, G.B.et al., 2010).

How it works: Rainfall interception, the tips of the cuttings extend beyond the slope face and grow buds and leaves that intercept rainfall , slow down runoff and filter off sediments.

Tensile reinforcement : the stems of the live cuttings are embedded into the slope and act as tensile reinforcements similar to geo synthetics or soil nails.

Root development also occurs overtime as the cuttings develop roots along the stems enhancing their reinforcement capability and pullout resistance.

Hydrological modifications: the embedded cuttings also serve as drains that modify the hydrologic conditions near the slope face reducing water saturation and increasing stability.

The goal of this experimental model is to quantify the mechanical contribtion of brushlayering to slope stabilisation . the model will include quantifying the factor of safety to measure slope strength improvement after brush layering , analysing the varying depths to determine the FS as stress and loads change with depth and establishing relationships between the factor of safety and brush layering design parameters such as bench spacing , length and diameter of the live cuttings (Bischetti, G.B.et al., 2010).

The principles the model uses are :

The limit equilibrium method that analyses the slope stability by balancing driving and resisting forces. It assumes that the failure occurs along a pre-defined surface and considers factors like soil properties , slope geometry and reinforcements that is live cuttings.

Infinite slope stability analysis: this principle applies to shallow slopes with failure planes parallel to the surface. Stability factors include soil cohesion , friction , unit weight , slope angle and pore water pressures. Brush layering basically enhances the cohesion and reduces infiltration improving stability of the slope.

During the pullout resistance prototype , the following assumptions are made: the soil within the testing apparatus is assumed to be uniform , the cuttings are taken to be consistent , the tests occur under static conditions , the root growth is ignored initially focussing on the soilcuttings interactions, the soil behaves linearly under applied forces and lastly , the constant pullot coeffiecient that is variations in the cuttings' diameter and soil conditions are not considered (Bischetti, G.B.et al., 2010).

Reinforcing Model:

Parameters such as soil cohesion , friction angle unit weight, cuttting dimensions and density will be optiised using a limit equilibrium principle formula of factor of safety for stabilisation using brushlayers (Bischetti, G.B.et al., 2010).

CHAPTER 3: METHODOLOGY

3.1 Evaluating the slope susceptibility of slopes to landslides in landslide prone areas.

3.1.1 Landslide causing factor selection

The landslide key causing factors were identified through targetted questionairres to the local community , experts in the kasika village to understand which causing factors contribute significantly to the landslides in the region. Different stakeholders such as the district Environmental Officer, the disaster focal person of Kasese district , the local community amongst other indivuals enabled us determine the factors that cause landslides. These factors that were provided by the different stakeholders affected were then vetted using literature reviews on the causes of landslides in kasika village and the most significant factors were selected as the landslide causative factors to be considered ignoring the less significant. The landslide causative factors selected were precipitation , aspect , slope angle , curvature , distance to stream ,landuse and landcover , rainfall and lastly lithology.

3.1.2 Spatial and non spatial data collection

After selecting the landslide causative factors , the spatial and non spatial data on them such as precipitation data for rainfall was obtained from the Kasese Airfield weather station in Rukoki Subcounty, digital elevation modules (DEM) for aspect , curvature , elevation , distance to stream mapping was obtained from the NASA earth datasets with 30m spatial resolution. Google earth satellite images from the

LANDSAT satellite were obtained from Google earth pro for landude and landcover mapping. A geological map from the geological survey of Uganda with a scale of 1:250,000 showing all geological units of uganda was used to obtain the lithological units of Kasika Village.

3.1.3 Creation of landslide causative factor maps

Raster maps of all the landslide causative factors selected were created as follows:

Digital Elevation Model: A digital elevation model obtained from the NASA earth data base with a spatial resolution of 30m was used to produce an elevation map of Kasika Village, the hill shade of Kasika village that enabled the understanding of the terrain of the village, slope angle mapping , aspect mapping , curvature mapping and lastly , distance to stream mapping.

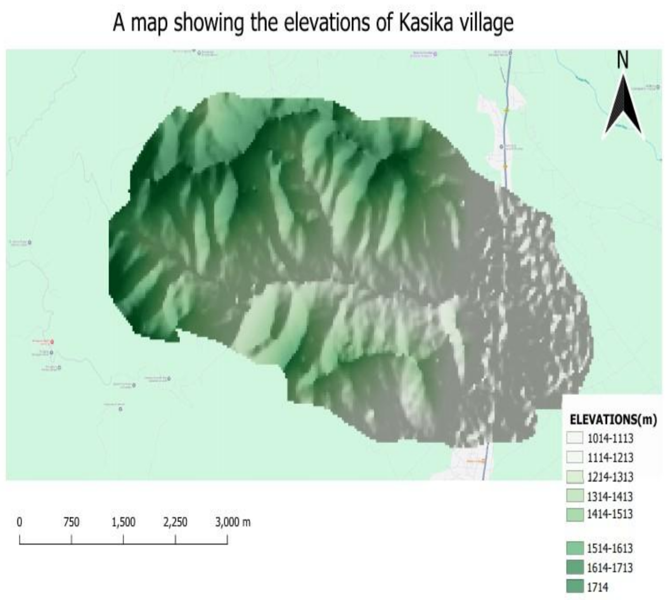

Figure 1: Digital elevation module of Kasika village in meters. Source:(NASA JPL, USGS (2000))

Slope Angle Mapping :

From the google earth pro software , a series of close points less than 10m apart from each other were chosen to obtain the different elevations , longitude and latitude of Kasika village. This attribute table of elevations, longitude and latitude was then placed in ArcGISpro software to generate a 10 meter Digital elevation through the IDW process. This Digital elevation model was then later used to obtain the slope angles of the slope in Kasika village using the spatial analyst tool in ArcGIS pro.

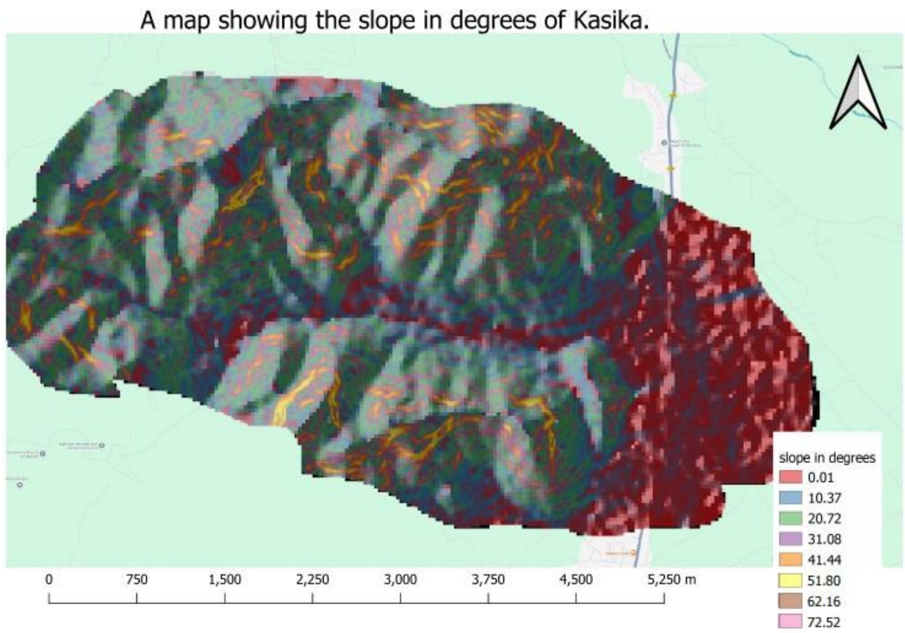

Figure 2 Slope angle map that was obtained from the 10m digital elevation model

Rainfall mapping

Rainfall values of kasika village were obtained from the Kasese Airfield , Rukoki subcounty weather station and weather and climate uganda for five years and a rainfall attribute table was created using the wettest months of 2022, since this is the year the landslides affected our case study, kasika village the most.

Place	Longitude	Latitude	Wettest month(mm)
Bubotyo	30.078078	0.1698986	475.31
Ruhiri	30.078078	0.1698986	482.56
Kihoko	30.078078	0.1698986	476.74
Kyehunda	30.078078	0.1698986	501.35
Rwenjura	30.0752529	0.160416	500.68
Rukoki	30.1098472	0.2043226	498.32
Kilembe	30.013072	0.197414	492.59
Kahendero	30.0500931	0.0559208	476.17
Hamukunga,	30.0751895	0.010089	471.73
Kabirizi,	29.92778	0.0225859	504.14
Bukangara	29.813236	-0.0113243	515.68
Katwe	29.8670563	-0.1276134	488.46
Ibanda	30.4991209	-0.1167162	502.25
Kahegwa	30.078078	0.1698986	503.17
Rwihingo	30.078078	0.1698986	470.48
Kanyansi,	30.0878942	0.1743272	511.22
Kahonda	30.05	0.25	511.26
Kalonge,	29.95	0.2	496.89
Hima	30.1849082	0.2935023	471.53
Kasenyi	30.1489508	-0.0316394	506.33
Kyabikere	29.75	0.1	515.63
Katojo	29.7614237	-0.0091086	502.8

Ruhiri,	30.078078	0.1698986	482.56
Kyehunda	30.078078	0.1698986	501.35
Busambo	30.0438255	0.0869143	517.17
Kyarumba,	29.95	0.133333	514.96
Kikorongo	30	0	498.46
Nyabusenyi	30.1489508	-0.0316394	499.86
Mpondwe	29.7599761	0.0364501	500.88
Kitojo	30.259184	0.515101	502.26
Kagondo			501.44
Cu-Co	30.078078	0.1698986	514.74
Kaba	30.078078	0.1698986	479.98
Nyakibingo	30.0306809	0.1616758	505.22
Mubuku	30.1228416	0.2642024	471.35
Bugoye	30.0982956	0.3059712	475.43
Ibimbo	29.891439	0.088667	470.25
Buhuhra	30.116667	0.4	491.44
Ruti,	29.833333	-0.083333	478.19
Mweya	29.8999895	-0.1889343	480.89

Table 1 Attribute table used for rainfall mapping of the kasika region using IDW interpolation. Source: (weather and climate ,n.d.)

Table 1 was placed in ArcGISpro and the rainfall values of the wettest months were interpolated using the Inverse Distance Weighting (IDW) to obtain the other rainfall values of the other places for instance the Kasika region with no rainfall records as the village has no raingauges to record precipitation.

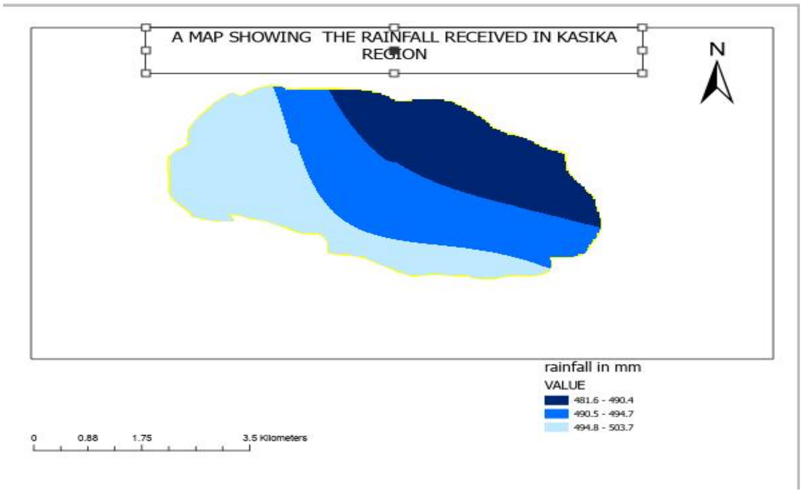

Figure 3 Map showing the rainfall measured in millimeters received in kasika village.

Aspect mapping : Aspect mapping refers to the process of determining the orientation of the slopes and is expressed in degrees from 0° to 360°. It influences landslides in a way that it affects the slopes' exposure to sunlight , wind direction , rainfall and discountinuity conditions all which affect the soil saturation that affects the stability of the region. The aspect map was derived from the digital elevation module with a spatial resolution of 30m got from NASA earth for Kasika village.

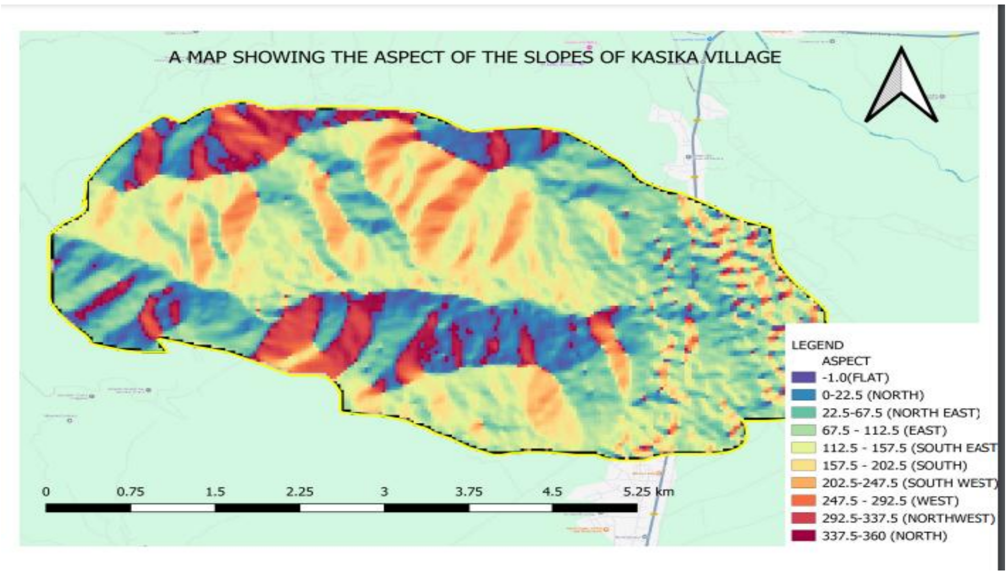

Figure 4 Map showing the aspect of the slopes of Kasika village created from the digital elevation of 30 m spatial resolution.

Curvature Mapping: curvature mapping involves analysing the shape of the terrain features and understanding its influence on the hydrology of the place and landslide susceptibility. Curvature maps are classified into three classes majorly that is the concave , convex and flat surfaces.

Concave surfaces on the map are the negative parts of the curvature and tend to collect water which increases soil saturation and the likelihood of landslides. Concave surfaces are those slopes of the mountains that enter inwards the mountains in form of a concave shape.

Convex surfaces on the map are those parts of the map that are having a positive curvature. They allow for quicker drainage , potentially reducing saturation but can also lead to instability if water accumulates into adjacent areas. Convex slopes are those slopes that bulge outwards inform of a convex shape in simple terms.

The curvature map of Kasika village was derived from the Digital Elevation Module of Kasika village with a spatial resolution of 30 m through the spatial analyst tool for curvature in QGIS software. The negative regions are the concave slopes , the positive grid cells are the convex slopes and the zeros are the flat surfaces.

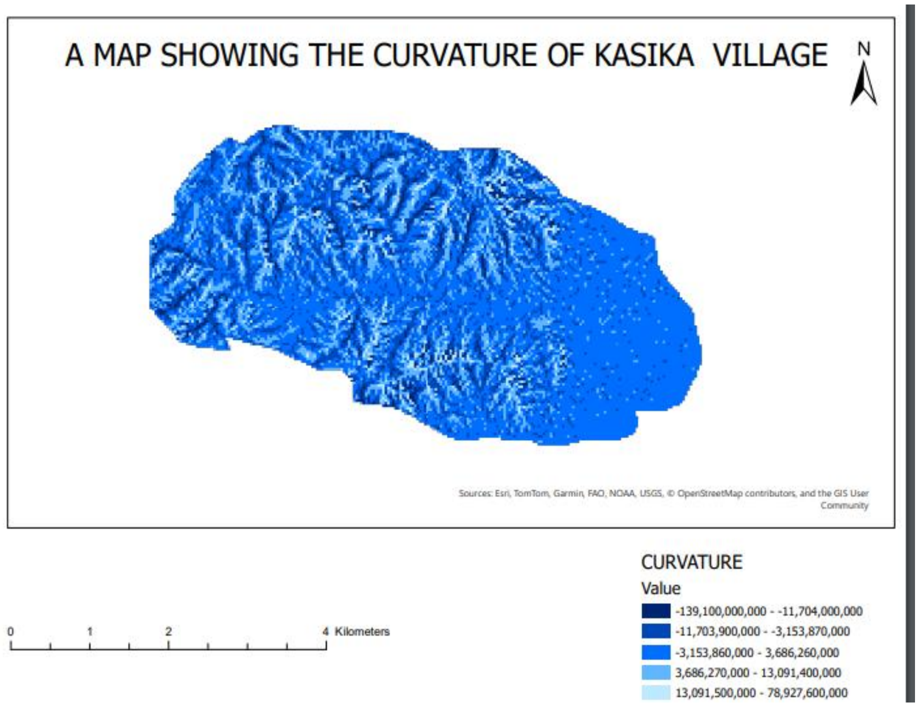

Figure 5 Map of kasika village showing the curvature of the slopes

Distance to the stream mapping:

The distance to the stream map was done using the euclidean distance buffering method from ArcGIS pro environment. Before getting the distance to the stream , the stream lines were derived from the digital elevation module (DEM) of kasika with a spatial resolution of 30 m . The DEM module was first filled and the vector lines of the stream lines in Kasika village were extracted from the Digital Elevation Module(DEM) using the hydrological analyst tool in the tool box of ArcGIS pro. From the streamlines the distnce from them was obtained using the Euclidean Distance Buffering method and the distances were made in eight classes that is 0-50 m(meters), 50-100m , 100-150m, 250-300m, 300-400m, 400-600m and greater than 600m. This classification helps in understanding the relationship between the proximity to the stream and to landslide susceptibility.

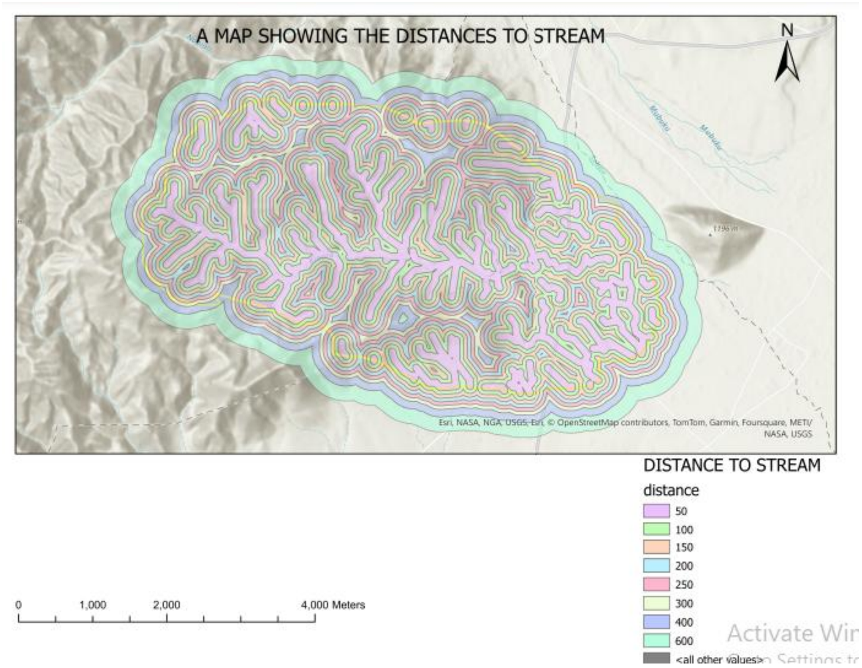

Figure 6 Distance to the stream map created through the Euclidean distance buffering method from stream line obtained from the Digital elevation module of 30m spatial resolution that was obtained from the NASA earth explorer database.

LITHOLOGY MAPPING IN ARCGIS PRO:

Lithology mapping was conducted in the ArcGIS pro software which involved preparing a lithological map by geo referencing an already existing geological map of the region from the uganda geological survey. This geological map having a scale of 1: 250,000 was placed on the arcgis pro software and georeferenced using common ground control points so that we could derive the geological units that are in the region of Kasika village. Vector polygon map was made to extract the geological units of kasika village and later this map was rasterised to form a raster lithological map. The kasika village was observed to have two lithological units that is quartzites and sands,clays, grits as per the georeferenced map used.

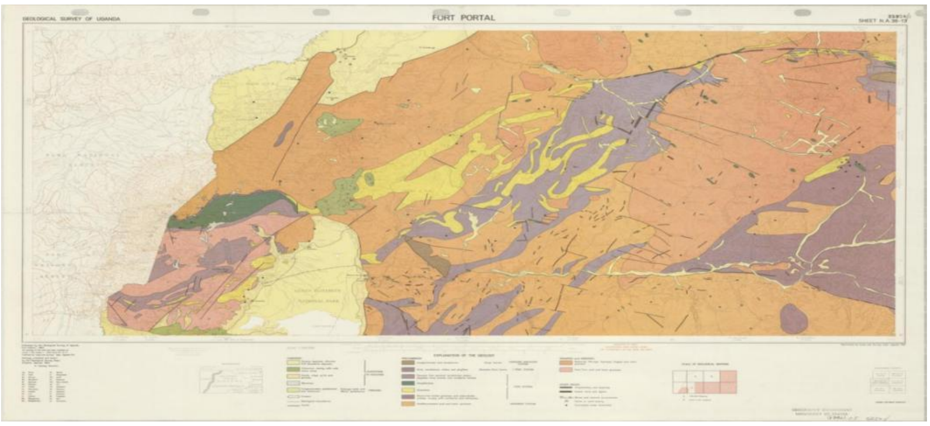

Figure 7 Showing the geological map obtained from the geological survey of Uganda that was georeferenced to produce the lithological map. Source: (Uganda Geological Survey,n.d.)

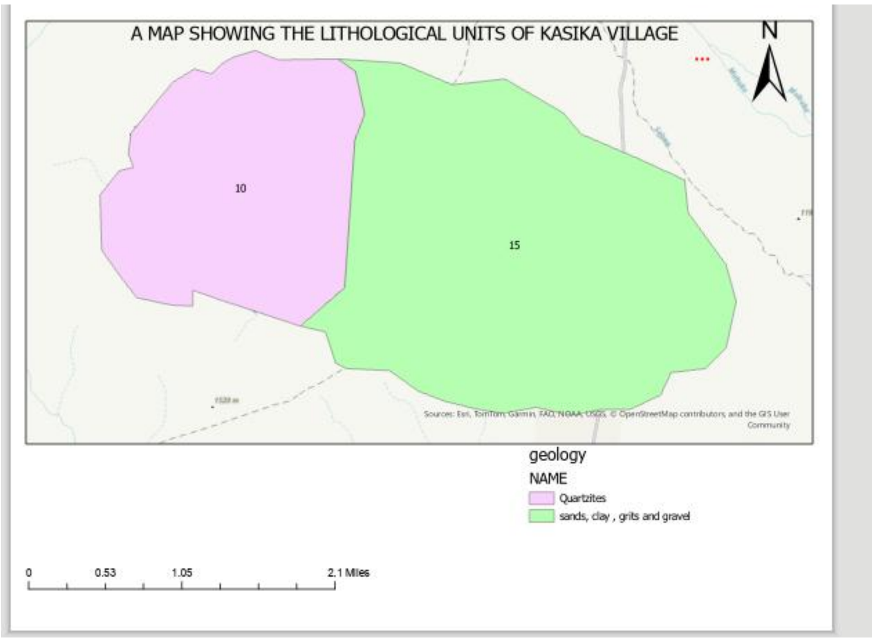

Figure 8 Map of the lithological units that are in Kasika village

Landuse And Landcover Mapping:

The landuse and land cover maps of Kasika village were created through intensive fieldworks to discover the different landuse and landcover types of Kasika village and interpretation of the LANDSAT image downloaded from google earth pro for

Kasika village with a resolution of 2180 x 1080p. This approach allowed for the classification of the various landuse and landcover types within Kasika village. This LANDSAT (land satellite) image was processed in ARCGIS pro with the supervised classification spatial analyst tool where different raster cell grids with different spectral resolutions were assigned a landuse and landcover type as the training dataset to help create the landuse and landcover map for Kasika village.

Figure 9 Google earth pro satellite image used for supervised classification to generate the landuse and landcover map of Kasika village.

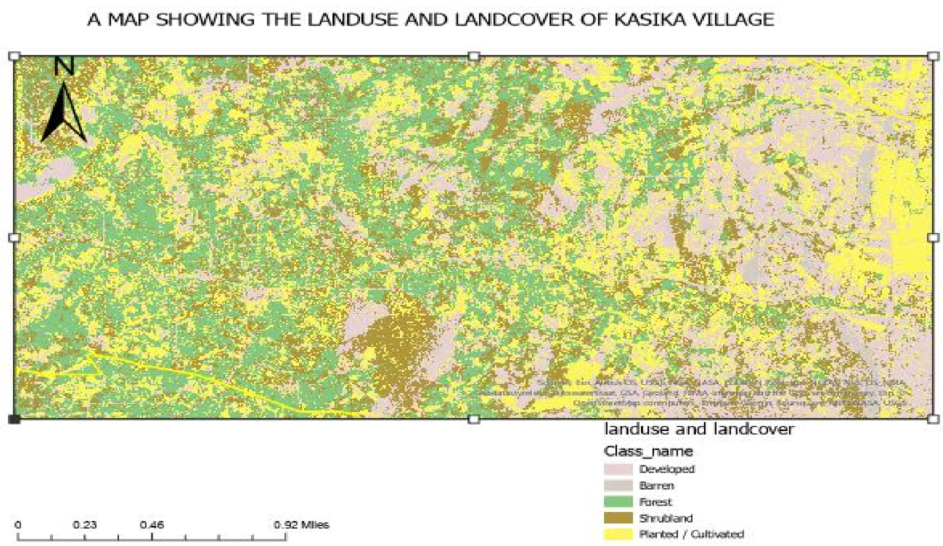

Figure 10 Landuse and landcover map that was produced after supervised classification of the LANDSAT image that was obtained from google earth pro.

3.1.4 Reclassification of the landslide causative factor maps

Reclassification of the landslide causative factor maps was done to simplify the analysis of the landslide causative factor maps and enhance the interpretability of the landslide causing factor maps. It was done to relate the landslide causative factors on how they actually influence the cause of landslides. The process involved grouping the continuous variables into five discrete classes of how they influence landslides that is very low susceptibility to landslides , low susceptibility to landslides , moderate susceptibility to landslides , high susceptibility to landslides and very high susceptibility to landslides for each landslide causative factor map.

The process of reclassification of the landslide susceptibility maps is to transform the complete data of these causative factor maps into actionable insights related to landslides providing actionable insights for risk assessment and management.

Slope angle map reclassification

The reclassification of the slope angle map was done by diving the slope angle map into five classes basiung on how those slope angles cause or influence landslides. The five classess were 0-5° which was taken as very low susceptiblity to landslides , 5-12° which was taken to have low likelihood to causew landslides , 12-30° which was taken to have moderate likelihood to landslides , 30 -45 ° where these slope angles are taken to have a high susceptibility to causing landslides and for slope angles greater than 45° , the slope angles grater than this were taken to have very high susceptibility to landslides. This classification identified those slopes in that format because areas with high suceptibility to landslides are associated with a higher probability to cause landslides (Mersha et al.,2020).

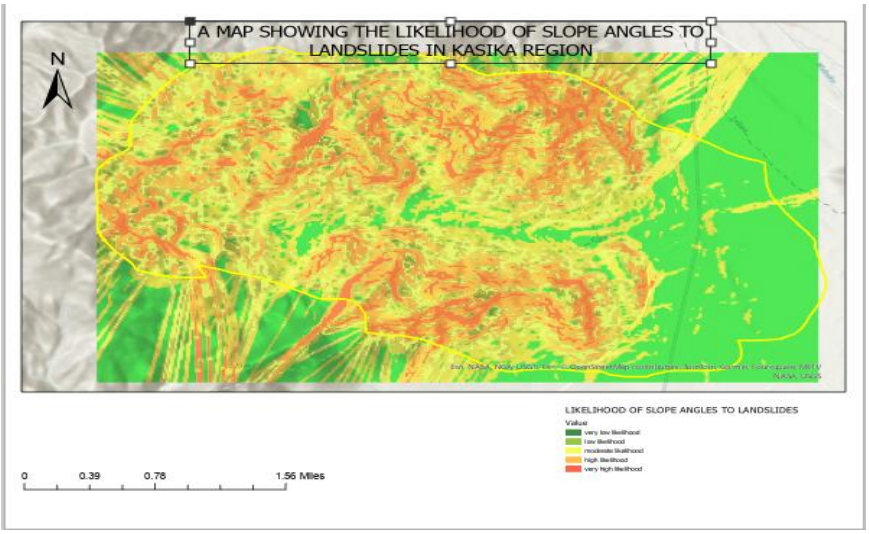

Figure 11 The reclassified raster of slope angle of Kasika

CURVATURE MAP RECLASSIFICATION

The curvature map was reclassified on how curvature of the slopes influences real world landslides. The higher positive values (convex curvature) and high negative values (concave curvature) were classified as very highly susceptible to landslides and for values that are near zero were taken to have very low suscpetibility to cause landslides in the Kasika region.

Basically, curvature influences landslides primarily through its effect on water accumulation. Concave surfaces have a tendency to collect water which leads to increase soil saturation conditions on the slope. This saturation raises the pore water pressure reducing the shear strength of the slope materials making the slope more susceptible to landslides. Convex surfaces may facilitate quicker drainage but they also lead to slope instability if water accumulates in the adjacent concave areas. This can create conditions favourable for landslides most especially after a heavy rainfall (Mersha et al.,2020).

Basically , the curvature of the slope affects how gravitational forces act on it with positive curvature (convex slopes) leading to less stability under certain conditions of the slope and negative curvature (concave curvature) can exaberate the effects of water retention and saturation. In overall, the interaction between curvature , water dynamics and slope stability is crucial for landslide susceptiility mapping.

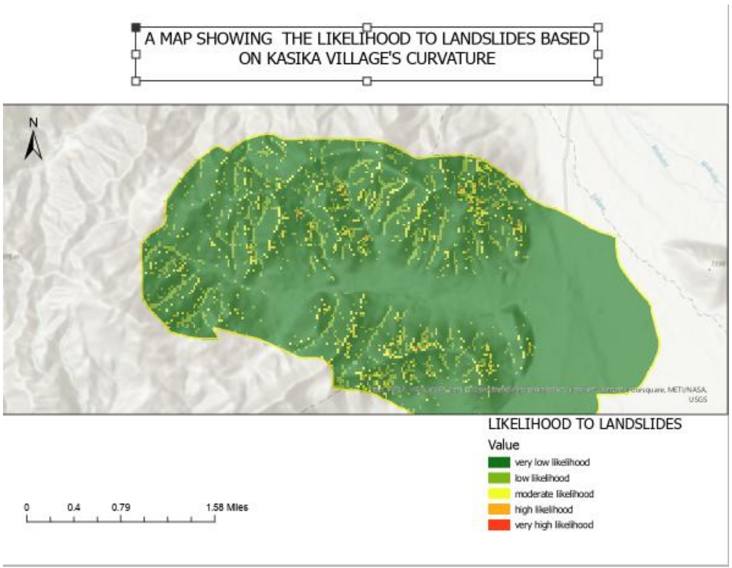

Figure 12: A map showing the reclassified curvature of the slopes in Kasika village.

Aspect map reclassification

The Aspect of the slopes was classified on how the different slope oreintations affect factors such as sunlight exposure, moisture retention on the overall slope stability of Kasika Village. The reclassification was dine by categorising the slopes' orientation into three classes based on degrees. Typically, the Aspect map was classified as follows:

North facing slopes(0-22.5°) were reclassified as very highly susceptible to causing landslides .

North east facing slopes(22.5 - 67.5°) were reclassified as moderately susceptible to causing landslides

East facing slopes (67.5 -112.5°) were reclassified as having a very low susceptibility to causing landslides

Southeast facing slopes (112.5-157.5°) were reclassified to moderately cause landslides in the region.

South facing slopes (157.5-202.5°) were reclassified as moderately susceptible to landslides.

West facing slopes (247.5-292.5°) were reclassified as very low susceptibility to cause landslides.

Northwest facing slopes (292.5-337.5 °) which were reclassified as moderately susceptible to cause landslides in the region.

North facing slopes (337.5- 360°) were recl;assified as slope very highly susceptible to cause landslides (**Mersha et al.,2020**).

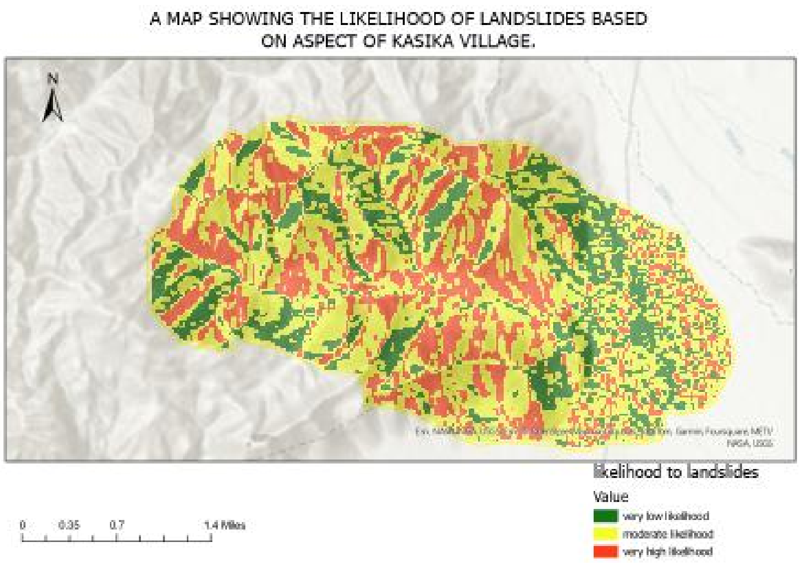

Figure 13 Reclassifed map of Kasika village based on the aspect of the slopes and how they influence the landslides in the region.

Distance to stream map reclassification

The reclassification of the distance to the stream map was done basing on the relationship between the proximity to streams and to how they influenced landslides as areas that are of closer proximity to landslide areas are taken to be more prone to landslides due to factors such as increased soil saturation and erosion (Mersha et al.,2020).

Distance to stream data was reclassified into five classes based on how there proximity can lead to landslides.

0-50 m from the streams were reclassified as very highly susceptible to cause landslides.

50- 100 m were reclassified as highly susceptible to landslides

100-150 m from the streams were reclassified to have a moderate effect to cause landslides.

150-200 m were reclassified to have low susceptibility to cause the landslides

Greater than 200 m were reclassified to have very low susceptibility to cause landslides.

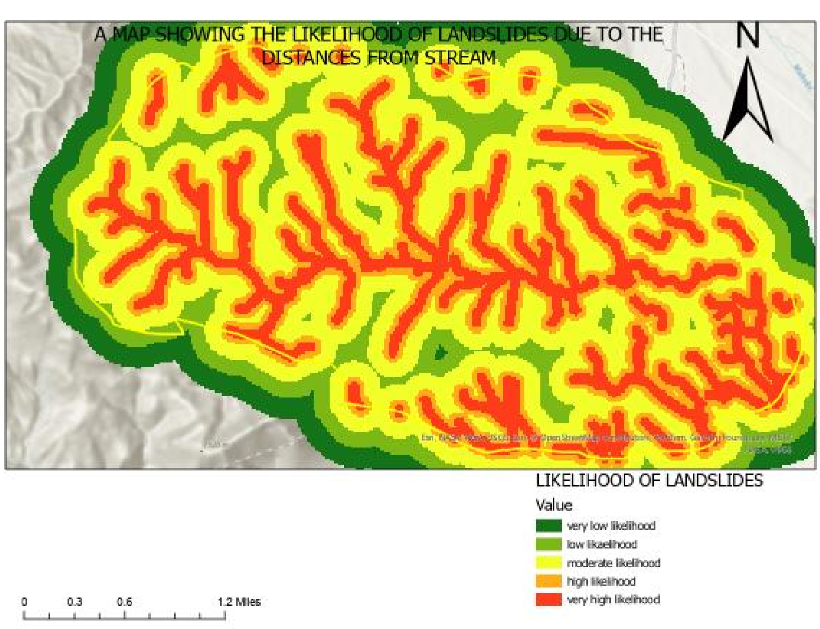

Figure 14 Map showing the likelihood of landslides to the distances from streams

Landuse and Landcover map reclassification

The landuse and landcover map was reclassified by categorising various landuse types and lancover on how they influence the landslides in the region. The landuse and landcover classes of agricultural lands, forests , built environments , shrubland and bare ground were classified with respect to how they influence landslides.

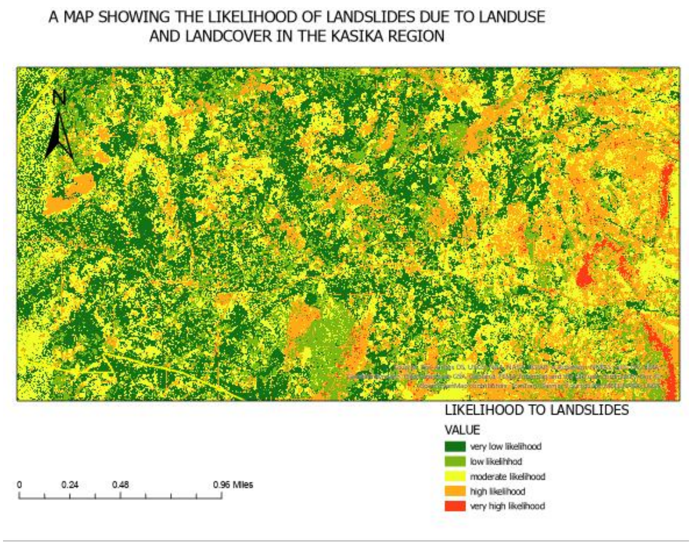

Figure 15 Map showing the reclassifed map of landuse and lancover and how they influence landslides in the Kasika Village.

Lithology map reclassification

The lithology map was reclassified by categorising the two lithological units of Kasika village and how they are susceptible to landslide failures. The class of quartzites was given low likelihood to cause landslides and the class of clay,grits, shale were given a high likelihood to experience landslides according to (Abramson L.W. et al.,2002).

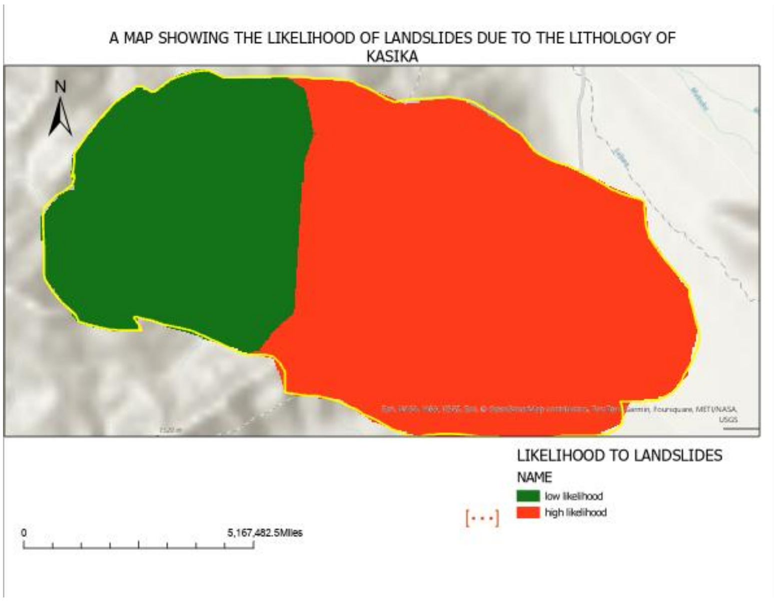

Figure 16 A reclassifeid map of lithology of Kasika and how they influence landslides in the region.

Rainfall map reclassification

The rainfall map was reclassified using the natural breaks method which involved dividing the rainfall values received in the region into five classes basing on the wet seasons rainfall values. The classification was based on that higher rainfall values are associated with more landslide occurences than low values (Mersha et al.,2020).

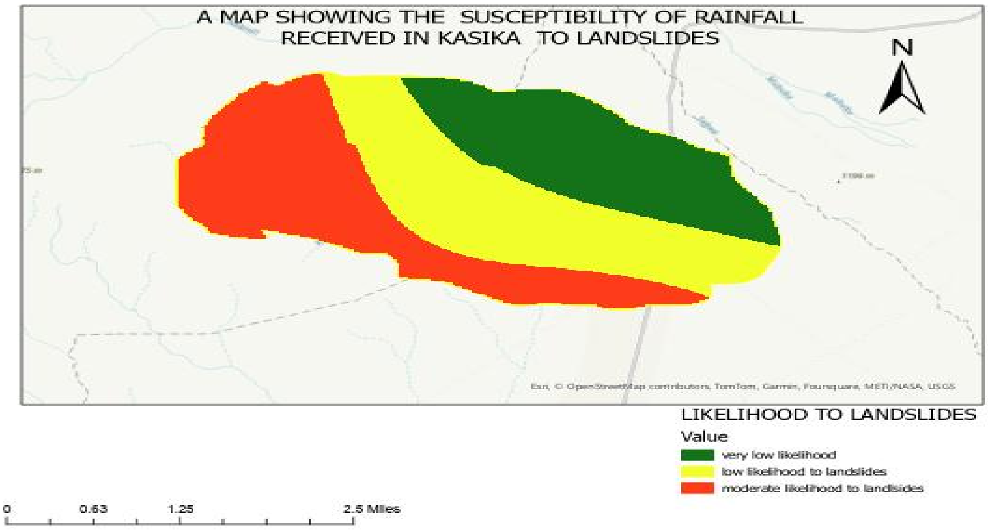

Figure 17 Reclassified map showing the likelihood of the rainfall values received in Kasika village and how they influence the cause of landslides in the region.

3.1.5 Landslide inventory mapping

A landslide inventory map was created through a combination of field surveys of the local community and interpretation of LANDSAT satellite imagery to locate and identify areas where the landslides happened in the region of Kasika village. A total of 4 landslides were identified during our field survey of the region of kasika and coordinates of latitude and longititude were recorded using a handy GPS . Other landslide scars were ontaoned from satellite imagery from google earth pro. The collected landslide scars data was then converted into vector based point data then, vector polygon drawn to map out the whole landslide scars and later the vector polygons of the landslide inventory were then rasterised into raster format of cell size 30m by 30m in ArcGIS pro with similar dimensions as the landslide causative reclassified factor maps.

3.1.6 Multi criteria Decision Analysis using the Analytical Hierarchy Process(AHP).

The AHP process was used to analyse and rank the reclassified landslide causing factor maps on how they contribute to landslides in the Kasika village. And this was the process on how it was done :

Defining the problem and criteria: The landslide reclassified causative factor maps were classified based on how they influence landslide occurences in the Kasika region.

The criteria that was used included the slope angle reclassified map, the rainfall reclassified map, the distance to stream reclassified map, the lithology reclassified map, the landuse and landcover reclassified map , the curvature reclassified map , the aspect reclassified map and lastly , the curvature reclassified map of Kasika village. These were arranged hierachically on how the influence the landslides in the Kasika region.

Constructing the Pairwise Comparison Matrix:

A pairwise comparison matrix was constructed based on expert judgement considering the relative likelihood of each factor causing the landslides. Slope was deemed the most significant to cause landslides in the region , followed by rainfall, distance to stream, lithology, landcover and landuse , aspect and curvature .

landslide causative factors	slope	lithology	curvature	rainfall	landcover and landuse	aspect	distance to stream
slope	1	3.0	6.0	1.0	4.0	5.0	2.0
lithology	0.3333333333	1	3.0	0.5	1.0	2.0	1.0
curvature	0.1666666667	0.3333333333	1	0.2	0.55	1.0	0.25
rainfall	1	2	5	1	3.0	4.0	1.0
landcover and landuse	0.25	1	1.8181818188	0.3333333333	1	1.0	0.5
aspect	0.2	0.5	1	0.25	1	1	0.33
distance to stream	0.5	1	4	1	2	3.03030303	1
SUM	3.45	8.8333333333	21.81818182	4.2833333333	12.55	17.03030303	6.08

Table 2 pairwise matrix of the landslide causative factors

AHP Scale of Importance for comparison of the pairs	Numerical rating	Reciprocal
Extremely importance	9	1/9
Very strong to extremely	8	1/8
Very strong importance	7	1/7
Strongly to very strong	6	1/6
Strong importance	5	1/5
Moderately to strong	4	1/4
Moderately importance	3	1/3
Equally to moderately	2	1/2
Equal importance	1	1

Table 3 Preference scale used to come up with the pairwise matrix.

Source: (Valdari L. et al.,2022).

Basically, during the population of the comparison pair matrix , values from the preference scale (1-9) were assigned importance based on expert judgement in the field of disasters as for Kasese district and reciprical values were used for inverse comparisons.

Calculating the Normalised Matrix:

Each column in the pairwise matrix was summed and each element was divided by its respective column total to normalise the matrix. This ensures all values are proportionate and fall between 0 and 1.

Column 1	slope	lithology	curvature	rainfall	landcover and landuse	aspect	distance to stream	Weights of causative factors	LEMDA(λ)
Slope	0.289855072	0.339622642	0.275	0.233463035	0.3187251	0.293594306	0.328947368	0.297029646	7.112016321
Lithology	0.096618357	0.113207547	0.1375	0.116731518	0.079681275	0.117437722	0.164473684	0.117950015	7.098807896
Curvature	0.048309179	0.037735849	0.045833333	0.046692607	0.043824701	0.058718861	0.041118421	0.046033279	7.091681604
rainfall	0.289855072	0.226415094	0.229166667	0.233463035	0.239043825	0.234875445	0.164473684	0.231041832	7.100667254
landcover and landuse	0.072463768	0.113207547	0.083333333	0.077821012	0.079681275	0.058718861	0.082236842	0.081066091	7.115345041
aspect	0.057971014	0.056603774	0.045833333	0.058365759	0.079681275	0.058718861	0.054276316	0.058778619	7.102796265
distance to	0.144927	0.113207	0.183333	0.233463	0.15936255	0.177935	0.16447368	0.168100518	7.079035

stream	536	547	333	035		943			352
SUM	1	1	1	1	1	1	1		7.11 5345 041

Table 4 Normalised matrix generated from the AHP process.

Deriving criteria weights

The weights (relative priorities) for each criterion were computed by averaging the normalized values in each row of the matrix. The results were as follows:

- Slope reclassified map got 0.2969
- Rainfall reclassified map got 0.2310
- Distance to stream map got 0.1678
- Lithology map got 0.1179
- Landcover and landuse map got 0.0822
- Aspect map got 0.0589
- Curvature map got 0.0454

Checked Consistency of the experts judgement:

consistency calculations confirmed logical coherence in the judgements :

- $\lambda(max)$ was 7.1033
- The consistency index (CI): CI=λ(max)-nn-1=(λ(max)-n)/(n-1)=0.0172
- Consistency ratio (CR): CR=0.013
- Since CR < 0.1 , THE MATRIX IS CONSISITENT.

Aggregating the results

The priority weights represent the relative contribution of each factor to landslide occurrence in Kasika Village. These weights are to be used for weighted Overlay Analysis.

Basically, slope had the highest weights from the AHP process that is (0.2969) as the most influential factor causing the landslides in Kasika village , followed by Rainfall and Distance to stream to Lithology, Landcover and Landuse, Aspect and Curvature. The consistency ratio confirms that the analysis using the AHP process was reliable.

3.1.7 Weighted overlay Proccess in the ArcGIS pro environment

The weighted Overlay Analysis method in ArcGIS pro combined multiple raster landslide reclassified maps to identify yhe areas in Kasika village where the landslides are more susceptible from the areas where the landslides are not more susceptible.

The reclassiffied landslide causative factor raster maps were obtained and assigned weights according to the AHP process on how they influence landslides in Kasika village .

The raster datasets were adjusted to have the same spatial resolution , cell size and uniform coordinate system.

The weights from the AHP process were used as percentages in the weighted overlay Analysis:

- Slope reclassified raster map was given 30%
- Rainfall reclassified raster map was given 23%
- Distance to stream raster map was given 17%
- Lithology raster map was given 12%

- Landcover and landuse reclassifed rater map was given 8%
- Aspect reclassified raster map was given 6%
- Curvature reclassified raster map was given 5%

Those were the weights required to generate the final landslide susceptibility map for Kasika village.

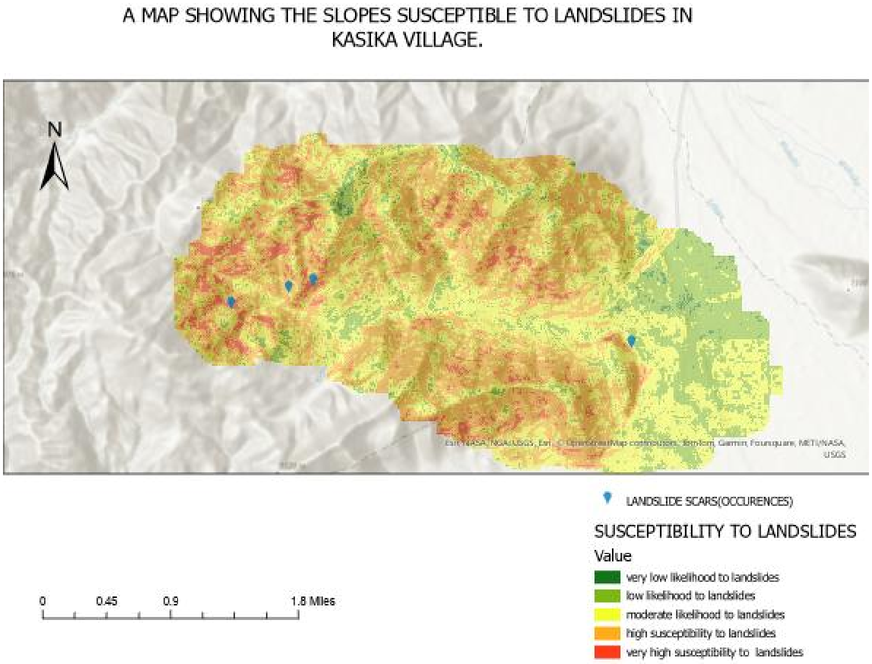

Figure 18 The landslide susceptibility map of Kasika village produced from the weighted overlay process.

3.1.8 Validation of the landslide susceptibility map using Receiver Operating Curve(ROC)

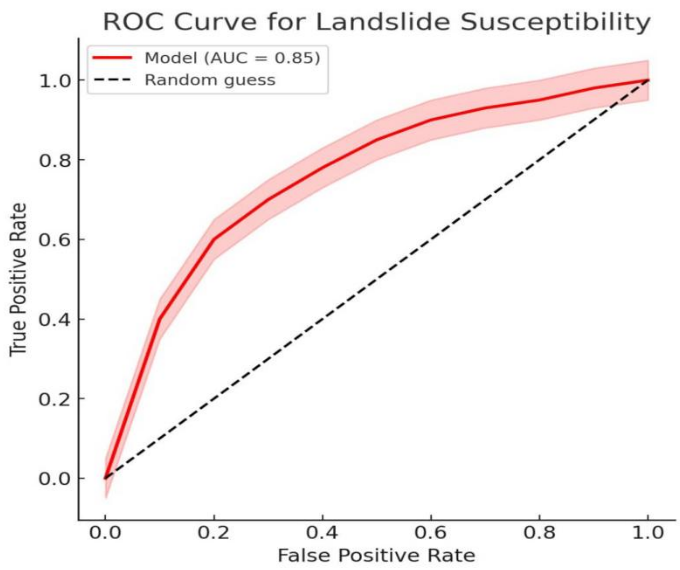

Figure 19 Receiver operating curve of Kasika Village for landslide suscpetibility

The receiver operating curve above had an area under the curve AUC of 0.85 which is cosidered very good and considers that the map had accurately map out landslide prone areas with no false alarms. Basicaly, area undr the curve was a measure applied to see how accurately the landslide susceptibility map mapped out landslide prone areas from those areas that are not prone to landslides.

3.2 Evaluating the suitability of the factor of safety of the slope before failure.

3.2.1 Identification of susceptible slope endagering infastructure such as roads

Endagered infastructure for this context roads were identified in the landslide prone areas from the landslide susceptibilty map and one slope was chosen to determine its factor of safety before failure.

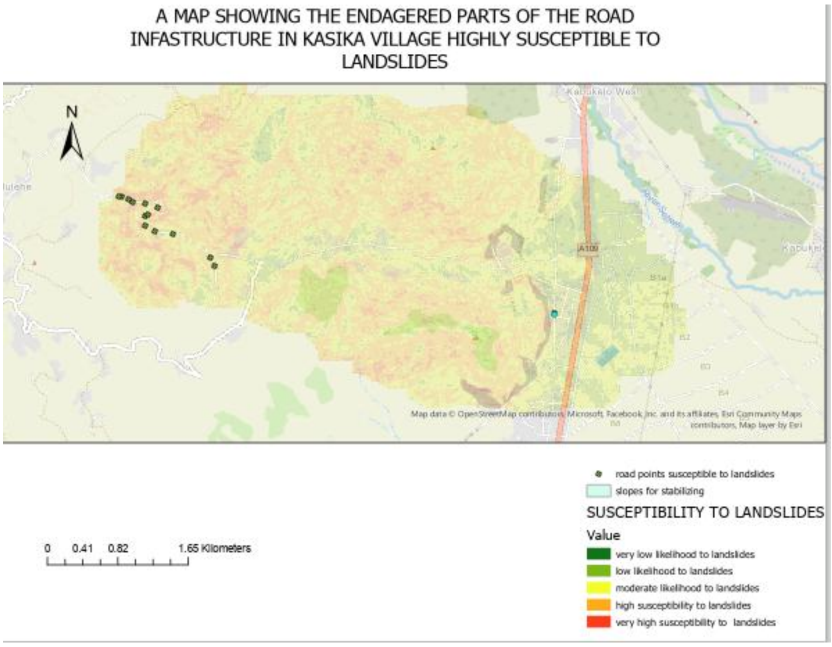

Figure 20 Map showing the endagered parts of the road network passing through Kasika village.

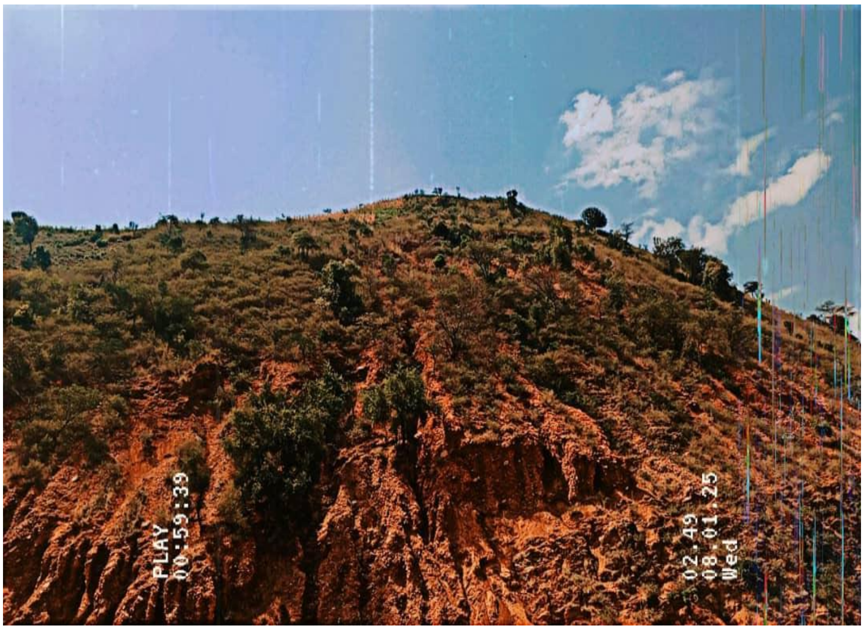

Figure 21 Chosen slope to determine its factor of safety before failure.

This study involved evaluating the geotechinical conditions of the soil for the endagered slope and determine the factor of safety of the slope to see how susceptible it is to failure.

3.2.2 Laboratory testing

The following laboratory tests were carried out to determine the soils properties of the slope of study:

Particle Size Distribution-BS 1377:Part 2 :1990.

The test involved the quantitative determination of particle size distribution in an essentially cohesion less soil down to fine sand size. In the wet preparation procedure, the sample was first soaked in order to dislodge soil particles and then wet sieved to remove silt and clay sized particles followed by dry sieving of the remaining coarse material.

Sieve analysis is an important classification test for soils, especially coarse soils, as it presents the relative portion of different sizes of particles and determines whether the soil consists of predominantly gravel, sand, silt or clay soils.

Atterberg tests BS 1377: Part 2: 1990.

LIQUID LIMIT (LL) - BS 1377: Part 2: 1990.

The liquid limit (LL) of the soil was determined by plotting a curve of the cone penetration through the soil pastes against the average moisture contents and considering the moisture content at 20mm penetration.The liquid limit of a soil is the moisture content, expressed as a percentage of the mass of the oven-dried soil, at the boundary between the liquid and the plastic states. The moisture content at this boundary is arbitrarily defined as the liquid limit and is the moisture content at a consistency determined by means of the standard liquid limit apparatus

PLASTIC LIMIT (PL) AND PLASTICITY INDEX (PI) – BS 1377: Part 2: 1990.

The Plastic Limit (PL) of a soil is the moisture content, expressed as a percentage of the mass of the oven-dried soil, at the boundary between the plastic and the semi-solid states. The Plasticity Index (PI) of a soil is the numerical difference between the liquid limit and the plastic limit of the soil and indicates the moisture content range in which soil is in a plastic state. That is to say; Plasticity Index (PI) = Liquid Limit (LL) – Plastic Limit (LL).

LINEAR SHRINKAGE LIMIT – BS 1377: Part 2: 1990 .

The Linear Shrinkage (LS) of a bar of a soil is the linear change in length of the fraction of a soil sample passing 0.425 mm sieve as it dries from the liquid limit moisture content.

SHEAR BOX TEST – BS 1377: Part 7: 1990.

The shear box allowed a direct shear test to be made by relating stress at failure to the applied normal stress. The objective of the test was to determine the effective shear strength parameters of the soil, the cohesion (C') and the angle of internal friction (ϕ). These values were used for calculating the factor of safety of the soil.

STANDARD PROCTOR COMPACTION TEST FOR OBTAINING MDD AND OMC – BS 1377: Part 4: 1990.

The Maximum Dry Density (MDD) of a material for a particular compaction effort is the highest density obtainable when the compaction is carried out on the moist mass of the material and the moisture content is varied.A 4.5Kg rammer with a height of 450mm compacts the material in a CBR mould in five equal layers. This test is used for soils in which all particles pass a 20mm test sieve. It is also used for coarser soils containing up to 15% material coarser than 37.5mm.

Consolidation Test BS 1377-5:1990.

The objective is to determine the rate and magnitude of the soil consolidation under loading, assessing settlement characteristics and behavior of soils under long term loads.The soil sample is prepared and fitted into the consolidometer ring. It is then saturated with water Incremental vertical loads are added maintaining each until primary consolidation is complete.The settlement readings are recorded at specified intervals. The sample is gradually unloaded to observe the rebound behavior The data is analyzed to determine consolidation parameters of Coefficient of consolidation and compression index.

3.2.3 Determining the factor of safety of the slope

To determine the factor of safety of the slope the Limit Equilibrium principle was used to assess the stability of the slope. This principle assumes that the potential failure mass is at a point of limiting equilibrium where the resisting forces (mainly the shear strength parameters of the slope) exactly balance the driving forces (primarily gravity and any additional loads). In other words, the slope is assumed to be on the verge of failure and the factor of safety (FS) was calculated as the ratio of the available shear strength to shear stress required to maintain equilibrium.

The reason for using the Limit equilibrium principle for slope analysis was due to its simplicity and practicability as the method uses static equilibrium (forces and moments) to derive the FS, making it straight forward compared to the other methods of deformation analysis Wischmeier R.N. et al.,1978. Empirical calibration as it has been calibrated to incorporate parameters of the slope such as soil parameters like cohesion , frictiom amgle and unit weight. Applicability to varied conditions as the approach requires assuming a failure surface and can be adapted to different slope geometries and loading conditions.

The assumptions we employed were:

Defined failure surface that is a potential slip surface was assumed.

Uniform material properties were assumed along the failure mass even though in reality the soil properties can vary.

No deformation was considered as the failure mass is rigid and does not account for the deformation of the soil prior to failure.

The entire sliding mass was assumed to be in state of equilibrium where the sum of forces and moments equal zero. Thus calculating the FS by comparing the resisting and driving forces.

The morgenstern price method was applied using GeoStudio 2018 because of its flexibility and rigor in evaluating complex slope geometries and for its capability to account for both force amd moment equilibrium.

The following were the assumptions given during the investigations with morgenstern price method:

Interslice force distribution was assumed to be a function to represent the distribution of forces between the slices.

Each slice was treated seperately and the interslice forces were used as a mechanism to account for mutual interaction.

Both the sum of horizontal and vertical forces and the sum of moments bout a chosen point were taken to be zero.

The shear resistance of each slice was given by the Mohr- Coulomb equation.

This assumptions simplified the true behaviour of the soil mass, provide a tractable means to compute the factor of safety Morgenstern J.A. et al.,1971.

Determining the water table conditions of kasika:

The pore water pressure conditions of kasika village were determined using the static water levels of the boreholes in Kasese district. This was used to establish the piezometric line in Geostudio of where the water table is.

place	SWL (m)	LATITUDE	LONGITUDE
Kivengenyi	3.92	0.22914722	30.1577
Kyondo	5.91	0.1865083	29.869972
Kikongo	10.24	0.3714972	30.206483
Hima town ward	7.16	0.2940472	30.17783
Rugyendabara	29.04	0.3121305	30.24095
Kizungu	1.50	0.1837805	30.08482
Mubuku	1.65	0.8642027	30.1228417
Kanamba	3.50	0.1721083	30.0872083
limestone works	6.50	0.170544	30.05464
Kilembe limestone works	6.50	0.19415	30.0112306
Kisojo	12.30	0.2869	30.1132
Kyangwali	34.23	0.1698972	30.078077
Ibuga Primary School	6.95	0.13666	30.215027
Bugoye	14.70	0.305972	30.098294
Rwakingi	6	0.283238	30.105844

block c	20.08	0.179283	30.176639
Hima C.O.U	13.91	0.291673	30.176639
Nyaruzikati	20.1	0.010961	29.9596194
Karambi	16.79	0.0607	29.736581
kayanja	2.41	-0.0878583	29.7648055
Katojo	11.43	-0.00910833	29.761425
Katunguru mosque	22.24	-0.122883	30.047094
kasenyi disp	5.73	-0.031733	30.1489194
Hamukung Parent's School	6.85	0.009005	30.0777083
Kamaiba Primary School	15	0.166183	30.072427
rugandabara	5	0.31514166	30.2397944
ruhindo	12.4	0.128883	30.065375

Table 5 Boreholes around Kasese District with there static water levels and coordinates of there positions.

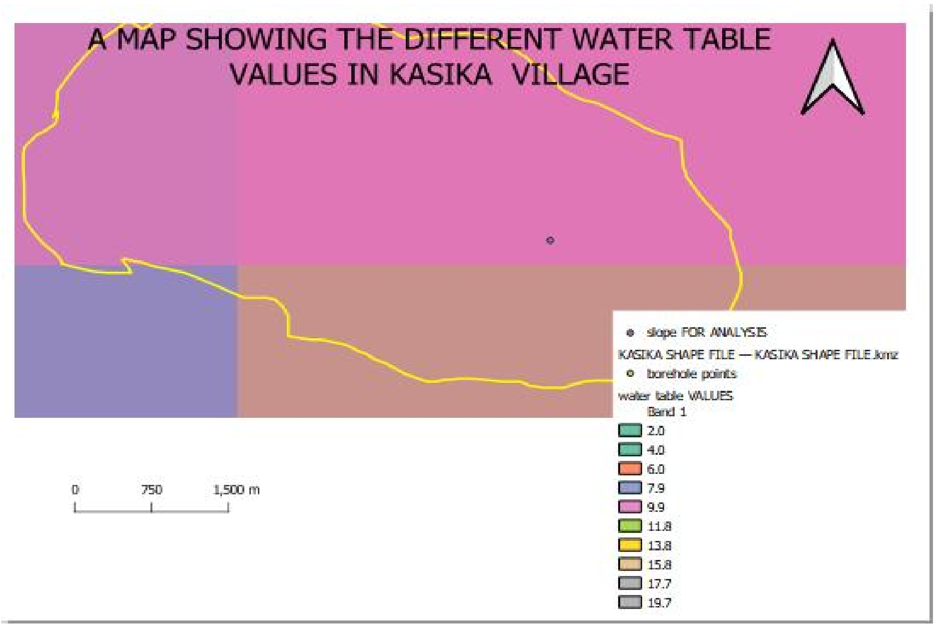

Figure 22 A map showing the different static water levels around Kasika Village obtained through Inverse Distance Weighting(IDW)

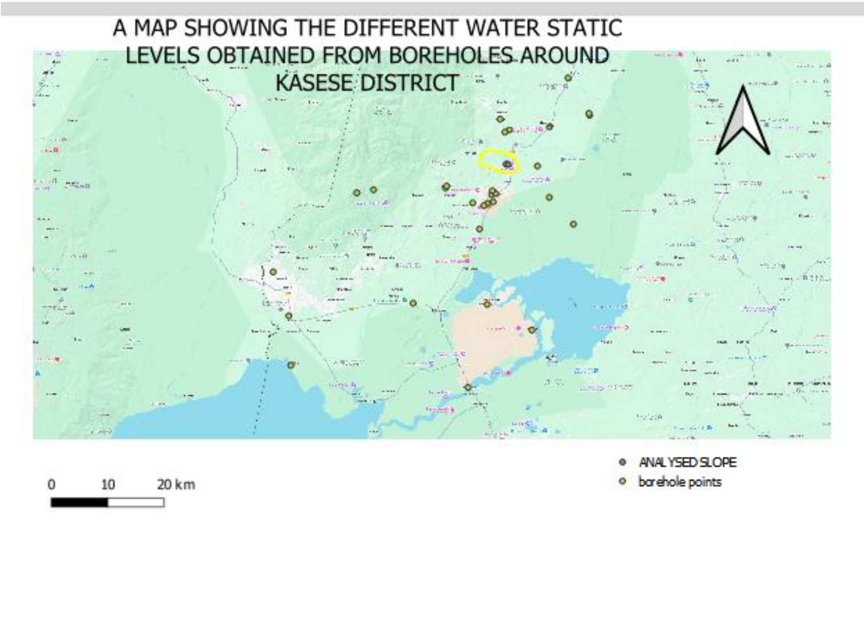

Figure 23 A map showing the different bore hole locations used to obtain the static water levels of Kasika Village.

Developing the slope geometry that was used in Geostudio for slope analysis.

Employed during our field survey the following procedure to determine the geometric parameters of a slope located at 0°13'38.71"N latitude and 30°6'43.03"E longitude. We used the collected data for stability analysis using GeoStudio software. Our procedures encompassed coordinate acquisition, elevation measurement, slope length determination, and subsequent geometric calculations. We utilized tools such as the Handy GPS application and Google Earth Pro, and we provide recommendations for enhancing data accuracy.

For coordinate aquisation , we used the handy GPS application to establish the geographical coordinates of the endangered slopes. This facilitated the accurate location and mapping in Google earth pro.

Elevation and slope length measurement: the google earth pro application was used to determine the elevation data in ft for the different slope points. Google earth pro was also used to visualise the 3D terrain of the slope. This allowed for comprehensive analysis of the slope's geometric features. Additionally, Google Earth Pro's elevation profile tool facilitated the assessment of elevation changes along specific paths, enhancing our understanding of the slope's gradient and overall morphology.

Figure 24 Showing the 3D terrain of the endagered slope

After establishing the slope geomterical properties of the slope , the factor of safety of the slope was analysed in Geoslope for both saturation and non saturated conditions of the slope.

3.3 Assessing the effectiveness of biotechnical slope stabilization techniques for slope stabilization in landslide prone areas.

3.3.1 Choosing the most appropriate biotechnical slope stabilization technique.

Brush layering with bamboo a species called Oldenia alpina was the slope stabilisation technique that was chosen because it involves the use of the limit equilibrium principle for infinite slope stability analysis that allows for the quantification of the factor of safety of both the saturation and normal soil conditions of the slope allowing for the reinforcement parameters(the bamboo live cuttings) to quantified basing on their bench spacing , reinforcement density along the different slope depths (Gray D.H. et al,1992).

Determined the pullout resistance of the live cuttings under different slope loads.

Pullout resistance tests were carried out to assess the actual performance(friction) of the live cuttings of bamboo with the soil along different depths of the slope(the different load conditions of the slope across its depth).

3.3.2 Quantifying and designing the reinforcement model for the slope.

Excell sheets were be designed to vary the parameters of the brush layers such as spacing , reinforcement density for slope conditions of saturation and normal conditions to see how the factor of safety improved as we varied those parameters under the given standards for reinforcing slopes with brush layering for every slope depth which were for reinforcement density 1 cuttings per metre, 2 cuttings per metre , 5 cuttings per metre and 15 cuttings per metre. For the bench spacing were were 1 metre , 2 metres , 5 metres and 10 metres. The angle of the brush layer bench varying from 5 to 10 degrees inclination. For depth of soil to be reinforced 0.5m , 1.0 m , 1.5m and 2m Bischetti, G.B.et al., 2010.

This enabled us to achieve the optimum design parameters of the slope to be stabilized and hence achieved the effectiveness of the brush layering to stabilize the slope.

CHAPTER 4: RESULTS AND DISCUSSIONS

4.1 Evaluating The Slope Susceptibility To Landslides In Landslide Prone Areas.

The landslide causative factors of slope angle , rainfall , curvature, distance to the stream ,Lithology, landuse and landcover , aspect and curvature were ranked using the Analytical hierarchy process(AHP) and the results showed that the slope angle was the most influential factor causing the landslides in the region of Kasika village followed by rainfall,distance to stream , landuse and landcover aspect and curvature.

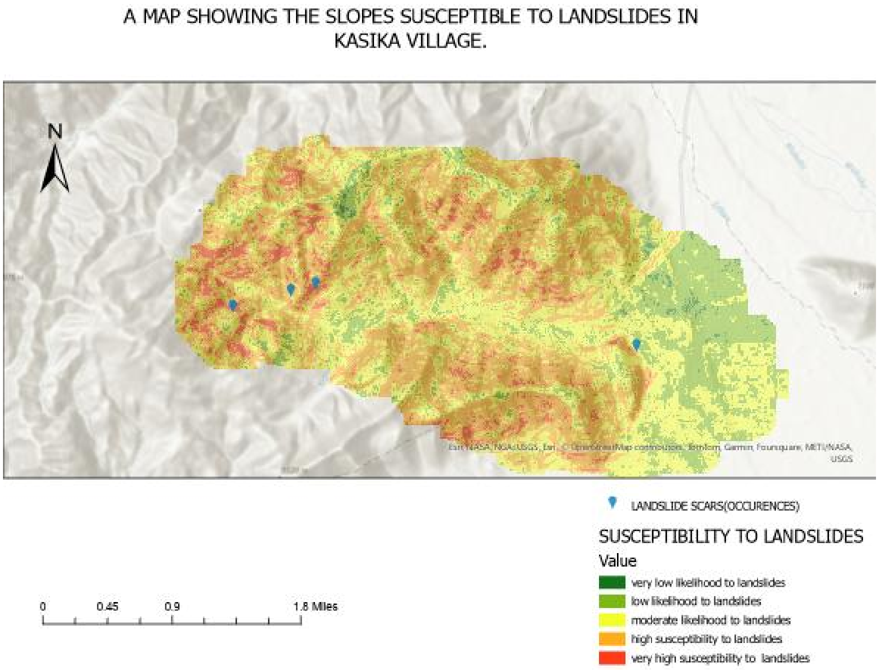

Figure 25 Landslide susceptibility map of Kasika village

The landslide susceptibilty map of Kasika village was categorised into five classes that is very low susceptibilty , low susceptibilty , moderate susceptibilty , high susceptibilty and very high susceptibilty to experience landslides. The areas with very high susceptibility to landslides were taken as landslide prone areas that are endangered to future landslides.

The landslide susceptibility map shown above for Kasika village was validated using the Receiver Operating Curve(ROC) which had an Area Under the Curve of 0.85. This Area under the Curve 0f 0.85 is considered very good and means the landslide susceptibilty map was able to accurately map out landslide prone areas form areas that are not prone to landslides. This ensures that the map is effective at locating landslide prone areas.

Area Under the Curve	Remarks
0.5 and below	No discrimination
0.7 -0.8	Acceptable
0.8 -0.9	Very good
>0.9	Outstanding perfomance

Table 6 Preference scale for Area Under the Curve. source: (Mersha et al.,2020).

4.2 Determining the factor of safety of the slope before failure

For saturated soil conditions

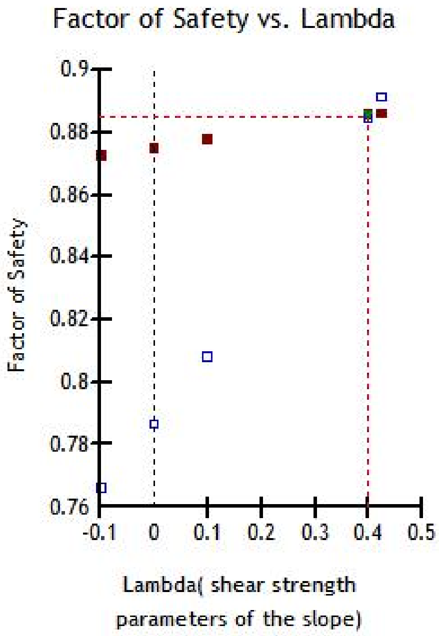

Figure 26 Factor of safety vs lambda of saturated soil conditions of the slope

For normal soil conditions

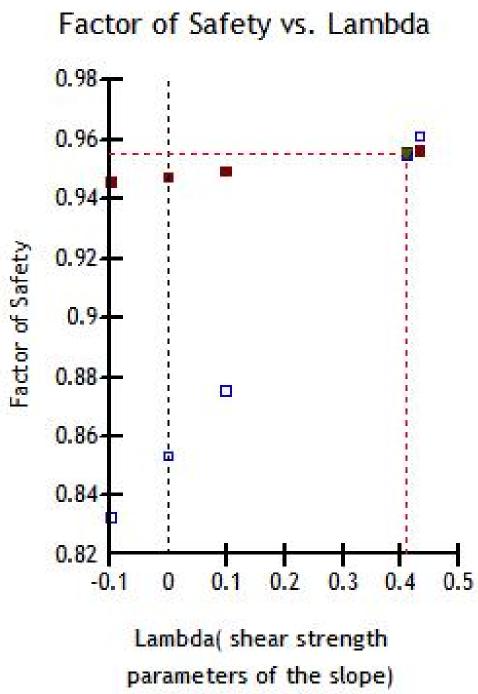

Figure 27 Factor of safety vs lambda of the slope under normal slope conditions

Those two graphs for both saturated and unsaturated soil conditions show that the slope is unstable in both saturation and normal conditions with a factor of safety of 0.885 and 0.955. A factor of safety of 0.885 and 0.955 mean that the slope is unstable. The factor of safety is calculated using the Limit equilibrium principle that is a classical approach used to assess the stability of slopes. The basic idea is that the potential failure mass is assumed to be at the point of limiting equilibrium where the resiting forces (mainly due to shear strength and any reinforcing measures) exactly balance the driving forces (primarily gravity and any additional loads). These results suggest that the slope is not fully stable under the analysed conditions and may be prone to failure under certain scenarios.

4.3 Assessing the effectiveness of biotechinical slope stabilization techniques foe slope stabilization in landslide prone areas.

4.3.1 pullout resistance testing

Pullout resistance tests were carried out to assess the actual mechanical performance of the live cuttings of the bamboo(species: Oldenai Alpina) with the endangered slope soil materials. The following were the diameters of the bamboo live cutting considered.

Bamboo live cuttings no.	D_1(mm)	D_2(mm)	D_3(mm)	D(m)
1	28.64	28.62	28.61	0.0286
2	25.46	20.69	22.85	0.0230
3	12.73	12.50	12.43	0.0125

4	22.28	22.54	22.32	0.0223

Table 7 : Average diameters of the four samples of bamboo live cuttings (Oldenai Alpina) used in the pull out resistance tests

Pullout resistance,R for the live cuttings was determined using the pullout force recorded at 5 % of the embedded length of the bamboo live cuttings extrusion from the metallic box.

$$R = \frac{Fpo}{\pi \; Le \; Dm}$$

Where R is the pullout resistance force at 5 % extrusion of the embedded length of the bamboo live cuttings.

L_e is the embedded length of the bamboo live cuttings into the soil materials from the endangered slope in the metallic box

D_m is the diameter of the live cuttings samples in meters.

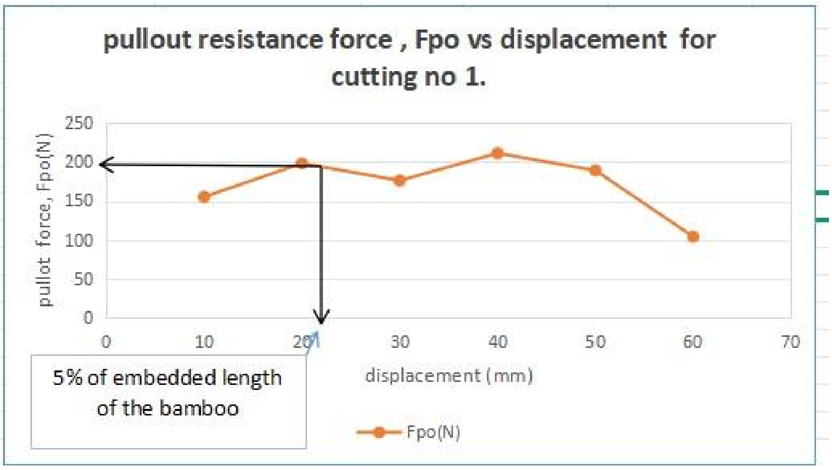

Figure 28 : Pullout force of 200 N was observed to pullout 5% of the embedded length of Bamboo livecuttings sample No. 1

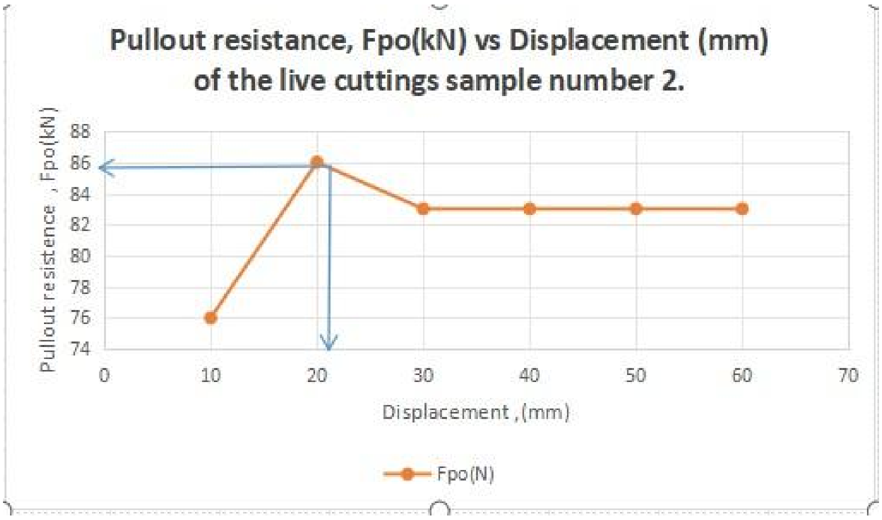

Figure 29 : Pullout force of 85 N was observed to pullout 5% of the embedded length of the Bamboo live cuttings sample No.2

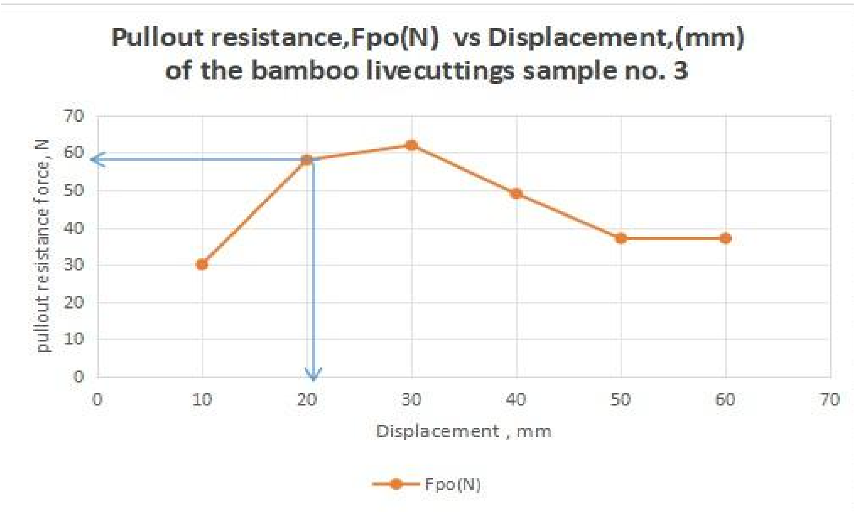

Figure 30 : Pullout force of 58N was observed to pullout 5% of the embedded length of the bamboo livecuttings sample No.3

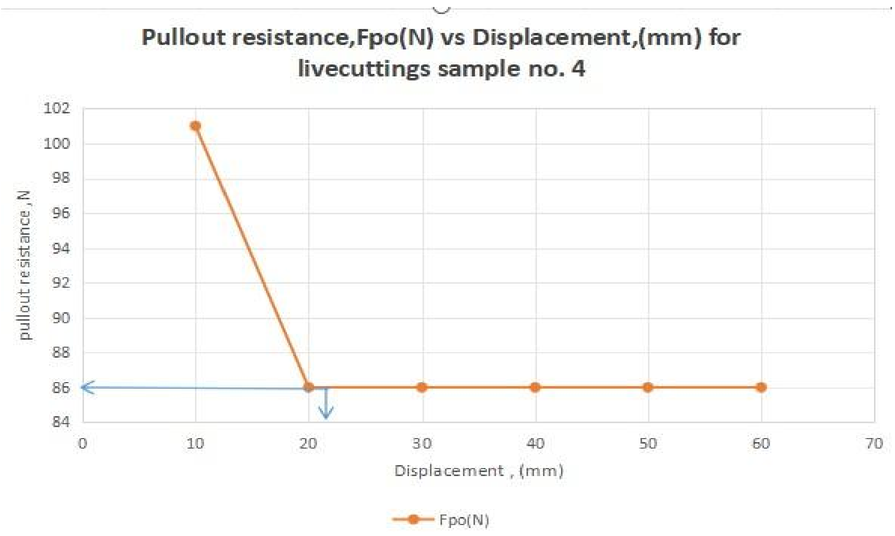

Figure 31 : Pullout force of 86 N was observed to pullout 5% of the embedded length of the bamboo live cuttings sample No.4

From the pullout forces obtained from the pullout resistance tests carried out the following pullout resistances were obtained:

- For the live cuttings sample no.1 had R of 5245.248364 N
- For the live cuttings sample no.2 had R of 2802.284026N
- For the live cuttings sample no.3 had R of 5149.701143N
- For the live cuttings sample no.4 had R of 1965.119535 N

Sample no.1 was observed to have the highest pullout resistance hence was used to quantify the effect of brushlayering of the endagered slope with Bamboo live cuttings(Oldenia Alpina).

4.3.2 REINFORCING MODEL

From the pullout resistance tests, R was obtained as 5245.248264 N and the limit equilibrium principle for slope stabilization for brush layering was used to quantify the effective brush layer parameters for slope stabilisation of the endagered slope.

$$FS(z)=\frac{c'l_1+[nR_{po}(z)\ \sin(\alpha+\beta)+(\gamma_t-\gamma_w m)z\cos^2\beta l_1]tg\phi'}{\gamma_t l_1 z\sin\beta\cos\beta-nR_{po}(z)\cos(\alpha+\beta)}.$$

Equation 1: Factor of safety equation used to quantify the effectiveness of brushalyering with bamboo livecuttings species (Oldenia Alpina) source:Bischetti G.B.et al., 2010.

QUANTIFICATION OF THE BRUSHLAYER PARAMETERS FOR NORMAL SOIL CONDITIONS

From quantification of the brush layer parameters for the endagered slope for normal soil condtions the following are the Factors of safety observed :

Reinforcement density	Brush layering spacing	Depth	Shear strength	Shear stress	Factor of safety
5	1	0.5	77.7	88.6	0.88
10	1	0.5	87.1	67.2	1.3
15	1	0.5	96.4	47.7	2.02
5	2	0.5	146	192.5	0.8
10	2	0.5	155.4	173.1	0.898
15	2	0.5	154.75	153.7	1.07
5	5	0.5	351	510.4	0.64
10	5	0.5	360.4	491	0.73
15	5	0.5	370	471.6	0.78
5	10	0.5	696.2	1040.23	0.67
10	10	0.5	702	1020.82	0.69
15	10	0.5	711.4	1001.4	0.71
5	1	1	71.2	88.6	0.8
10	1	1	80.6	67.2	1.2
15	1	1	90	47.7	1.9
5	2	1	133	192.5	0.7
10	2	1	142.4	173.1	0.8
15	2	1	152	153.7	1
5	5	1	318.4	510.4	0.62
10	5	1	327.8	491	0.67

15	5	1	337.2	471.6	0.72
5	10	1	627.5	1040.23	0.6
10	10	1	636.9	1020.82	0.62
15	10	1	646.2	1001.4	0.645
5	1	1.5	64.7	88.6	0.73
10	1	1.5	74	67.2	1.1
15	1	1.5	83.4	47.7	1.75
5	2	1.5	120	192.5	0.62
10	2	1.5	129.3	173.1	0.75
15	2	1.5	138.7	153.7	0.9
5	5	1.5	285.9	510.4	0.560148903
10	5	1.5	295.2	491	0.601221996
15	5	1.5	304.6	471.6	0.645886344
5	10	1.5	562.3	1040.23	0.540553531
10	10	1.5	571.7	1020.82	0.560039968
15	10	1.5	581.1	1001.4	0.580287597
5	1	2	58.2	88.6	0.656884876
10	1	2	57.5	67.2	0.855654762
15	1	2	76.9	47.7	1.612159329
5	2	2	107	192.5	0.555844156
10	2	2	116.3	173.1	0.671865973
15	2	2	125.7	153.7	0.817826936
5	5	2	253.3	510.4	0.496277429

10	5	2	262.7	491	0.53503055
15	5	2	272	471.6	0.576759966
5	10	2	497.2	1040.23	0.477971218
10	10	2	506.6	1020.82	0.496267706
15	10	2	515.9	1001.4	0.51517875

Table 8 : Observed results from the quantification of brushlayer parameters for normal soil conditions of the endagered slope

EFFECTIVE BRUSHLAYER PARAMETERS AS OBSERVED FOR NORMAL SOIL CONDITIONS FOR THE ENDAGERED SLOPE AFTER QUANTIFICATION USING THE LIMIT EQUILIBRIUM PRINCIPLE.

Depth of bench excavation (m)	Reinforcement density (cuttings/m)	Bench spacing (m)	Factor of safety
0.5	15	1	2.02
1.0	15	1	1.9
1.5	15	1	1.75
2.0	15	1	1.61

Table 9 : Effective brush layer parameters for normal soil conditions for the endangered slope after quantification using the limit equilibrium principle .

QUANTIFICATION OF THE BRUSHLAYER PARAMETERS FOR SATURATED SOIL CONDITIONS

From quantification of the brush layer parameters for the endagered slope for saturated soil condtions the following are the Factors of safety observed :

Reinforcement density	Brush layering spacing	Depth	Shear strength	Shear stress	Factor of safety
5	1	0.5	62.09	88.6	0.7
10	1	0.5	71.47	67.2	1.06
15	1	0.5	80.84	47.7	1.69
5	2	0.5	114.83	192.5	0.6
10	2	0.5	124.195	173.1	0.72
15	2	0.5	133.56	153.7	0.87
5	5	0.5	273	510.4	0.53
10	5	0.5	282.38	491	0.58
15	5	0.5	291.75	471.6	0.62
5	10	0.5	536.65	1040.23	0.52
10	10	0.5	546.02	1020.82	0.53
15	10	0.5	555.39	1001.4	0.554613541
5	1	1	55.58	88.6	0.62731377
10	1	1	64.95	67.2	0.966517857
15	1	1	74.32	47.7	1.558071279
5	2	1	101.79	192.5	0.528779221
10	2	1	111.167	173.1	0.642212594
15	2	1	120.54	153.7	0.784255042
5	5	1	240.44	510.4	0.471081505
10	5	1	249.8	491	0.508757637
15	5	1	259.18	471.6	0.549575912

5	10	1	471.51	1040.23	0.453274757
10	10	1	480.88	1020.82	0.471072275
15	10	1	490.25	1001.4	0.48956461
5	1	1.5	49.06	88.6	0.553724605
10	1	1.5	58.43	67.2	0.869494048
15	1	1.5	67.81	47.7	1.421593291
5	2	1.5	88.79	192.5	0.461246753
10	2	1.5	98.14	173.1	0.566955517
15	2	1.5	107.51	153.7	0.699479506
5	5	1.5	260.34	510.4	0.510070533
10	5	1.5	217.24	491	0.442443992
15	5	1.5	266.61	471.6	0.565330789
5	10	1.5	406.37	1040.23	0.39065399
10	10	1.5	415.74	1020.82	0.40726083
15	10	1.5	425.11	1001.4	0.424515678
5	1	2	68.6	88.6	0.774266366
10	1	2	77.98	67.2	1.160416667
15	1	2	87.35	47.7	1.831236897
5	2	2	127.85	192.5	0.664155844
10	2	2	137.22	173.1	0.792720971
15	2	2	146.59	153.7	0.953741054
5	5	2	305.58	510.4	0.598706897
10	5	2	314.95	491	0.641446029
15	5	2	324.32	471.6	0.687701442

5	10	2	601.79	1040.23	0.57851629
10	10	2	611.16	1020.82	0.598695167
15	10	2	620.53	1001.4	0.619662473

Table 10 : Observed results from the quantification of brushlayer parameters for saturated soil conditions of the endagered slope

EFFECTIVE BRUSHLAYER PARAMETERS AS OBSERVED FOR SATURATED SOIL CONDITIONS FOR THE ENDAGERED SLOPE AFTER QUANTIFICATION USING THE LIMIT EQUILIBRIUM PRINCIPLE.

Depth of bench excavation (m)	Reinforcement density (cuttings/m)	Bench spacing (m)	Factor of safety
0.5	15	1	1.69
1.0	15	1	1.56
1.5	15	1	1.42
2.0	15	1	1.39

Table 11 : Effective brush layer parameters observed for saturated slope conditions of the endangered slope.

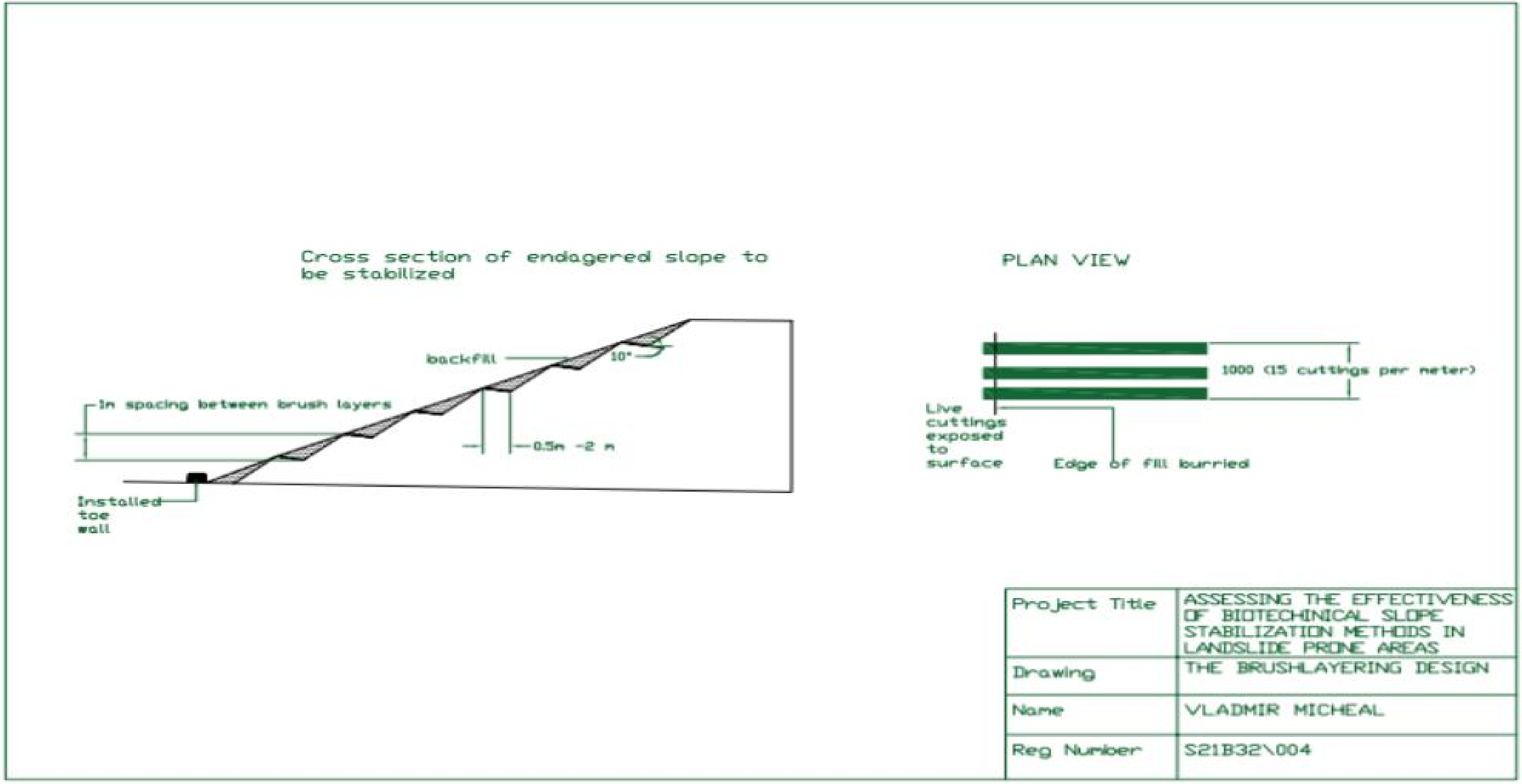

Figure 32: Design of the endagered slope with brushlayers of bamboo livecuttings (Oldenai Alpina)

CHAPTER 5 : CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

This study aimed to identify areas that are prone to landslides in Kasika village using GIS and the Analytical Hierarchy Process, determine the suitability factor of safety of any endangered slope in Kasika village to slope failure and lastly, use a bio technical slope stabilization technique (brush layering with bamboo live cuttings a species Oldenai Alpina) to assess its effectiveness in stabilization in landslide prone areas.

For specific objective one, Mapping the spatial extent of the landslide causing factors in Kasika village was performed,reclassified those maps according to how they influence landslide, analytical hierarchy processing was performed to weigh the intensity of these landslide causative factors on how they actually influence the landslides in this village using expert opinions from the region, performed weighted overlay analysis to produce the landslide susceptibility map which had an Area under the curve of 0.85 after validation showing that the map accurately mapped out landslide prone areas without false alarms.

For specific objective two, obtained the unit weights , friction angle and cohesion for the endangered slopes soil material for both saturated and normal soil conditions which gave FS of 0.845 and 0.945 respectively which is below the threshold for slope stability and signified reason to provide an intervention for stabilization before catastrophic slope failure.

For objective three, the brush layering with bamboo was seen to be effective at stabilizing both saturated and normal soil conditions of the endangered slopes materials at a depth of excavation of the bench at 1m spacing, bench spacing of 1m and reinforcement density of 15 cuttings/m.

5.2 Recommendations

For landslide susceptibility mapping, probabilistic approaches such as the Bayesian Probabilistic approaches of Frequency Ratio among others in the GIS environment should be studied further to understand the susceptibility of the village to landslides based on the probability of the likelihood of landslides are to happen with actual evidence of the past landslides from landslide inventories of the area.

Evaluation of the performance of the brush layers under dynamic loading should be studied and this can be achieved with soft wares such as PLAXIS that cater for real time loading conditions.

For the pullout resistance tests, the long term development of the root systems and their contribution to the pullout resistance needs to be studied more to understand the overall effectiveness of these brush layers and hence understand the full improvement of the Factor of Safety of the endangered slope after maturity of the bamboo live cuttings' roots.

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APPENDICES

LABORATORY AND FIELD RESULTS

THE REPUBLIC OF UGANDA
MINISTRY OF WORKS AND TRANSPORT
MATERIALS TESTING AND RESEARCH DIVISION
CENTRAL MATERIALS LABORATORY- KIREKA
P.O. Box 7174, Kampala-Uganda. Tel: 256-414-287132, Email: cml@works.go.ug

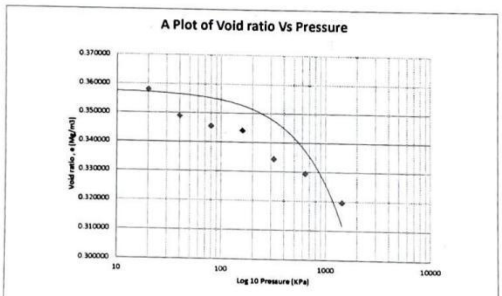
TEST CERTIFICATE FOR CONSOLIDATION OF SOIL

CLIENT : M/S NAKINKUNDA PRISCA AND VLADIMIR MICHAEL
PROJECT : ASSESSING THE EFFECTIVENESS OF BIOTECHNICAL SLOPE STABILISATION IN LANDSLIDE PRONE AREA
DATE : 10 FEBRUARY 2025
Test Standard/ Method: BS 1377-2:2022
Sample Ref. CML 003/31/01/25

THE CONSOLIDATION TEST DATA SHEET

SAMPLE LABEL	TP 01 - Neat		DEPTHS	1.0	m
DIAMETER OF SPECIMEN	0.075	m	THICKNESS ($2H_1$)	0.02	m
VOLUME OF SPECIMEN	0.0000884	m^3			
MC BEFORE TEST	11.2	%	BULK DENSITY	2.032	Mg/m^3
WT OF SAMPLE $ RING	265.13	g	DRY DENSITY (γ_D)	1.827	Mg/m^3
WT OF EMPTY RING	85.55	g	SPECIFIC GRAVITY	2.55	
WT OF WET SOIL	179.58	g	e_o	0.396	
WT OF DRY SOIL		g	SATURATED UNIT WEIGHT	20.704	
			VOID RATIO FACTOR (F)	0.0698	
RING CALIBRATION FACTOR	0.01				

APPLIED PRESSURE Kpa	INITIAL GAUGE READING Dev	FINAL GAUGE READING Dev	CHANGE IN HEIGHT (2H) mm	CHANGE IN VOID RATIO (F*change in 2H)	e (e_o-Change in void ratio)	VOLUME COMPRESSIBILITY: Incremental Changes					
						Viod ratio	Pressure	$1+e_1$	m_v m^2/MN	Settlement (Pc), mm	Compression Index, Cc
0	0.0				0.395739	0	0				0
20	0.0	54.00	0.5400	0.037685	0.358054	0.03768	20.0	1.396	1.350	14.5800	0.000
40	54.00	121.00	0.6700	0.046757	0.348982	0.00907	20.0	1.358	0.334	8.9517	0.030
80	121.00	193.00	0.7200	0.050247	0.345492	0.00349	40.0	1.349	0.065	3.7248	0.012
160	193.00	267.00	0.7400	0.051642	0.344097	0.00140	80.0	1.345	0.013	1.5353	0.005
320	267.00	355.00	0.8800	0.061413	0.334326	0.00977	160.0	1.344	0.045	12.7934	0.032
640	355.00	450.00	0.9500	0.066298	0.329441	0.01466	480.0	1.344	0.023	13.8110	0.049
1440	433.00	542.00	1.0900	0.076068	0.319671	0.01466	1120.0	1.334	0.010	15.3923	0.042
Average									**0.263**	**10.1126**	**0.024**



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CENTRAL MATERIALS LABORATORY KIREKA

THE REPUBLIC OF UGANDA

MINISTRY OF WORKS AND TRANSPORT

MATERIALS TESTING AND RESEARCH DIVISION

CENTRAL MATERIALS LABORATORY- KIREKA

P.O. Box 7174, Kampala-Uganda. Tel: 256-414-287132, Email: cml@works.go.ug

TEST CERTIFICATE FOR GRAVEL/SOIL

CIIENT : M/S NAKINKUNDA PRISCA AND VLADIMIR MICHAEL
PROJECT : ASSESSING THE EFFECTIVENESS OF BIOTECHNICAL SLOPE STABILISATION IN LAND SLIDE PRONE AREAS
DATE : 10-Feb-25
REF. CML 003/31/01/25

Test Standard/ Method: BS 1377-2:2022 and BS EN ISO 17892-10: 2018
Evaluation of Bearing Capacity based on Terzaghi's Model for 1.0m square footing sizes (Local Shear Failure Mechanism)

Test pit/ location	Depth, D	Width, B	Bulk Density, γb	Effective Vertical Stress, σ	Shear Strength, s_u	Yield Stress Ratio	Adhesion Factor	Unit Skin Friction	Cohesion	Modified Cohesion	Angle of Friction	Modified Angle of Friction	Bearing Capacity Factors			Ultimate Bearing Capacity	Safety Factor	Allowable Bearing Capacity
	(m)	(m)	(kN/m³)	(kPa)	(kPa)	s_u/σ	α	f_s	C (KPa)	C' (KPa)	ϕ (Degrees)	ϕ' (Degrees)	Nc	Nq	N_g	q_{ult} (kPa)	(F)	q_{all} (kPa)
TP.01 - Neat	1.00	1.00	2.08	2.08	58.84	28.31	0.842	49.54	18	12	25	17	14.82	5.60	3.50	246	3	82

$q_{ult} = 1.3CN_c + q_oN_q + 0.4gBN_g$

Where $q_o = g\,D$ $\quad C = 0.67C \quad q_{all} = q_{ult}/F$

$\phi = \tan^{-1}(0.67 \tan\phi)$

For :	strip	round	square
sc	1	1.3	1.3
sg	1	0.6	0.8

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DATE : 10-Feb-25
REF. CML 003/31/01/25

Test Standard/ Method: BS 1377-2:2022 and BS EN ISO 17892-10: 2018
Evaluation of Bearing Capacity based on Terzaghi's Model for 1.0m square footing sizes (General Shear Failure Mechanism)

Test pit/ Location	Depth, D (m)	Width, B (m)	Bulk Density, γ_b (kN/m³)	Effective Vertical Stress, σ (kPa)	Shear Strength, s_u (kPa)	Yield Stress Ratio s_u/σ	Adhesion Factor, α	Unit Skin Friction, f_s	Cohesion C (KPa)	Angle of Friction ϕ (Degrees)	Bearing Capacity Factors Nc	Nq	N_γ	Ultimate Bearing Capacity q_{ult} (kPa)	Safety Factor (F)	Allowable Bearing Capacity q_{all} (kPa)
TP.01 - Neat	1.0	1.0	2.08	2.08	58.84	28.31	0.84	49.54	18	25	25.10	12.70	9.70	620	3	207

$q_{ult} = CN_c sc + q_o N_q + ½\gamma BN_\gamma s\gamma$

Where: $q_o = \gamma D$

$q_{all} = q_{ult}/F$

For :	strip	round	square
sc	1	1.3	1.3
sγ	1	0.6	0.8

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CLIENT M/S NAKINKUNDA PRISCA AND VLADIMIR MICHAEL
PROJECT ASSESSING THE EFFECTIVENESS OF BIOTECHNICAL SLOPE STABILISATION IN LANDSLIDE PRONE AREA
DATE 10 FEBRUARY 2025
Test Standard/ Method: BS 1377-2:2022
Sample Ref. CML 003/31/01/25

THE CONSOLIDATION TEST RESULTS SUMMARY SHEET ON UNDISTURBED SAMPLES

Test Point Label	Depth (m)	Saturated Unit weight, γ_{sat} (kN/m³)	Average Coefficient of Volume Compressibility m_v, (m²/MN)	Range of Coefficient of Volume Compressibility (m²/MN)	Elastic Modulus, E_{oed} (MN/m²)	Settlement (Pc), mm	Compression Index, Cc	Remarks based on average values
TP 01- Neat	1.0	20.70	0.263	0.1 - 0.3	3.81	10.113	0.024	Medium compressiblity

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UGANDA CHRISTIAN UNIVERSITY
A Centre of Excellence in the Heart of Africa

FACULTY OF ENGINEERING, DESIGN, AND TECHNOLOGY
Department of Engineering and Environment

Certificate Number: A003		
Client Name: NAKINKUNDAPRISCA & VLADIMIR MICHAEL **Client Address and Contact:** UCU P.O Box 4, Mukono 0760450271 **Client Sample ID:** For pull out resistance tests between Bamboo live cuttings (Oldeania Alpina) and the endangered slope materials(soils). **Sample type and Location:** Soil sample from a slope in Kasika-Kasese district.	**Sample Receipt Date:** 07/03/2025	**Analysis Start Date:** 07/03/2025
Tom More Mwanje **Head of Department-Engineering & Environment** ………………………………………………		

UGANDA CHRISTIAN UNIVERSITY
H.O.D
24 MAR 2025
DEPARTMENT OF ENGINEERING AND ENVIRONMENT

Table 1: The bamboo live cuttings used for the pullout resistance tests and there respective mean diameter

Bamboo live cutting no.	D1(mm)	D2(mm)	D3(mm)	D(mm)	D(m)
1	28.64	28.62	28.61	28.62333333	0.028623333
2	25.46	20.69	22.85	23	0.023
3	12.73	12.5	12.43	12.55333333	0.012553333
4	22.28	22.54	22.32	22.38	0.02238

Table 2: pullout resistance Force, Fpo vs dispalcement for cutting no.1 with mean diameter of 0.029m.

Fpo(N)	displacement (mm)
155	10
198	20
176	30
211	40
189	50
104	60

Table 3: pullout resistance Force, Fpo vs dispalcement for cutting no.2 with mean diameter of 0.023 m.

Fpo(N)	displacement (mm)
76	10
86	20
83	30
83	40
83	50
83	60

Table 4: pullout resistance Force, Fpo vs displacement for cutting no.4 with mean diameter of 0.022 m.

Fpo(N)	displacement (mm)
101	10
86	20
86	30
86	40
86	50
86	60

Table 5 : pullout resistance Force, Fpo vs dispalcement for cutting no.3 with mean diameter of 0.013 m

Fpo(N)	displacement (mm)
30	10
58	20
62	30
49	40
37	50
37	60

5% of the embedded length is 21 mm of the live cuttings embedded into the soil.

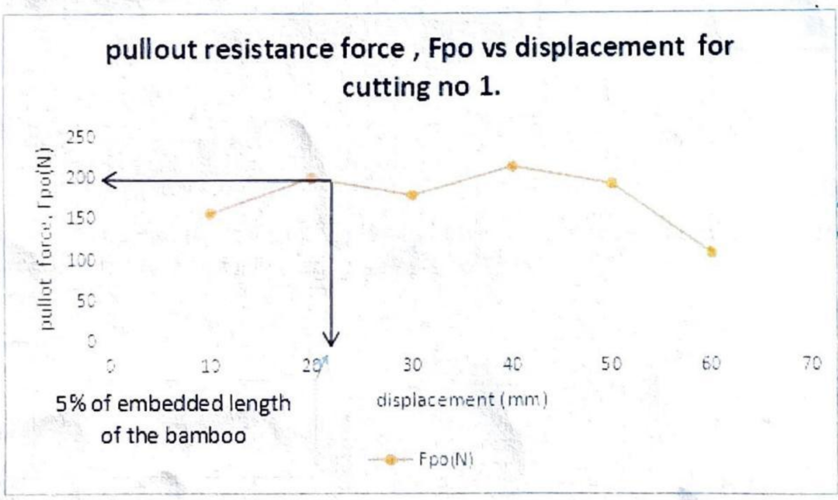


Figure 1 : pullout resistance of 200 N was observed to pullout 5% of the embedded length of the bamboo live cutting sample no.1.

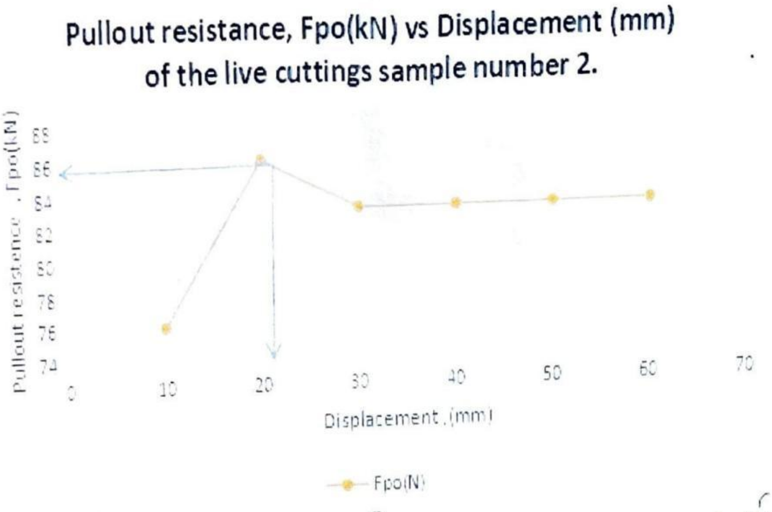


Figure 2 : pullout resistance of 85 N was observed to pullout 5% of the embedded length of the bamboo live cutting sample no.2.

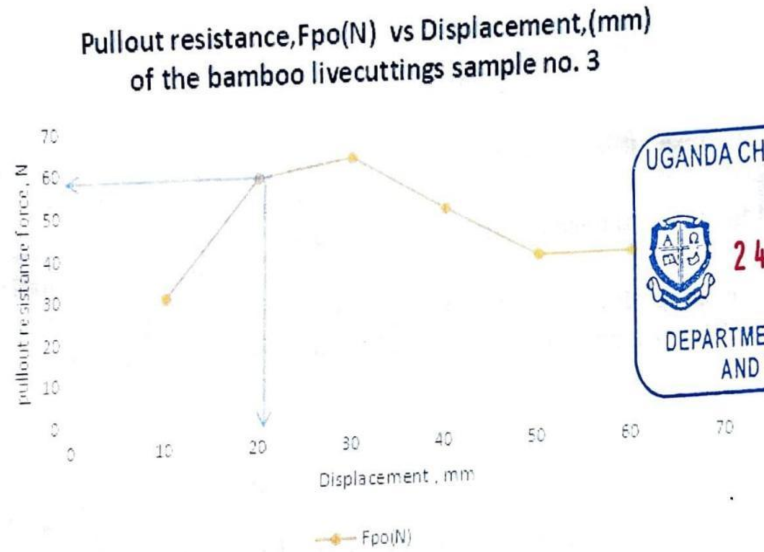


Figure 3 : pullout resistance of 58 N was observed to pullout 5% of the embedded length of the bamboo live cutting sample no.3.

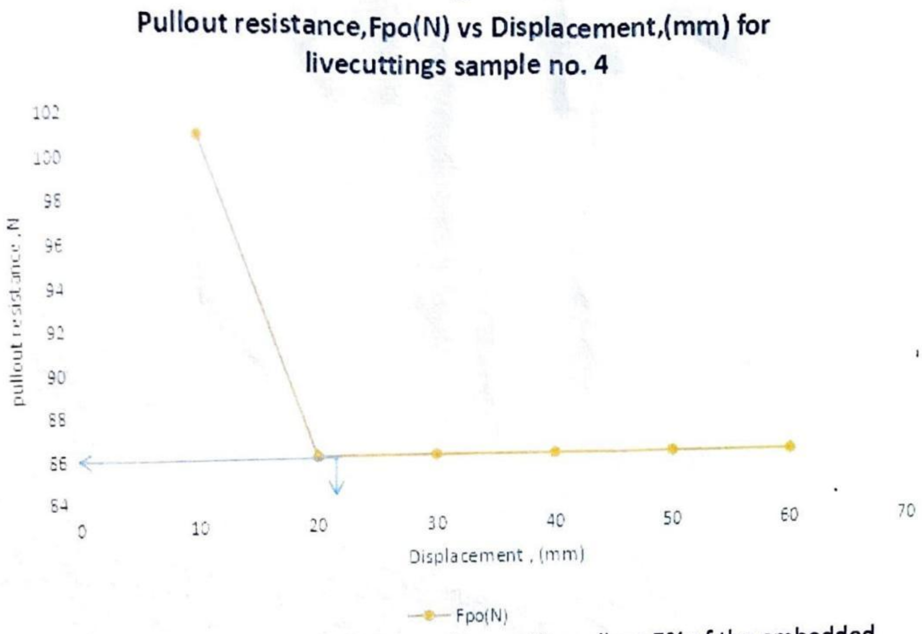


Figure 4 : pullout resistance of 86 N was observed to pullout 5% of the embedded length of the bamboo live cutting sample no.4.

$$Rpo = \frac{Fpo}{\pi \text{ x } Le \text{ x } \mathbf{D(m)}}$$

Where F_{po} is the pullout force required to cause 5% of displacement of the livecuttings from the soil.

$\mathbf{D(m)}$ is the diameter of the bamboo live cuttings used to carry out the pullout resistance tests.

$\boldsymbol{Le}$ is the embedded length of the bamboo livecuttings into the soil.

$\boldsymbol{Rpo}$ is the maximum friction force between the bamboo live cuttings and the soil.

Observations :

For live cutting sample no.1 had a Rpo of 5245.248264N

For live cutting sample no.2 had a Rpo of 2802.284026N

For live cutting sample no.3 had a Rpo of 5194.701143N

For live cutting sample no.2 had a Rpo of 1965.119535N

YEAR		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT
2024	MAX	30.1	31.2	32.2	30.4	31.7	31.9	30.3	30.6	31.9	30.7
	MIN	17.1	17.2	17.4	17.9	17.4	15.7	15.3	15.5	15.4	19.5
	R/F	3.7	93.5	125.9	125.5	185.6	20.2	28.4	84	86.6	190
2023	MAX	31.4	32.7	30.7	30.8	31.9	31.4	32.7	33.3	31.2	30.2
	MIN	17.1	18.3	18.8	19	19.4	18.4	16.9	18.2	17.2	17.5
	R/F	19.7	12.1	167.1	125.2	58.5	37.2	20.8	5.8	57.6	115.6
	0600 RH%	83	78	87	85	82	85	80	77	85	84
	1200 RH%	49	42	56	55	49	50	37	42	54	60
2022	MAX	30.6	30.8	32.3	30.7	31.2	31	31.5	30.4	28.9	30
	NiN	17.8	18.8	18.7	19.2	19.1	18.2	18.5	18.8	17.7	17.8
	R/F	33.7	32.1	61.7	222.7	27.9	21	11.2	98.1	150	82.3
	0600 RH%	83	83	81	85	84	80	76	86	88	83
	1200 RH%	51	49	44	57	54	40	40	51	62	58
2021	MAX	29.8	31.1	32	30.5	30.5	31.2	30.8	30.8	30.4	30
	MIN	16.6	16.7	17.4	17.9	18.3	17.7	18.1	17.5	17.7	17.8
	R/F	80.6	21.2	47.6	118.1	70.6	48.8	54.2	115.4	126.9	99
	0600 RH%	87	84	84	85	88	82	86	85	86	84
	1200RH%	58	49	47	58	55	54	49	49	55	58
2020	MAX	30.1	31.9	31.1	30.9	31.5	31	30.3	30.5	30.1	29.9
	MIN	16.7	17.2	17.8	18.4	18.4	17.6	17	17.1	16.9	16.5
	R/F	52.8	90.5	131.1	76.6	62.1	82.7	22.8	199.9	65.8	103.3
	0600 RH%	86	84	87	85	84	84	88	86	86	85
	1200 RH%	55	48	54	57	52	48	50	52	56	59

NOV	DEC
29.6	30.4
14.7	14.1
131.3	24
28.9	30.3
17.3	17.3
218.6	58.1
89	84
66	58
28.8	29.2
18.7	17.5
119.4	59.3
88	86
63	64
30.6	30.6
17.5	18.5
41.1	95
82	87
52	55
28.6	30.1
16.3	15.6
103.1	61.4
88	83
68	56

Rainfall is one of the major cause of Landslides in Kasese district. ~~Here~~ where most of it is received is the months between March and May & then between months of August and December as per the data.

However, studying its relationship with soil texture in the mountainous area and the slope is something I highly recommend.

UGANDA NATIONAL METEOROLOGICAL AUTHORITY
P.O. BOX 7025, KAMPALA, UGANDA
KASESE
METEOROLOGICAL STATION

Kakuru Bright
Meteorological Supervisor
Kasese Met station,
08/01/2025.

DISTRICT: KASESE

BOREHOLE DATA SUMMARY
PERIOD 01/01/87 TO 31/12/95

Page: 1
07/12/95

SR	B/H No.	NAME	Coordinates East	South	Alt (m)	Depth (m)	SWL (m)	C.Depth (m)	Yield (m3/h)	Pop
1	WDD3925	KIVENGENYI	-	-	-	22.0	3.92	15.0	5.3	1000
2	WDD3926	KYONDO II	-	-	1030	36.0	5.91	18.0	0.9	1000
3	WDD3927	KYONDO SHEDS	-	-	1030	21.0	5.26	15.0	1.9	700
4	WDD3928	KIKONGO	-	-	1040	26.8	10.24	24.0	2.3	1000
5	WDD3929	HIMA TOWN WARD	30.17783	0.294	1040	30.0	7.16	18.0	-	1000
6	WDD3930	MOWLEM	-	-	-	42.0	12.05	15.0	-	2200
7	WDD3931	RUGYENDAWARA	30.241	0.3121	-	62.0	29.04	45.0	-	-
8	WDD3932	KIZUNGU	30.0848	~~30~~ 0.1838	-	28.0	1.50	15.0	-	600
9	WDD3933	KYARANGA	-	-	-	22.8	1.70	15.0	-	-
10	WDD3934	KYARANGA	-	-	-	26.0	1.48	15.0	-	-
11	WDD3935	KASESE ARMY BA	-	-	-	60.0	DRY	-	-	-
12	WDD3936	KABUKERERO	-	-	-	21.8	3.20	15.0	-	-
13	WDD3937	KAKONGA T/C	-	-	-	21.0	-	-	-	-
14	WDD3938	KANATETE	-	-	-	21.0	1.65	15.0	-	500
15	WDD3939	MUBUKU	-	-	-	60.0	-	-	-	-
16	WDD3940	RUHITA 11	30.1228	0.864	-	54.0	34.99	48.0	-	100
17	WDD3941	MUBUKU	-	-	1040	30.0	6.00	12.0	-	360
18	WDD3942	KABAKA RAILWAY	-	-	930	24.0	2.50	15.0	-	100
19	WDD3943	KABAKA RAILWAY	-	-	-	30.0	4.30	15.0	0.9	500
20	WDD3944	KABUGA	-	-	900	36.0	4.90	15.0	-	900
21	WDD3945	KANAMBA	30.087	0.1721	-	24.0	3.50	15.0	-	70
22	WDD3946	MUBUKU	-	-	1030	27.0	5.80	15.0	-	500
23	WDD3947	LIME WORKS	30.05464	0.17054	1050	27.0	6.50	15.0	0.6	-
24	WDD3948	KILEMBE LIME-W	30.01123	0.19415	1050	60.0	-	-	-	-
25	WDD3949	KADAHI	-	-	-	126.0	DRY	-	-	-
26	WDD3950	KISOJO	30.1132	0.2869	1040	21.6	12.30	18.0	3.1	500
27	WDD4481	KYANGWALI II	30.0781	0.1698	-	34.2	34.23	45.0	-	300
28	WDD4482	KYANGALI	-	-	-	42.0	35.29	39.0	-	-
29	WDD4483	KYARANGA P/S	-	-	-	21.0	0.99	15.0	-	-
30	WDD4484	KIGISU	-	-	-	50.0	36.68	45.0	-	750
31	WDD4485	IBUGA P/S	30.2150	0.1366	-	43.0	-	-	-	-
32	WDD4486	RUHIMI	-	-	-	90.0	46.00	57.0	64.0	-
33	WDD4487	BUGOYE T/C	30.098294	0.305972	-	40.0	14.70	30.0	-	350
34	WDD4488	IHANI	-	-	-	42.0	3.43	24.0	-	150
35	WDD4489	RWAKINGI	-	-	-	21.0	4.60	15.0	-	300
36	WDD4490	RWAKINGI	-	-	-	-	-	-	-	-
37	WDD4491	rwakingi	-	-	-	48.0	6.00	21.0	-	-
38	WDD4492	KYARUGOMOKA	-	-	-	-	-	-	-	-
39	WDD4493	BLOCK C II	30.1766	0.179283	-	78.0	20.80	36.0	-	350
40	WDD4494	KINYANKOLE	-	-	-	120.0	-	-	-	-
41	WDD4496	kasese camp	-	-	-	96.0	37.34	75.0	-	-
42	WDD4498	MPARO	-	-	1100	-	25.50	42.0	-	-
43	WDD4499	KIBISIRE	-	-	1190	42.0	8.50	24.0	-	-
44	WDD4502	HIMA C.O.U	30.176639	0.291673	-	40.0	13.91	-	-	-
45	WDD4507	KANAMBA P SCH.	-	-	-	21.0	2.92	-	-	-
46	WDD4931	NYARUZIGATI	29.9596194	0.010961	-	120.0	-	-	-	-
47	WDD4932	RWENTUHA	-	-	-	60.0	12.24	24.0	-	500
48	WDD4933	BUSWANGA	-	-	-	42.0	5.64	24.0	-	400
49	WDD4934	KIBISIRE	-	-	-	60.0	17.08	36.0	-	700
50	WDD4935	RWENTUNTU II	-	-	-	77.0	28.57	48.0	-	120
51	WDD4936	KALEBERIO	-	-	-	120.0	-	-	-	-
52	WDD4937	KYONDO/KARAMBI	-	-	-	30.0	16.79	24.0	-	250
53	WDD4938	KATIKALE	-	-	-	110.0	-	-	-	-
54	WDD4940	KITATURWA	-	-	-	24.0	10.03	21.0	-	850

DISTRICT WATER OFFICER
KASESE

For [signature]

SN	B/H No.	NAME	Coordinates East	South	Alt (m)	Depth (m)	SWL (m)	C.Depth (m)	Yield (m3/h)	Pop
55	[illegible]	KAKANJA NORTH	-	-	-	24.0	2.11	21.0	-	150
56	[illegible]	KAKANJA SOUTH	-	-	1020	24.0	2.02	21.0	1.7	150
57	[illegible]	[illegible]	-	-	1030	30.0	21.56	27.0	-	150
58	[illegible]	NKEHINGO	-	-	-	96.0	DRY	-	-	-
59	[illegible]	KASOHOLO II	-	-	-	36.0	23.96	30.0	-	-
60	[illegible]	KASOHOLO I	-	-	-	96.0	DRY	-	-	-
61	[illegible]	NYAKARIRU	-	-	-	42.0	12.00	30.0	-	-
62	[illegible]	KINYAMINAGA	-	-	-	102.0	23.19	30.0	1.[illegible]	-
63	[illegible]	KASOZI	-	-	-	60.0	13.82	36.0	1.[illegible]	-
64	[illegible]	KINYATSEKE	-	-	-	30.0	9.08	21.0	1.[illegible]	-
65	[illegible]	KATOJO SOUTH	-	-	1030	24.0	11.43	-	1.6	-
66	WDD5151	KATUNGURU MOSQ	-	-	-	58.0	22.24	36.0	-	-
67	WDD5152	KATUNGURU T.CE	-	-	-	60.0	21.12	36.0	1.3	-
68	WDD5153	KASENYI DISP.	-	-	-	30.0	5.73	24.0	1.7	-
69	WDD5154	KASENYI T.CENT	-	-	-	34.0	8.27	24.0	1.8	-
70	WDD5155	MAHUKUNGU DISP	30.0777083	-0.0090	-	38.0	12.90	24.0	1.5	-
71	WDD5156	MAHUKUNGU P. S	-	-	-	66.0	18.31	36.0	-	-
72	WDD5157	MAHUKUNGU T. C	-	-	-	36.0	6.85	24.0	1.1	-
73	WDD5158	NYANGYEREKA VE	-	-	-	60.0	16.33	54.0	0.8	-
74	WDD5159	KAMAYIBA P/S	30.0724	0.16618	-	78.0	-	-	-	-
75	WDD5160	KYANGWALI	-	-	-	96.0	-	-	-	-
76	WDD5161	RUGENDABARA	30.2397	0.31514	-	66.0	-	-	-	-
77	WDD5162	RUGYENDABARA	-	-	-	49.0	-	-	-	-
78	WDD5163	KISORO ALT.	-	-	-	35.0	21.48	30.0	-	300
79	WDD5164	IBUGA PRISON	-	-	-	54.0	-	-	-	-
80	WDD5165	CORNER BAR	-	-	-	64.0	43.94	42.0	-	750
81	WDD5166	BLOCK "A" CENT	-	-	-	66.0	26.99	48.0	-	150
82	WDD5167	PROTIO	-	-	-	42.0	8.86	30.0	-	120
83	WDD5168	block C11	-	-	-	72.0	-	-	1.1	-
84	WDD5169	KENDALE II	-	-	-	120.0	DRY	-	-	-
85	WDD5170	PRIMARY SCHOOL	-	-	-	54.0	38.60	48.0	-	-
86	WDD5171	BWANIKA II	-	-	1020	30.0	24.60	27.0	6.7	-
87	WDD5172	NYAMAGASANI	-	-	-	36.0	-	-	-	-
88	WDD5173	BWERA/MUSINGA	-	-	1040	30.0	12.40	24.0	1.5	-
89	WDD5174	RUHINDO I	-	-	1030	24.0	12.60	211.0	7.5	-
90	WDD5175	RUHINDO II	-	-	1030	24.0	14.60	216.0	6.1	-
91	WDD5176	KATOJO	-	-	1030	24.0	10.30	18.0	1.6	-
92	WDD5177	BWENGO	-	-	-	108.0	DRY	-	-	-
93	WDD5178	BWANIKA CENTRA	-	-	1030	36.0	19.40	30.0	6.5	-
94	WDD5179	KINYAMASEKE	-	-	-	27.0	-	-	-	-
95	WDD5180	BAGANA	-	-	-	30.0	-	-	-	-
96	WDD5181	RUBAHIRA	-	-	-	60.0	51.70	54.0	-	300
97	WDD5182	[illegible]	-	-	-	25.6	-	-	-	-
98	WDD5183	NYAMATOGA III	-	-	-	120.0	-	-	-	-
99	WDD5184	RWETUTU	-	-	-	61.6	-	-	-	-
100	WDD5185	KARIRIZI	-	-	-	77.2	-	-	-	-
101	WDD5186	KAHOKYA T/C	-	-	-	36.4	-	-	-	-
102	WDD5187	KARAMI	-	-	-	47.6	-	-	-	-
103	WDD5188	KAHOKYA C.O.U.	-	-	-	58.8	-	-	-	-
104	WDD5189	KANYABUSOGHA	-	-	-	60.0	-	-	-	-
105	WDD5441	KILEMBERI	-	-	-	36.0	0.30	24.0	-	900
106	WDD5442	SEED STORE	-	-	-	23.0	5.05	21.0	-	-
107	WDD5443	KILEMBERI II	-	-	-	23.0	9.59	18.0	-	-
108	WDD5444	KIZUNGU	-	-	-	23.8	9.10	18.0	-	-

DISTRICT WATER OFFICER
KASESE

DISTRICT: KASESE

BOREHOLE DATA SUMMARY
PERIOD 01/01/87 TO 31/12/95

Page: 3
07/12/95

SN	B/H No.	NAME	Coordinates East	South	Alt (m)	Depth (m)	SWL (m)	C.Depth (m)	Yield (m3/h)	Pop
109	WDD5445	NYAKASANGA			-	11.0	11.00	18.0	-	-
110	WDD5446	NYAKASANGA	-			23.0	11.28	21.0	-	-
111	WDD5447	UMOJA	30.08592	0.19144		20.0	10.09	18.0	-	-
112	WDD5448	BASE CAMP		-	-	50.0	27.54	39.0	-	-
113	WDD5449	DYAKABONA			-	72.0	22.69	63.0	-	-
114	WDD5450	NWADIHINGU	-	-	-	19.2	13.88	36.0	-	-
115	WDD5451	KINYATEKE				30.0	17.98	27.0	-	-
116	WDD5452	KIGHHENDARA	-	-	-	120.0	DRY	-	-	-
117	WDD5453	KIKORONGO	-	-	-	69.8	33.84	63.0	-	-
118	WDD5454	MWEYA GATE I	29896542	-0.1914425		24.0	-	-	-	-
119	WDD5455	MWEYA GATE II	-	-	-	32.1	25.12	30.0	-	-
120	WDD5456	BARACKS	-	-	-	20.0	-	-	-	-
	Totals					5698	1297.6	2703	125.5	21700
	Averages					48.7	15.45	33.4	4.83	585

Total District pop = 342,000 People
Coverage = 6.33%

DISTRICT WATER OFFICER
KASESE

For [signature]

Questionnaire for Experts to Determine Landslide Susceptible Areas (KASIKA, RUKOKI S/C

Section 1: General Information

1. Name: (Optional for anonymity)

KOOLI AUGUSTINE 0782544911

2. Field of Expertise:

DISTRICT ENVIRONMENT OFFICER
KASESE

- Geology
- Civil Engineering
- Environmental Science ✓
- Hydrology
- GIS/Remote Sensing
- Other (specify): ....

Section 2: Landslide Factors and Susceptibility

A. Physical and Environmental Factors

6. Rate the importance of the following factors in determining landslide susceptibility in Kasika on a scale of 1 - 9 (1 = Least Important, 9 = Most Important):

- Slope angle: 9
- Rainfall intensity and duration: 9
- Aspect (slope orientation):...............
- Curvature (concave/convex slopes):......
- Distance from streams: 2
- Elevation: 7
- Land use/land cover: 9
- Lithology (soil/rock type): 9
- Proximity to fault lines: 1

7. What other physical or environmental factors influence landslides in Kasika?

Earth quakes

B. Human Activities

8. How significant are the following human activities in contributing to landslides in Kasika (1 = Not Significant, 9 = Highly Significant):

- Deforestation:.........9..........
- Agricultural practices: ....9.........
- Construction on steep slopes:..7....
- Poor drainage systems: ....1.......
- Quarrying/mining activities:.....8........

9. Are there any other human activities contributing to landslides in Kasika?

.......Mudflow Speed.........................

Section 3: Identifying Landslide-Prone Areas

10. Based on your expertise, which areas in Kasika are most prone to landslides?

(Please name or describe specific locations, landmarks, or villages):

....

....

....

11. What physical features indicate that an area is highly susceptible to landslides? (Check all that apply):

- Steep slopes ✓
- Bare or eroded soil ✓
- Cracks in the ground
- Waterlogged areas
- Proximity to streams or rivers
- Others (specify): ....

12. Are there areas that were previously safe but have recently become prone to landslides?

- Yes ✓
- No

14. If yes, what changes have contributed to the increased susceptibility?

- Deforestation ✓
- Increased rainfall ✓
- New construction – Construction on Steep slope with no regard to landscaping
- Other (specify): Poor Agriculture Practices

15. Are there any existing slope stabilization techniques being used in Kasika region ?

1. Yes
2. No ✓

1. If Yes, please specify the type of techniques and the locations of the projects

....

....

2. What is the effectiveness of the techniques in mitigating slope instability

1. Very effective
2. Moderate effective
3. Less effective
4. Not effective at all

N/A

17. What mitigation measures would you recommend for landslide-prone areas in Kasika?

- Covering landslides
- Installing support structures
- Using drainage to regulate groundwater
- Using retaining walls
- Using soil bioengineering ✓
- Converting agricultural fields to forests and orchards ✓
- Planting vegetation – Trees with adequate tap roots to counter Mass wasting
- Removing weight from the head of the slope
- Other (specify): ....
  - Conducting Soil analysis on Steep Slopes befor a development
  - Public Education / community awareness
  - More resilient structures to be Erected on landslide prone areas

Section 5: Additional Information

18. Have you noticed any changes in the frequency or severity of landslides in recent years? And what could be the cause?

1. Yes ✓ It has increased in the last 3 years

2. No

....

18. Are there any other factors or considerations not covered in this questionnaire that should be included in the analysis? - Community guidance ~~during~~ before, during and after a landslide occurrence

- Causes of community vulnerability to landslides

19. Do you have any additional comments or suggestions for improving landslide susceptibility assessments in Kasika?

- Remote Sensing, GIS and Historical data (Indigenous Knowledge

Questionnaire for Experts to Determine Landslide Susceptible Areas

Section 1: General Information

1. Name: (Optional for anonymity)

SINGOMA JOSEPH

SENIOR PLANNER 7/01/2025 0771631966. Kasese.

2. Field of Expertise:

- Geology
- Civil Engineering
- Environmental Science
- Hydrology
- GIS/Remote Sensing
- Other (specify): SENIOR PLANNER, DISASTER MAGT FOCAL PERSON DISASTER RESILIENCE LEADERSHIP.

Section 2: Landslide Factors and Susceptibility

A. Physical and Environmental Factors

6. Rate the importance of the following factors in determining landslide susceptibility in Kasika on a scale of 1 – 9 (1 = Least Important, 9 = Most Important):

- Slope angle: 9
- Rainfall intensity and duration: 7
- Aspect (slope orientation): 6
- Curvature (concave/convex slopes): 8
- Distance from streams: 3
- Elevation: 6
- Land use/land cover: 8
- Lithology (soil/rock type): 8
- Proximity to fault lines: 4

7. What other physical or environmental factors influence landslides in Kasika?

....

B. Human Activities

8. How significant are the following human activities in contributing to landslides in Kasika (1 = Not Significant, 9 = Highly Significant):

- Deforestation:……1……………
- Agricultural practices: ……8……
- Construction on steep slopes:……2…
- Poor drainage systems: ………2……
- Quarrying/mining activities:……1………

9. Are there any other human activities contributing to landslides in Kasika?

………………………………………………

Section 3: Identifying Landslide-Prone Areas

10. Based on your expertise, which areas in Kasika are most prone to landslides?

(Please name or describe specific locations, landmarks, or villages):

⇒ 5 Villages were affected by the massive mudflow ~~that~~ occured on 9th Sept, 2004
⇒ Villages affected are; Kasika, Mukati, Kigoro, Kabughabugha and Kalingatha.
⇒ IDP Camp of the Persons displaced from these villages, established at Kogere Cou in Kasika village, Kigoro Parish.

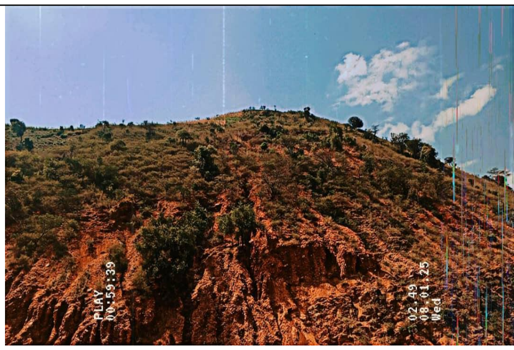
11. What physical features indicate that an area is highly susceptible to landslides? (Check all that apply):

- Steep slopes ✓
- Bare or eroded soil ✓
- Cracks in the ground ✓
- Waterlogged areas
- Proximity to streams or rivers
- Others (specify): ……Lithology

12. Are there areas that were previously safe but have recently become prone to landslides?

- Yes ✓
- No

(1) Mapatha village in Bugoye Parish – Bugoye Sub County.
(2) Kiraro Village – ~~Kitholhu~~ Kiraro parish – Kitholhu Subcounty.
(3) Kyondo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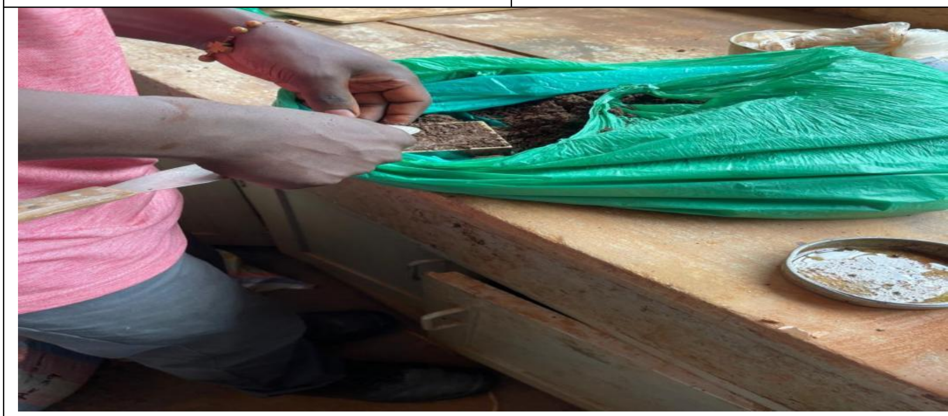	

B. Human Activities

8. How significant are the following human activities in contributing to landslides in Kasika (1 = Not Significant, 9 = Highly Significant):

- Deforestation:......1..............
- Agricultural practices: ....8.......
- Construction on steep slopes:...2.....
- Poor drainage systems: ......2.........
- Quarrying/mining activities:....1.........

9. Are there any other human activities contributing to landslides in Kasika?

....

Section 3: Identifying Landslide-Prone Areas

10. Based on your expertise, which areas in Kasika are most prone to landslides?

(Please name or describe specific locations, landmarks, or villages):

⇒ 5 villages were affected by the massive mudflow ~~that~~ occured on 9th Sept, 2024
⇒ Villages affected are; Kasika, Mukati, Kigoro, Kabughabugha and Kalingatha.
⇒ IDP Camp of the persons displaced from these villages, established at Kogere C.O.U in Kasika village, Kigoro parish.

11. What physical features indicate that an area is highly susceptible to landslides? (Check all that apply):

- Steep slopes ✓
- Bare or eroded soil ✓
- Cracks in the ground ✓
- Waterlogged areas
- Proximity to streams or rivers
- Others (specify): ....Lithology....

12. Are there areas that were previously safe but have recently become prone to landslides?

- Yes ✓
- No

① Mapatha village in Bugoye parish – Bugoye Subcounty.
② Kiraro Village – ~~Kithothu~~ Kiraro parish – Kithothu Subcounty.
③ Kyondo —— Kyondo Subcounty.