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

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A FINAL YEAR RESEARCH AND DESIGN PROJECT REPORT SUBMITTED TO THE FACULTY OF ENGINEERING, DESIGN AND TECHNOLOGY, IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF A DEGREE OF BACHELOR OF SCIENCE IN CIVIL AND ENVIRONMENTAL ENGINEERING OF UGANDA CHRISTIAN UNIVERSITY

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ABSTRACT

This research was conducted in Kasika Village with the primary objective of assessing the effectiveness of various biotechnical slope stabilization methods in landslide-prone areas. The study was motivated by the increasing problem of slope instability in the region, which has led to loss of lives and the destruction of critical community infrastructure, including roads. The research aimed to identify sustainable and environmentally friendly solutions for stabilizing vulnerable slopes.

The study was guided by three key objectives: to evaluate the susceptibility of slopes to landslides in the affected areas, to determine the factor of safety of the slope before failure, and to assess the effectiveness of biotechnical slope stabilization techniques. The Analytical Hierarchy Process (AHP) was employed to develop a landslide susceptibility map achieving an AUC of 0.85 while the Morgenstern-Price method of slices was used to calculate the factor of safety under both saturated and normal soil conditions.

Findings revealed that the studied slope was highly unstable and prone to landslide with a factor of safety of 0.885 for normal conditions and 0.955 for saturated conditions. The research recommended the implementation of brush layering using bamboo live cuttings (Oldeania alpina) as a sustainable biotechnical stabilization method to enhance slope stability in the area.

DECLARATION

I hereby declare that this is my original work, is not plagiarized and has not been submitted to any other institution for any award.

Signed: Date:

………………………………………………………….

Nakinkunda Prisca

S21B321/084

PPROVAL

I certify that this report is for Nakinkunda Prisca and I fully accept that he has been under supervision and so submitted to the Faculty of Engineering, Design and Technology Uganda Christian University in partial fulfillment of the requirements for an award of aBachelor of science in civil and environmental engineering.

Signed: Date

………………………………………

Dr. Makabayi Brain

Academic Supervisor

DEDICATION

This work is dedicated to the loving memory of my dear father the Late Matsiko Wilson who passed away while I was pursuing this research project. He was my greatest supporter and source of encouragement throughout my academic journey. His unwavering belief in me, his sacrifices, and his love shaped the person I am today. He left an unfulfilled void but his legacy lives on in me. This research is a testimony to the value he installed in me. May his soul rest in eternal peace.

ACKNOWLEDGEMENT

I thank the Almighty God for enabling me to carry out this research project and seeing me through this entire duration. I would also like to thank my parents as well as my siblings for their continued support financially and emotionally for their unwavering support allowed me to focus on this research project. I would like to extend my gratitude to Dr. Makabayi Brain, my research supervisor for the guidance, assistance, advice and time that she dedicated to this research project.

Appreciation goes out to Mr. Michael Vladimir my project partner for being collaborative and active throughout this research process.

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CHAPTER ONE: INTRODUCTION

1.1 Background

Landslides are destructive hazards and play an important role in landscape processes (Fabio et al,2021). Landslides are phenomena triggered by heavy rainstorms with short duration and intense precipitation or rainfall with long duration and medium-low intensity. The phenomena in mountains and hill slope environment represent one of the most important denudation processes and can affect human life and infrastructure both directly and indirectly (Mohammed et al.,2020). The spatial distribution of landslides is strongly influenced both by different climatic conditions and by environmental frameworks including weathered rock grade, soil characteristics, land use/ cover and morphological features (Anto et al., 2023). Furthermore, in the recent decades the landslides occurrence seems to be increasing due to climatic changes. And several countries including Uganda were identified as a high landslides risk area.

Uganda is largely affected by landslides events mainly because of its climatic and geological features. Also, in Uganda instability phenomena are often linked to uncorrected land use management. Kasese region in Western Uganda is periodically affected by landslides events which cause considerable damage to buildings and infrastructure posing serious threats to people and economic loss (Kitutu et al.,2022). The use of landslides susceptibility maps becomes a useful tool both to better identify areas probe to landslides and the interaction between the last areas and the geo- Environmental features able to control the instability process Consequently, landslides susceptibility zoning represents the first step for the evaluation of landslides risk and also supply important information for decision making (GAO et al., 2020).

Key geo-environmental factors such as geology and soil. Land cover and climate affect landslides susceptibility but there is no agreement on which factors are most important. One of the purposes of this study is to create a landslide susceptibility map using GIS to understand the main factors influencing landslides. And assessing the various slope stabilization methods in landslides prone areas with the goal of identifying the most effective strategies to reduce slope failure and protect vulnerable communities. This includes an evaluation of natural methods including vegetation-based approaches. By understanding the effectiveness of different stabilization techniques. This research aims to provide practical recommendations for improving slope stand reducing landslide risk.

1.2 Introduction

Landslides are natural hazards with devastating consequences including injury, loss of life, environmental degradation and several damage to infrastructure. While various natural factors like rainfall, rugged terrain and hydrological conditions contribute to landslides, human activities such as deforestation, slope excavation for construction and urbanization are significant triggers (Deckers et al 2019). In regions like Kasika with features like steep slopes and mountainous landscapes, rainfall induced landslides are particularly prevalent. These landslides threaten infrastructure especially along road networks as well as agricultural land and the natural environment (Muwanga et al., 2018). The Kasika Road sector in Kasese which traverses the hilly and mountainous terrain is especially prone to slope instability leading to rockfall and soil material flows. These slope failure poses significant threats to both transportation infrastructure and the local ecosystem (Richard et al.,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 stabilization measures (Bieber et al.,2020). Several studies have shown that variety of factors contribute to slow failures including the lithological and structural characteristics of land, geo water conditions, slope geometry and changes in land use. When road cuts or other infrastructure development disturb the natural balance of the slope, they trigger landslides. The geotechnical properties of the soil and rock such as cohesion, shear strength and permeability play a crucial role in determining a slopes stability. Accurate soil and rock characteristics are therefore essential for predicting slope failure modes and identifying vulnerable areas (Brandon et al.,2019).

Given the frequent occurrence of slope failures in Kasika and other similar landscapes. This research aims to assess the slope stabilization techniques in landslides prone areas. The study will focus on geotechnical analysis, slope stability assessment and development of practical stabilization strategies suitable to the region's unique environmental and geological conditions.

By evaluating the effectiveness of the various slope stabilization methods this research seeks to propose sustainable solutions to mitigate landslides and protect critical infrastructure in Kasika sub-county.

1.3 Problem statement

Landslides refer to the downward movement of rocks, debris or soil along the slope due to gravity (Xinmin et al.,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 et al., 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, causing 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 evaluate the effectiveness of the different slope stabilization techniques along them and provide biotechnical soil stabilization technique with the ability to adapt to the varying environmental and climatic changes.

1.4. Main Objective

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

1.5 Specific Objectives

1. To evaluate the slope susceptibility of slopes 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

1.6 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?

1.7 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 (Citizen report, et al., 2021)

1.8 Justification

Landslide susceptivity mapping using the Analytical Hierarchy Process assigns weights to landslide causative factors enabling a weighed overlay analysis of geospatial data. This approach helps evaluate the influence of these factors on landslides and accurately identifies high risk areas (Mersha et al 202).

For the slope stability analysis of the identified vulnerable slopes the limit equilibrium principle was applied. This principle assesses the balance between forces resisting movement and those driving it to determine the factor of safety for the slope. The Morgenstern Price method which considers both force and moment equilibrium was used to provide a precise analysis of the slope susceptibility to landslides (Abramson Wet al 2002).

Biotechnical slope stabilization techniques integrate native vegetation with structural measures to enhance slope stability by improving soil cohesion and increasing resistance to slope movement. The limit equilibrium principle is utilized to evaluate the stability of these reinforced slopes by analyzing the balance between driving and resisting forces along potential failure surfaces. This method facilitates the calculation of factors of safety, offering a quantities measure of slope stability after biotechnical reinforcement (Gary DH et al 1992).

The use of native plant species ensures that the stabilized slopes are well suited to the local environment and climatic conditions. This approach promotes a sustainable and resilient solution for slope stabilization in areas prone to landslides (Gary dh et al 1992)

CHAPTER TWO: LITERATURE REVIEW

2.1 Landslides

Landslides are the downward movement of rock, soil, debris or a combination of these materials along a slope under the influence of gravity. They occur when the gravitational forces acting on a slope exceed their resisting forces which may be due to natural or human induced factors (Bobrowsky et al.,2008). Landslides are considered a major geohazard and are often triggered by events such as heavy rainfall, earthquakes, volcanic activity or human activities like deforestation and construction.

2.1.1 Factors influencing landslides

Landslides are complex phenomena influenced by a combination of natural and human induced factors. These factors affect the stability of slopes by altering the balance between driving forces (gravity) and resisting forces (cohesion and friction). Below is an in-depth discussion of key factors influencing landslides.

2.1.1.1 Precipitation

This is one of the most common and significant triggers of landslides particularly in areas with steep slopes and loose soils.

Mechanism

Saturation of soil: Prolonged or intense rainfall increases soil water content, reducing cohesion and shear strength. Saturation also increases pore water pressure which reduces friction along potential failure planes. (Skilodimou et al., 2018).

Erosion: Heavy rain can erode slope material, leading to undercutting and destabilization.

Flooding: Overflowing rivers or streams can saturate nearby slope increasing the like hood of landslides.

Examples

Tropical regions often experience rainfall induced landslides during monsoon seasons.IN Kasese district Uganda heavy rainfall during March-May and September - November has triggered recurring landslides. (Monitor team 2024).

2.1.1.2 Slope Angle and Geometry

The steepness and geometry of a slope significantly influence its stability.

Slope Angle

Steeper slopes have a higher gravitational component acting downslope increasing the likelihood of failure. Critical slope angles vary depending on material types of fine-grained soils may fail at angles as low as a15-30 degrees while rock slopes can withstand steeper angles (Varnes et al., 2009).

Slopes geometry

Concave slopes: These tend to accumulate water making them more prone to landslides.

Convex slopes: Erosion and mass waste are more likely near the crest.

Planar slopes: Thes are generally more stable but can fail if a weak layer exists underneath (Petley et al., 2016).

2.1.1.3 Land use and vegetation cover

Human land use practices and vegetation cover directly impact slope stability.

Deforestation

Trees and vegetation stabilize slopes by providing root reinforcement and reducing soil erosion. Deforestation removes this stabilizing effect, making slopes more vulnerable to failure. In Kasese district deforestation for agriculture has exacerbated landslide occurrences.

Agriculture Practices

Poor farming practices such as overgrazing and slashing and burn agriculture, degrade soil structure and increase erosion.

Cultivation on steep slopes without proper terracing accelerates soil loss.

Urbanization and construction

Land use changes due to road construction, building developments and mining disrupt the natural balance of slopes. (Ainomugisha et al., 2021).

Excavation at the base of slopes or adding load near the top can trigger landslides.

Human Activities: Human activities can directly or indirectly destabilize slopes.

Infrastructure development: Roads, railways and dams often involve slow cutting and excavation which can weaken slope stability. Vibrations from machinery or traffic can act as triggers.

In Kasese road construction has been identified as a significant factor in slope failures.

Improper drainage systems can lead to water accumulation increasing pore water pressure.

Lack of proper stormwater management system exacerbates the impacts of heavy rainfall (Richard et al., 2022).

Quarrying mining

Extraction of minerals and rocks destabilizes the natural slope structure

Overburden removal and blasting can trigger landslides.

2.1.1.4 Geological and Soil Factors

While not human induced the geological characteristics of a slope amplify the effects of precipitation, slope angle and land use.

Lithology

Weak rocks such as shale, siltstone or weathered volcanic material are more prone to failure.

Soil Properties

Soils with low cohesion (e.g., sandy soils and high permeability are more vulnerable to erosion and landslides (Abramson et al.,2002).

2.2 Landslide susceptibility

Landslide susceptibility mapping is a method used to identify areas at risk for landslides by analyzing various causing factors which can be geological, hydrological and also related to the environment in nature. This process utilizes data and advanced techniques to assess the likelihood of landslide occurrences in specific regions, helping in disaster risk reduction and land-use planning (Geological Survey

Ireland. n.d.). Landslide inventory mapping is done to show where historical landslides happened in the area, and this is achieved through field observations, historical records and satellite imagery. A vector map is created in a GIS environment showing past landslides in the area according to their magnitude, characteristic and type. These slides act as the future landslides during the validation of the maps while checking their reliability in detecting areas with actual landslides areas. While selecting causative factors to be used in GIS, it's crucial to ensure that each causative factor selected is relevant to the phenomenon of landslides. These landslide causative factors must be operational clearly showing a clear relationship with landslides, complete (well-represented across the study area), variable (showing spatial differences), measurable (quantifiable using various scales), and non-redundant (not causing overlapping effects in the final analysis). This will ensure that the model's accuracy and reliability in predicting or analyzing the 9 model, while the false positive rate represents the proportion of non-landslide areas incorrectly predicted as landslide prone. The area under the ROC curve is then calculated to provide a single measure of the model's performance. An AUC value of 0.7 to 0.8 indicates acceptable performance, 0.8 to 0.9 indicates excellent performance, and above 0.9 indicates outstanding performance (Kumar et al,2016 and Mersha et al, 2020).

2.3 Slope stabilization

Slope stabilization in landslide-prone areas is a crucial aspect of geotechnical engineering aimed at minimizing the risk of slope failure. Various techniques are employed based on the characteristics of the slope, soil type, and severity of the landslide risk. Modern slope stabilization methods focus on reinforcing the soil, improving drainage systems, and using both natural and engineered structures to prevent landslides. Key techniques involve retaining walls, soil nailing, drainage control, and vegetation, which work either independently or in combination to enhance the stability of slopes.

Here is a detailed exploration of these commonly used techniques.

2.4 Types of stability analysis

There are two different ways of carrying out slope stability analysis. The first approach is the total stress approach which corresponds to Clay soils under short term loading where the pore pressure is not dissipated. The second approach corresponds to the effective stress approach which applies to long stability analysis in which drained conditions prevail. Natural slopes and slopes in residual soils should be analyzed with the effective stress method considering the maximum water level under severe precipitation. This is particularly important for places where intensive rainfall may occur over long periods. (Cheng et al., 2021).

2.5 Geotechnical properties of slopes

Cohesion and shear strength are critical geotechnical factors in slope stability analysis. Cohesion provides resistance by bonding soil or rock particles while shear strength combines cohesion and frictional resistance to withstand stress. Both factors are influenced by moisture with saturation, reducing their effectiveness often leading to slope failure.

Cohesion is vital in clay rich soils while shear strength governs overall slope resistance balancing resisting forces against driving forces like gravity and water pressure. Stabilization techniques such as vegetation soil reinforcement and drainage systems, enhance these properties. Analyzing cohesion and shear strength through lab tests and modeling is crucial for predicting and mitigating slope failures (Brandon et al., 2019).

2.6 Biotechnical methods of slope stabilization

Biotechnical stabilization, also known as soil bioengineering, is a method used to stabilize steepened slopes along highway rights-of-way by incorporating live, cut brush layers in place of or alongside synthetic fabrics or geogrids. This technique uses living vegetation, particularly woody plant material, embedded in the ground to prevent surface erosion and control shallow mass movement. The brush layers provide immediate structural reinforcement, and secondary stabilization occurs as roots grow along the buried stems. Additionally, the brush layers act as natural drainage systems, improving the hydrologic conditions of the slope (Mersha et al., 2020).

Guidelines for analyzing the stability of brush layer-reinforced slopes—both surficial and global—are provided. A case study from Massachusetts discussed where brush layer inclusions were used to stabilize a steep highway slope. In this case, a composite rock and brush layer fill was chosen due to environmental and scenic considerations.

The rock section was placed at the base to intercept failure surfaces, and the brush layer inclusion effectively stabilized the slope while blending with the natural surroundings. Reinforced or mechanically stabilized earth embankments, which include tensile reinforcements within the fill soil, are commonly used for highway construction. These embankments offer advantages such as improved mass stability, reduced fill requirements, and elimination of additional right-of-way, making them suitable for widening roads. MSE systems use both primary and secondary reinforcements to ensure structural stability, prevent surface sliding, and control erosion. (Robbin et al.,2018).

Many residents of the landslide prone areas try to reinforce the slopes with the local material available in order to protect their homes and property. Live plant cuttings reinforcement not only protects the slope from failure but also saves the environment through ecological restoration which is of great importance as of today. Despite the widespread use of brush layering around the world, the quantification of its effects on slope stability has received little attention. The design parameters reported in most handbooks and guidelines (e.g., Schlecht, 1980; Gray and Sotir, 1996) give some general guidelines, based on past experience, about bench width, inward inclination, and spacing, regardless of factors such as slope steepness, the geotechnical properties of the soil, and the soil water content. In a modern approach to soil bioengineering works, however, new design paradigms must be developed to account for soil and slope properties and for design parameters (such as, in the case of brush layering, number of cuttings and bench spacing).

In this research, we develop a scheme to design brush layers works, and live reinforcements in general, which is able to quantify the Factor of Safety at different depths as a function of the design parameters. Experimental tests have also been carried out to estimate the pullout resistance of live cuttings.

For the reinforcing model, it’s based on the limit equilibrium principle and the failure surface is taken to be planar. Reinforcement with brush layers is taken to account for shallow landslides.

The factor of safety formulae:

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

Shear strength parameters:

$$s = c' l_1 + [nR_{\mathrm{po}}(z)\ \sin(\alpha+\beta) + (\gamma_t - \gamma_{\mathrm{w}} m) z \cos^2 \beta l_1]\mathrm{tg}\phi',$$

Shear stress parameters:

$$\tau = \gamma_t l_1 z\ \sin\beta\cos\beta - nR_{\mathrm{po}}(z)\cos(\alpha+\beta).$$

Source:(Bichetti 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 Landslides causing factor selection

Targeted questionnaires given to Kasika Village professionals and the local population helped identify the main causes of landslides. The goal of this strategy was to identify the key causes of landslides in the area. The main causes of landslides were identified with the assistance of input from a number of stakeholders, including the District Environmental Officer, the Kasese District Disaster Focal Person, and local residents. The literature on landslide causes unique to Kasika Village was used to further review and validate the criteria submitted by these stakeholders. Less important criteria were eliminated, while the most important ones were chosen. Precipitation, aspect, slope angle, curvature, distance to streams, land use and land cover, rainfall, and lithology were the last group of elements that caused landslides.

3.1.2 Spatial and non-spatial data collection

Digital elevation modules (DEM) for aspect, curvature, elevation, and distance to stream mapping were obtained from NASA earth datasets with 30m spatial resolution, and precipitation data for rainfall was obtained from the Kasese Airfield weather station in Rukoki Subcounty after the landslide causative factors were chosen. For the purpose of mapping land cover and land use, Google Earth Pro was used to acquire LANDSAT satellite pictures. The lithological units of Kasika Village were derived from a 1:250,000 scale geological map of Uganda's geological survey that displayed all of the country's geological units.

Making maps of the factors that cause landslides. The following raster maps were produced for each of the chosen landslide causative factors: Model of Digital Elevation: In order to create an elevation map of Kasika Village, the NASA earth database provided a digital elevation model with a spatial resolution of 30 meters. This allowed for the creation of maps of the village's hill shade, slope angle, aspect, curvature, and, finally, distance to stream as shown in **figure 1.**

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

3.1.3 Slope Angle Mapping

To determine the various elevations, longitudes, and latitudes of Kasika village, a set of close sites that were less than 10 meters apart were selected using Google Earth Pro software. ArcGIS software was then used to create a 10-meter digital elevation using the IDW procedure using this attribute table of elevations, longitude, and latitude. The spatial analyst tool in ArcGIS Pro was then used to determine the slope angles of the slope in Kasika village using this digital elevation model as shown in **figure 2.**

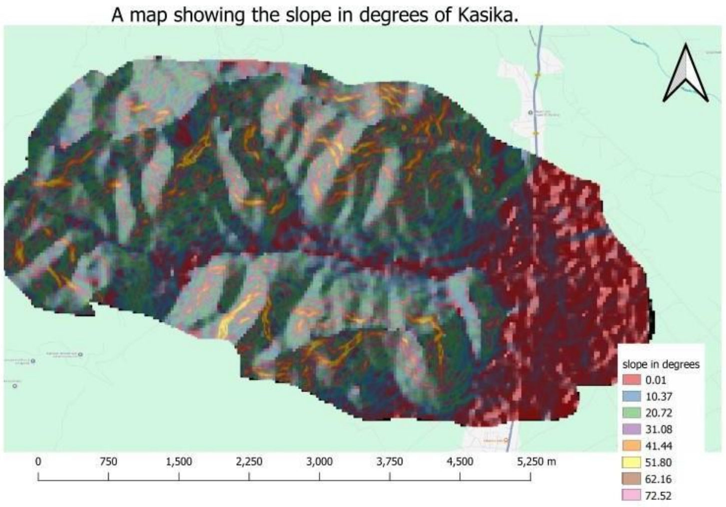


Figure 2 :Slope angle map that was obtained from the 10m digital elevation model

3.1.4 Mapping of rainfall

The wettest months of 2022 were used to create a rainfall attribute table because this is the year that landslides most affected our case study, Kasika village. Rainfall values for Kasika village were gathered from the Kasese Airfield, Rukoki subcounty weather station, and weather and climate Uganda for five years as shown in **table 1.**

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

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

In order to determine the rainfall values of the other locations, such as the Kasika region, which has no rainfall records because the village lacks rain gauges to record precipitation, **Table 1** was loaded into ArcGIS. The rainfall values of the wettest months were then interpolated using the Inverse Distance Weighting (IDW).

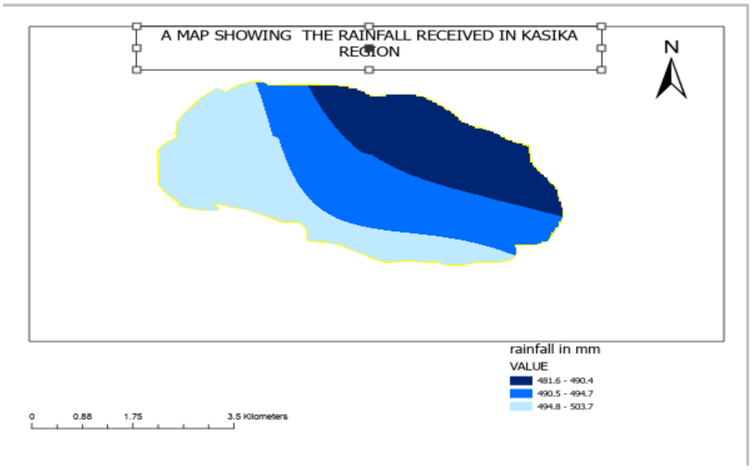


Figure 3: Map showing the rainfall measured in millimeters received in Kasika village.

3.1.5 Aspect mapping

The technique of figuring out the slopes' orientation is known as aspect mapping, and it is represented in degrees ranging from 0° to 360°. It affects landslides by influencing the slopes' exposure to sunshine, wind direction, rainfall, and discontinuity conditions, all of which have an impact on soil saturation and, ultimately, the region's stability. The digital elevation module for Kasika village, which has a spatial resolution of 30 meters, was used to create the aspect map.

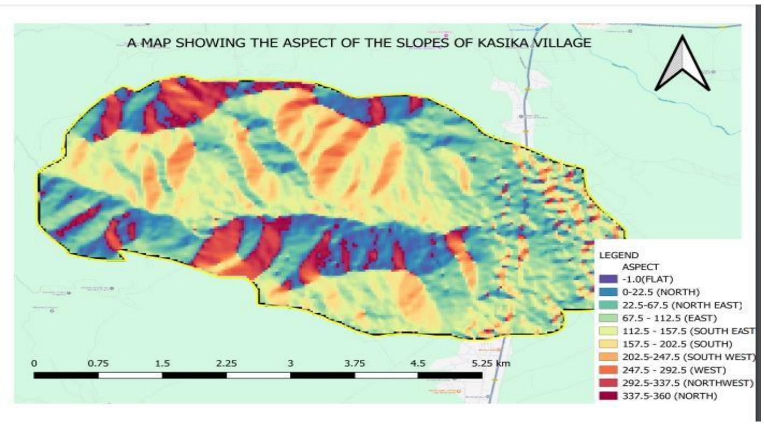


Figure 4: Map showing the aspect of the slopes of Kasika village created from the digital elevation of 30 m spatial resolution.

3.1.6 Curvature mapping

The process of curvature mapping entails examining the terrain's features and determining how they affect the area's hydrology and landslide risk. Concave, convex, and flat surfaces are the three main types into which curvature maps are divided. The map's concave surfaces, which are the negative portions of the curve, tend to retain water, increasing soil saturation and the risk of landslides. Concave surfaces are mountain slopes that form a concave shape when they enter the mountains from the inside. The areas of the map with a positive curvature are known as convex surfaces. They facilitate faster drainage, which may lessen saturation, but they may also cause instability if water builds up in nearby places. Simply put, convex slopes are those that bulge outward to indicate a convex shape. Using the QGIS software's spatial analyst tool for curvature, the digital elevation module of Kasika village was used to create the village's curvature map, which had a spatial resolution of 30 meters. Concave slopes are represented by negative grid cells, convex slopes by positive grid cells, and flat surfaces by zero as shown in **figure 5.**

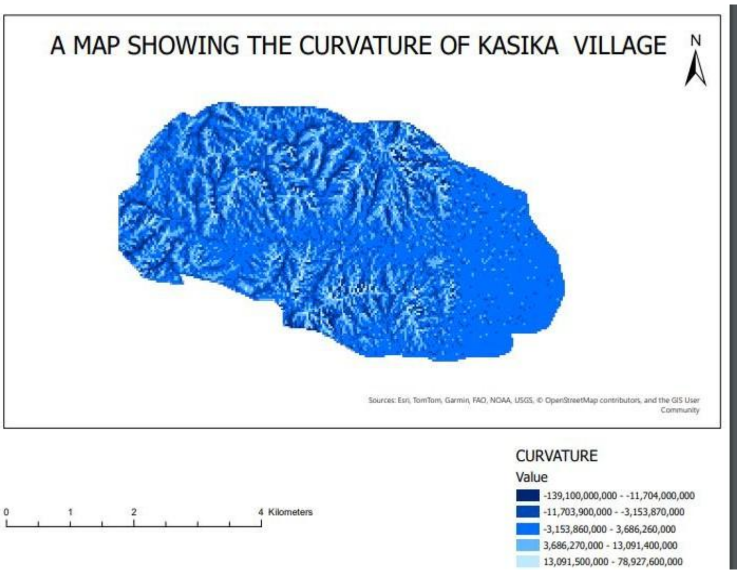


Figure 5: Map of Kasika village showing the curvature of the slopes

3.1.7 Distance to the stream mapping:

Convex surfaces are those parts of the map that have a positive curvature. They may reduce saturation by facilitating faster drainage, but they may also lead to instability if water accumulates in adjacent areas. Convex slopes are, in essence, those that bulge outward to show a convex form. The settlement's curvature map, which had a spatial resolution of 30 meters, was made using the QGIS software's spatial analyst tool for curvature and the digital elevation module of Kasika village. Flat surfaces are represented by zeros, convex slopes by positive grid cells, and concave slopes by negative grid cells as shown in **figure 6.**

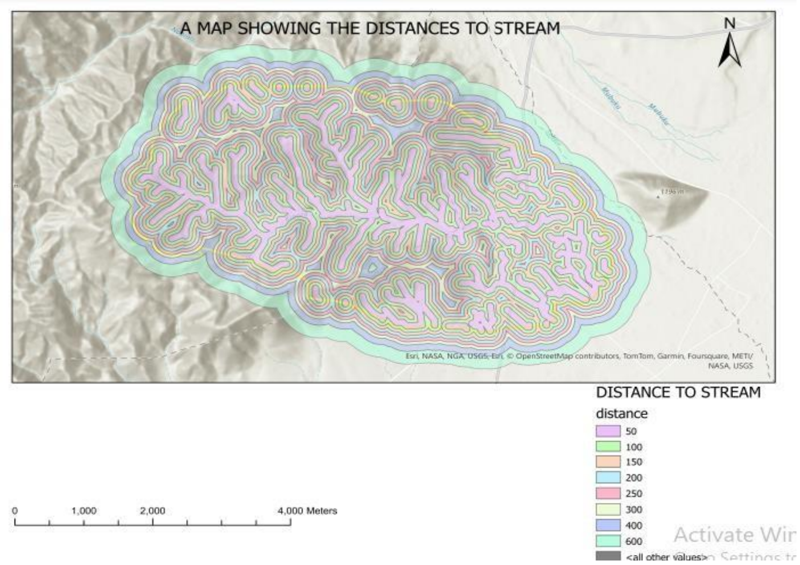


Figure 6: Distance to the stream map (NASA earth explorer database).

3.1.8 ArcGIS pro lithology mapping:

The process of creating a lithological map using the ArcGIS Pro program entailed georeferencing an existing geological map of the area from the Uganda Geological Survey. To determine the geological units in the area of Kasika village, this 1: 250,000 scale geological map was loaded onto the ArcGIS Pro program and georeferenced using common ground control points. The geological units of Kasika Village were extracted using a vector polygon map, which was then rasterized to create a raster lithological map. According to the georeferenced map that was used, the Kasika village was found to have two lithological units: quartzites and sands, clays, and grits.

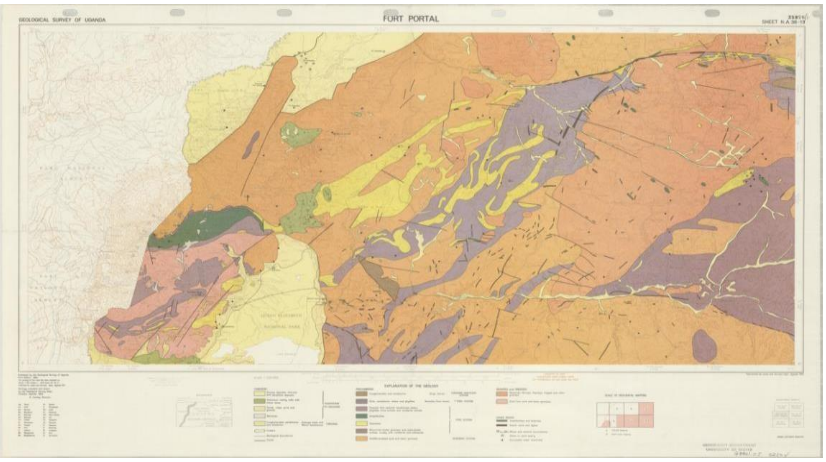


Figure 7 : Showing the geological map obtained from the geological survey of Uganda that was georeferenced to produce the lithological map. Source: (Uganda Geological Survey, n.d.)

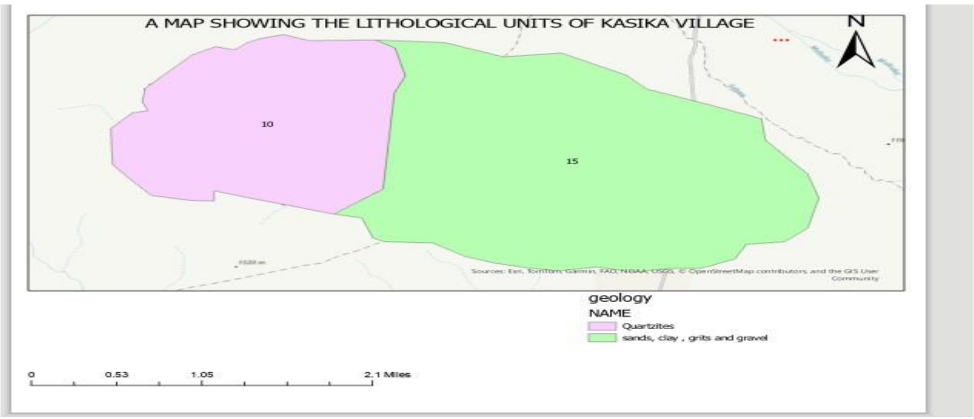


Figure 8 : Map of the lithological units that are in Kasika village

3.1.9 Land use and Landcover Mapping:

Extensive fieldwork was conducted to identify the various land use and landcover types in Kasika village, and the LANDSAT image, which was downloaded from Google Earth Pro and had a resolution of 2180 x 1080p, was interpreted to create the land use and landcover maps of Kasika village. This method made it possible to categorize the different forms of landcover and land use in Kasika village. In order to assist in creating the land use and landcover map for Kasika village, this LANDSAT (land satellite) image was processed in ARCGIS Pro using the supervised classification spatial analyst tool. Various raster cell grids with varying spectral resolutions were assigned to a land use and landcover type as the training dataset as shown in **figure 9.**

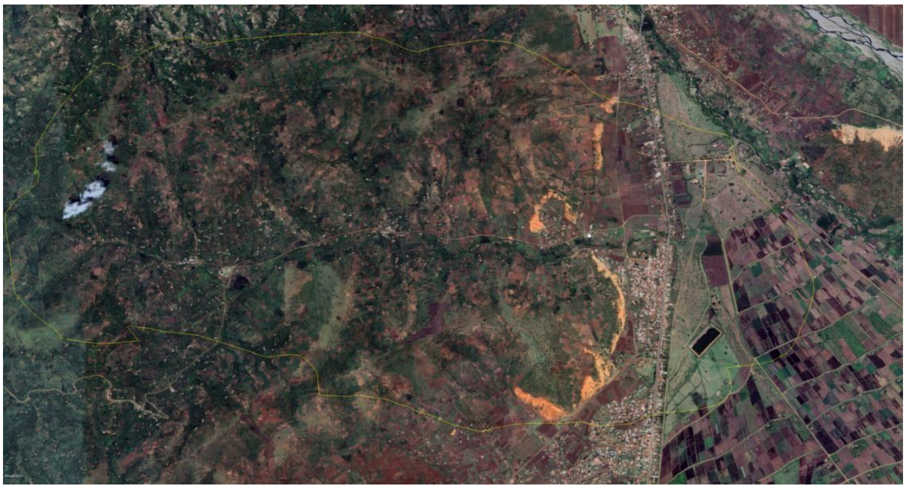


Figure 9: Google earth pro satellite image used for supervised classification to generate the land use and landcover map of Kasika village

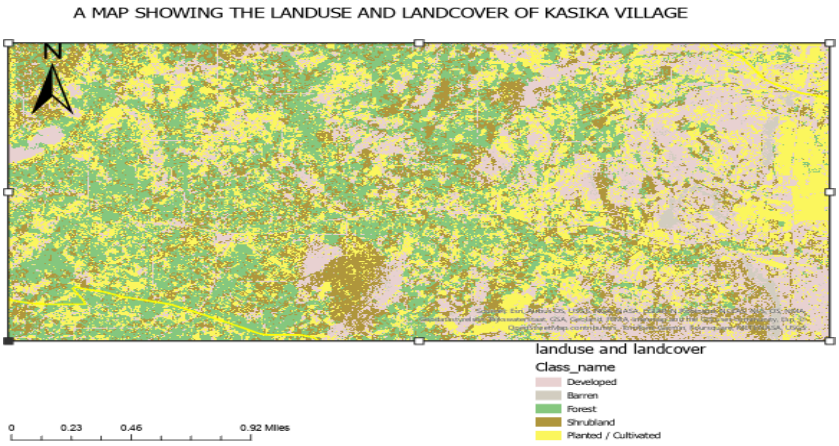


Figure 10 : Land use and landcover map that was produced after supervised classification of the LANDSAT image that was obtained from google earth pro.

3.1.10 Reclassification of the maps showing the causes of landslides

To make the study of the landslide causative factor maps easier and improve the interpretability of the landslide causing factor maps, the landslide causative factor maps were reclassified. The purpose of the study was to relate the elements that produce landslides and how they affect the cause of landslides. For each landslide causative factor map, the continuous variables were grouped into five distinct classes based on their respective effects on landslides: very low susceptibility to landslides, low susceptibility to landslides, moderate susceptibility to landslides, high susceptibility to landslides, and very high susceptibility to landslides. 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.

3.1.10.1 Map classification for slope angle

The slope angle map was reclassified by dividing it into five classes according to the ways in which certain slope angles contribute to or affect landslides. The five classes were 0–5°, which was considered to have very lo w landslide susceptibility; 5–12°, which was considered to have low landslide susceptibility; 12–30°, which was considered to have moderate landslide susceptibility; 30–45°, which was considered to have high landslide susceptibility; and slope angles greater than 45°, which was considered to have very high landslide susceptibility as shown in **figure 11**.This classification identified those slopes in that format because areas with high susceptibility to landslides are associated with a higher probability to cause landslides (**Mersha et al.,2020**).

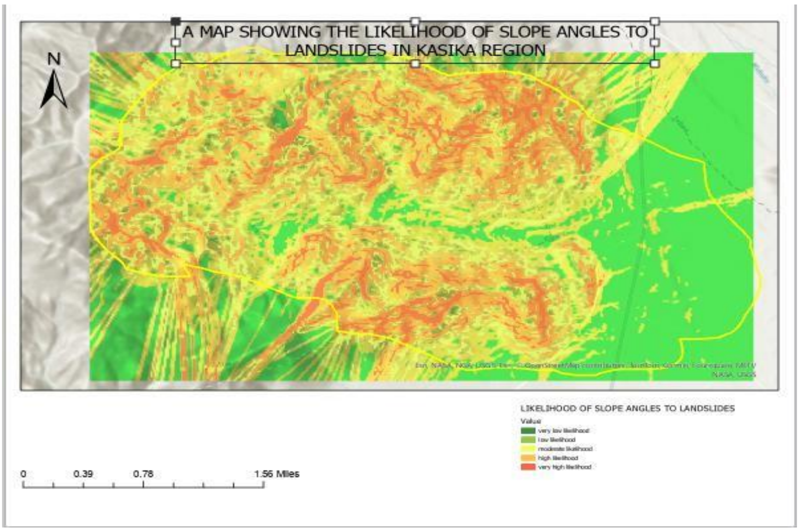


Figure 11:The reclassified raster of slope angle of Kasika

3.1.10.2 Map reclassification for curvature

Based on how the slopes' curvature affects actual landslides, the curvature map was classed. In the Kasika region, values close to zero were deemed to have very low susceptibility to causing landslides, while higher positive values (convex curvature) and high negative values (concave curvature) were categorized as extremely vulnerable to landslides. In essence, curvature mostly affects water accumulation, which in turn affects landslides. The slope's soil saturation conditions rise as a result of concave surfaces' propensity to retain water. This saturation increases the pore water pressure, which lowers the slope materials' shear strength and increases the slope's vulnerability to landslides.

Although convex surfaces can speed up drainage, if water builds up in the nearby concave sections, they can also cause slope instability. This may make landslides more likely, particularly during a period of intense precipitation (Mersha et al., 2020). In essence, the slope's curvature influences how gravity acts on it; a slope with a positive curvature (convex slopes) is less stable under specific slope conditions, while a slope with a negative curvature (concave curves) can exacerbate the effects of saturation and water retention. All things considered, the interplay of slope stability, water dynamics, and curvature is essential for mapping landslide susceptibility as shown in **figure 12.**

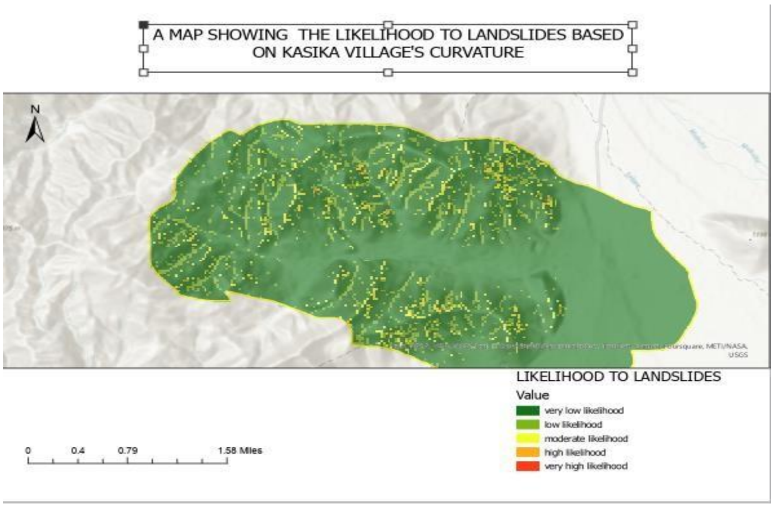


Figure 12: A map showing the reclassified curvature of the slopes in Kasika village

3.1.10.3 Reclassification of aspect maps

The slopes were categorized according to how the various slope orientations impact elements like sunlight exposure and moisture retention on Kasika Village's overall slope stability. The slopes' orientation was reclassified by dividing them into three classes according to degrees. The Aspect map was typically categorized as follows: Slopes that face north (0–22.5°) were classed as extremely likely to cause landslides. Slopes that face northeast (22.5 to 67.5°) were classed as having a moderate risk of landslides. Slopes that face east (67.5–112.5°) were classed as having a very low risk of landslides.

The area's southeast-facing slopes (112.5–157.5°) were classed as having a moderate risk of landslides. Slopes that face south (157.5–202.5) were classed as having a moderate risk of landslides. Slopes that face west (247.5–292.5°) were classed as having a very low risk of landslides. Slopes that face northwest (292.5–337.5 °) were classed as being moderately likely to trigger landslides in the area. According to Mersha et al. (2020), slopes that face north (337.5–360°) were classified as extremely prone to landslides as shown in **figure 13.**

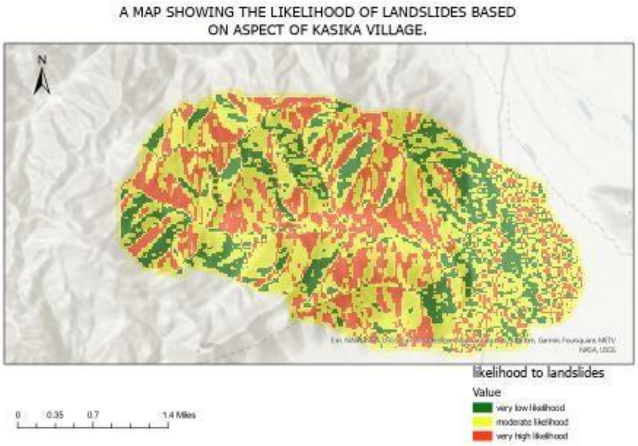


Figure 13: Reclassified map of Kasika village based on the aspect of the slopes and how they influence the landslides in the region.

3.1.10.4 Distance to stream map reclassification:

Since areas closer to landslide areas are thought to be more susceptible to landslides due to factors like increased soil saturation and erosion, the distance to the stream map was reclassified based on the relationship between proximity to streams and how they influenced landslides (Mersha et al., 2020). Based on how their proximity can cause landslides, the distance to stream data was divided into five types.

The area between 0 and 50 meters from the streams was classed as extremely vulnerable to landslides. The 50-100 m range was classed as being extremely vulnerable to landslides. The area between 100 and 150 meters from the streams was classed as having a moderate impact on landslides. The 150–200 m range was classed as having a low risk of landslides. More than 200 meters were classed as having very little risk of causing landslides as shown in **figure 14.**

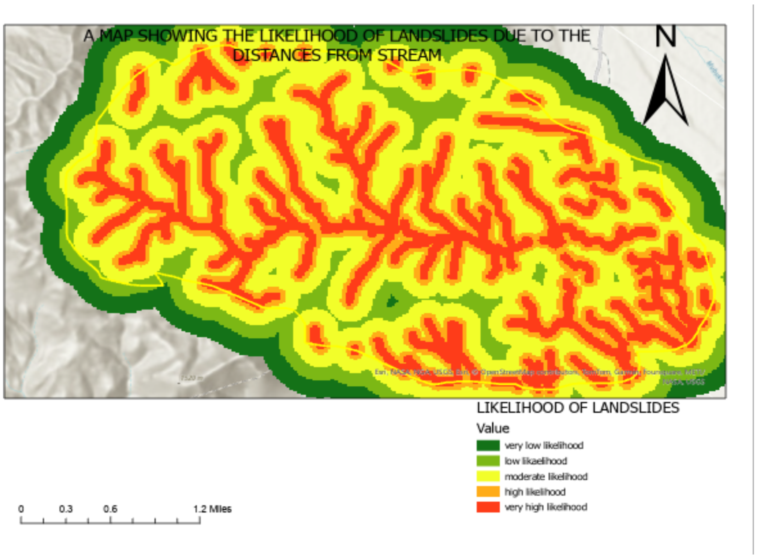


Figure 14: A map showing the likelihood of landslides to distances from stream

3.1.10.5 Reclassification of Land use and Landcover Maps

By classifying different land use types and landcover according to their impact on landslides in the area, the land use and landcover map was categorized. Based on how they affect landslides, the land use and landcover classifications of bare ground, forests, developed environments, shrublands, and agricultural lands were categorized.

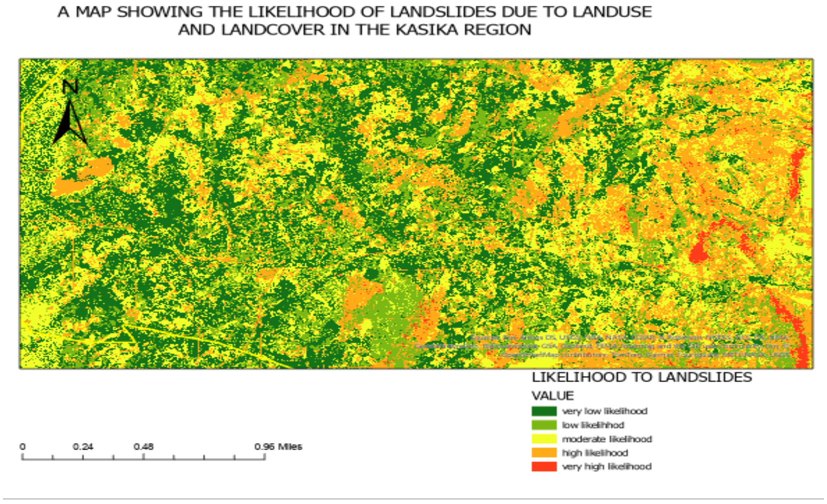


Figure 15: Map showing the likelihood of landslides to the distances from streams

3.1.10.6 Map lithology reclassification

By classifying Kasika village's two lithological units according to their susceptibility to landslide failures, the lithology map was reclassified. According to Abramson L.W. et al. (2002), the class of clay, grits, and shale was assigned a high risk of experiencing landslides, whereas the class of quartzites was assigned a low likelihood as shown in **figure 16.**

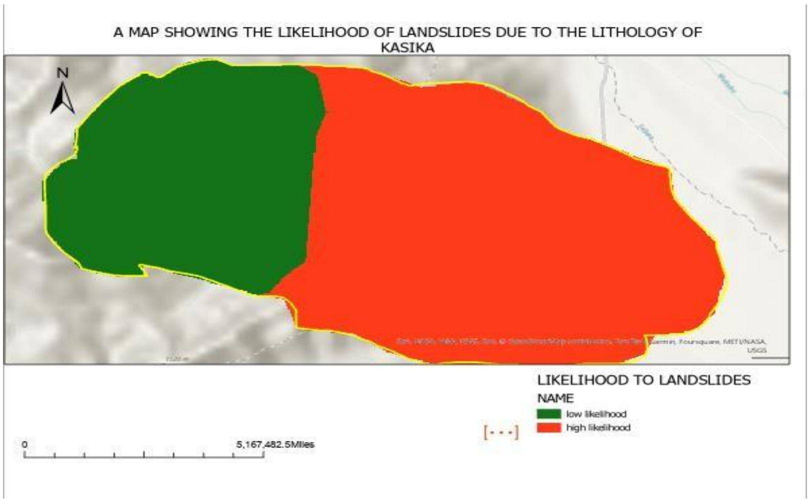


Figure 16: A reclassified map of lithology of Kasika and how they influence landslides in the region.

3.1.10.7 Map reclassification for rainfall

The natural breaks approach, which entailed classifying the region's rainfall values into five classes based on the rainfall values of the wet seasons, was used to reclassify the rainfall map as shown in **figure 17.** Higher rainfall levels are linked to more landslides than lower ones, according to the classification (Mersha et al., 2020).

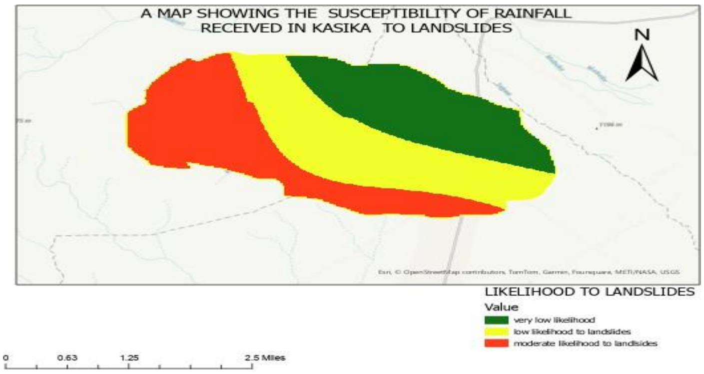


Figure 17: Reclassified map showing the likelihood of the rainfall values received in Kasika village and how they influence the cause of landslides in the region.

3.1.11 Mapping of landslide inventories

In order to find and identify the places where the landslides occurred in the Kasika village area, a landslide inventory map was produced by combining field surveys of the local population with the interpretation of LANDSAT satellite images. During our field investigation of the Kasika region, we discovered four landslides in all, and we used a portable GPS device to record the latitude and longitude of each. Google Earth Pro satellite photography revealed further landslide scars. 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 rasterized into raster format of cell size 30m by 30m in ArcGIS pro with similar dimensions as the landslide causative reclassified factor maps.

3.1.12 The Analytical Hierarchy Process (AHP)

This is used in multicriteria decision analysis. The reclassified landslide triggering factor maps were analyzed and ranked according to their contribution to landslides in the Kasika village using the AHP process. And the steps used to do that were as follows: Specifying the issue and requirements: Based on their impact on landslide occurrences in the Kasika region, the landslide reclassification causative factor maps were categorized. The criteria that were applied were the following: the reclassified maps of slope angle, rainfall, distance to stream, lithology, land use, and landcover; the curvature reclassified map, the aspect reclassified map and lastly, the curvature reclassified map of Kasika village. These were arranged hierarchically on how the influence the landslides in the Kasika region.

3.1.12.1 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 land use, aspect and curvature as shown in **table 2 and 3.**

Table 2: Pairwise matrix for landslide causing factors

landslide causative factors	Slope	Lithology	Curvature	Rainfall	landcover and land use	aspect	distance to stream
Slope	1	3.0	6.0	1.0	4.0	5.0	2.0
Lithology	0.333333333	1	3.0	0.5	1.0	2.0	1.0
Curvature	0.166666667	0.333333333	1	0.2	0.55	1.0	0.25
Rainfall	1	2	5	1	3.0	4.0	1.0
landcover and land use	0.25	1	1.818181818	0.333333333	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	8.833333333	21.81818182	4.283333333	12.55	17.03030303	6.08

Table 3:Preference scale used to come up with the pairwise matrix (Valdari L et al.,2022)

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	¼
Moderately importance	3	1/3
Equally to moderately	2	½
Equal importance	1	1

Reciprocal values were utilized for inverse comparisons, and values from the preference scale (1–9) were essentially given importance during the generation of the comparison pair matrix based on expert judgment in the field of disasters as for Kasese district as shown **table 4**. The Normalized Matrix was calculated by adding up each column in the pairwise matrix and dividing each element by the total of its corresponding column. This guarantees that all values lie between 0 and 1 and are proportionate.

Table 4: Normalized matrix generated from AHP process

Column1	slope	Lithology	Curvature	Rainfall	landcover and land use	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 land use	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 stream	0.144927536	0.113207547	0.183333333	0.233463035	0.15936255	0.177935943	0.164473684	0.168100518	7.079035352
SUM	1	1	1	1	1	1	1		7.115345041

3.1.12.2 Deriving weight criteria

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 land use map got 0.0822

Aspect map got 0.0589

Curvature map got 0.0454

Checked Consistency of the expert's judgement

consistency calculations confirmed logical coherence in the judgements:

λ(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.

3.1.12.3 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 Land use, Aspect and Curvature. The consistency ratio confirms that the analysis using the AHP process was reliable.

3.1.12.4 Overlay with weights Procedure in the ArcGIS Pro setting

Multiple raster landslide classification maps were integrated using ArcGIS Pro's weighted overlay analysis method to determine which sections of Kasika village are more vulnerable to landslides and which are not. The AHP approach was used to obtain the reclassified raster maps of landslide causative factors and give weights based on their influence on landslides in Kasika village as shown in **figure 18**. The raster datasets were modified to have uniform coordinate systems, cell sizes, and geographic resolutions.

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 land use reclassified rater map was given 8%

Aspect reclassified raster map was given 6%

Curvature reclassified raster map was given 5%

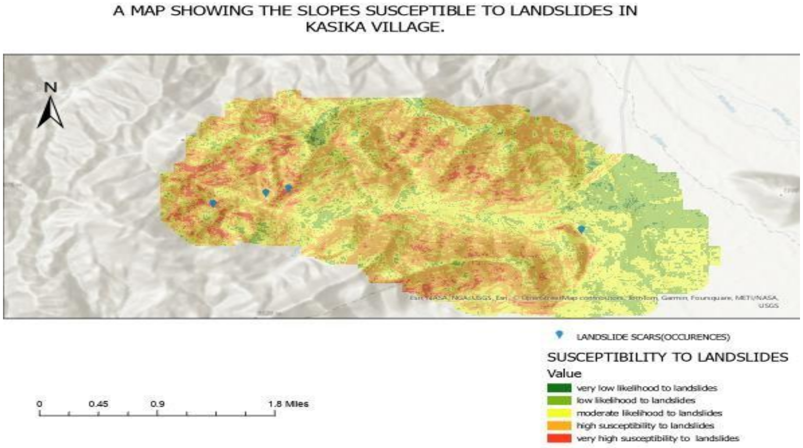


Figure 18: The landslide susceptibility map of Kasika village produced from the weighted overlay process.

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

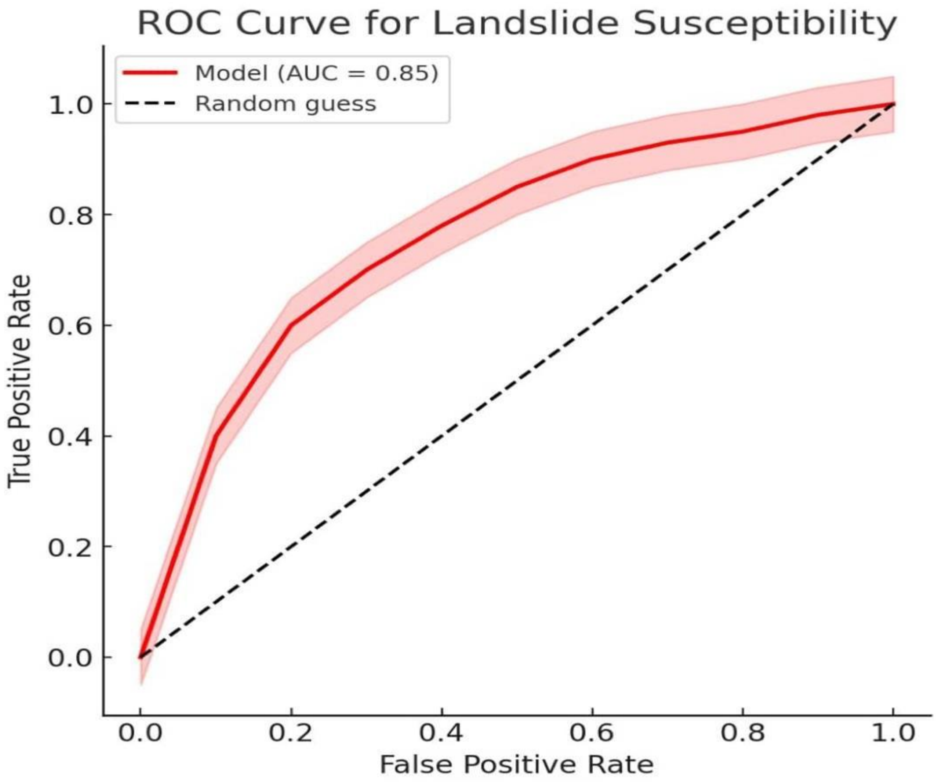


Figure 19: Receiver operating curve of Kasika Village for landslide susceptibility

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

Identification of susceptible slope endangering infrastructure such as roads

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

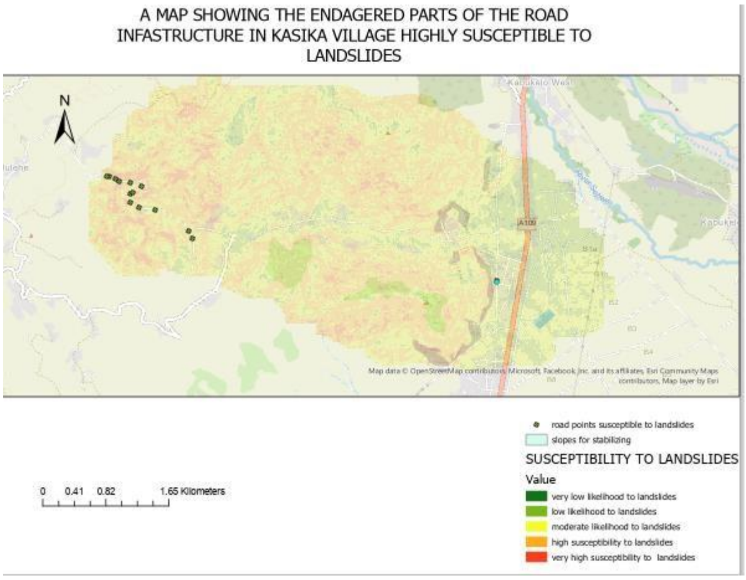


Figure 20: Map showing the endangered parts of the road network passing through Kasika village.

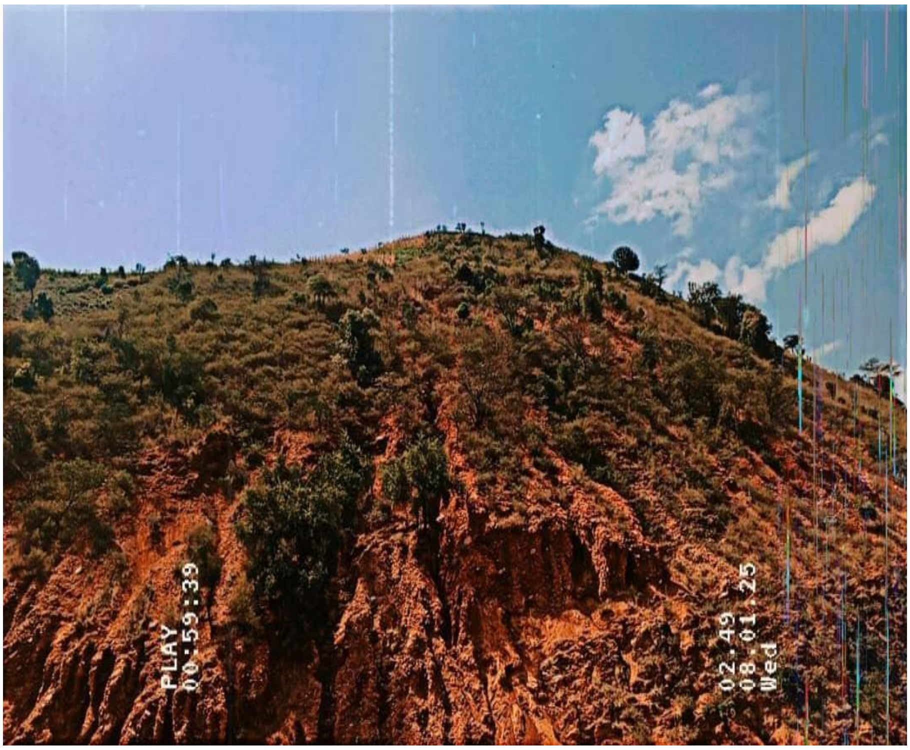


Figure 21:Chosen slope to determine its factor of safety before failure.

This study involved the assessment of the effectiveness of the current slope stabilization techniques in the identified landslide prone areas on the landslide susceptibility map produced. This included gathering of information through case studies, expert consultation and literature research.

The study also involved evaluation of the geotechnical conditions of the slope prone to landslides was carried out to understand the factors contributing to instability and determine the factor of safety. This involved conducting geotechnical investigations to determine the soil properties.

The tests carried out included;

3.2.1 Laboratory tests done.

3.2.1.1 Particle size distribution – BS 1377: Part 2: 1990

The test involved the quantitative determination of particle size distribution in an essentially cohesionless 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. From this it is possible to determine whether the soil consists of predominantly gravel, sand, silt or clay soils.

3.2.1.2 Atterberg tests BS 1377: Part 2: 1990

3.2.1.2.1 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. Definition: 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

3.2.1.2.2 Plastic limit (pl) and plasticity index (pi) -BS 1377: part 2: 1990

The Plastic Limit (PL) of 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).

3.2.1.2.3 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 moisture content.

3.2.1.3 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 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.

3.2.1.4 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 mound 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.

3.2.1.5 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.

3.2.2 Limit Equilibrium Principle, Morgenstern-Price Method, and Vegetation in Brush Layering for Slope Stabilization

3.2.2.1 Limit Equilibrium Principle in Slope Stability Analysis

What It Is and Why It's Used

The limit equilibrium (LE) principle is a classical approach used to assess the stability of slopes. The basic idea is that a potential failure mass is assumed to be at the point of "limiting equilibrium" where the resisting forces (mainly due to soil shear strength and any reinforcing measures) exactly balance the driving forces (primarily gravity and any additional loads). In other words, the slope is just on the verge of failure, and the factor of safety (FoS) is calculated as the ratio of available shear strength to the shear stress required to maintain equilibrium.

Reasons for Using it

Simplicity and Practicality: The method uses static equilibrium (forces and moments) to derive the FoS, making it relatively straightforward compared with more complex, deformation-based analyses. This simplicity has led to its wide acceptance in both academic and professional practice (Wischmeier and Smith, 1978).

Empirical Calibration: Many of the LE methods, including those that incorporate soil parameters (cohesion, internal friction, unit weight), have been calibrated against field data. This makes them practical tools for design.

Applicability to Varied Conditions: Although the approach requires assuming a failure surface, it can be adapted to different slope geometries and loading conditions, including those encountered in biotechnical applications where both mechanical and vegetative reinforcements are used.

3.2.2.2 Key Assumptions in Limit Equilibrium Analysis

When applying the LE principle, the following assumptions are typically made:

Defined Failure Surface: A potential slip surface (often circular or non-circular) is assumed. The analysis does not predict this surface; it is proposed by the analyst.

Uniform Material Properties: Soil strength parameters (cohesion cc and internal friction angle ϕ\phi) are assumed to be uniform along the slip surface, even though, in reality, soil properties can vary.

No Deformation Considered: The method assumes that the failure mass is rigid and does not account for the deformation of the soil prior to failure.

Static Equilibrium: The entire potential sliding mass is assumed to be in a state of equilibrium where the sum of forces and moments equals zero. The factor of safety is then calculated by comparing resisting and driving forces.

Neglect of Pore Water Variability: While pore water pressures can be included as additional forces, many analyses assume constant or known pore pressure distributions.

3.2.2.3 The Morgenstern-Price Method:

3.2.2.3.1 Rationale for Choosing the Morgenstern-Price Method

Among the various methods of slices (e.g., Bishop's simplified method, Jambu's method, Spencer's method), the Morgenstern–Price method was selected for its flexibility and rigor in evaluating complex slope geometries. The key points in its favor included:

Simultaneous Equilibrium: Unlike some other methods that assume force equilibrium only in the vertical direction, the Morgenstern–Price method satisfies both force and moment equilibrium simultaneously. This is particularly useful for complex or non-circular slip surfaces.

Interslice Force Function: It introduces an assumed function to distribute interslice forces. This additional degree of freedom allows the method to more accurately account for the interaction between adjacent slices.

Adaptability: Because it can incorporate both the variation in geometry and the complex stress distributions along a potential slip surface, the Morgenstern–Price method is highly adaptable to the mixed mechanical–biological systems found in biotechnical stabilization (Gray and Sotir, 1992).

3.2.2.4 Assumptions Specific to the Morgenstern-Price Method

The use of the Morgenstern–Price method comes with its own set of assumptions:

Interslice Force Distribution: An assumed function (which can be linear, exponential, or otherwise defined) represents the distribution of forces between slices. This function is critical because it governs how forces are transferred from one slice to another.

Slice Independence with Interaction: While each slice is treated separately, the interslice forces provide a mechanism to account for their mutual interaction.

Equilibrium Conditions: Both the sum of forces (horizontal and vertical) and the sum of moments about a chosen point must equal zero.

Soil Shear Strength: The shear resistance of each slice is given by the Mohr–Coulomb equation.

These assumptions, while simplifying the true behavior of the soil mass, provide a tractable means to compute the factor of safety, especially in situations where biotechnical measures such as brush layering are used in conjunction with structural elements (Morgenstern and Price, 1971).

3.2.3 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 as shown in **Table 5**

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

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

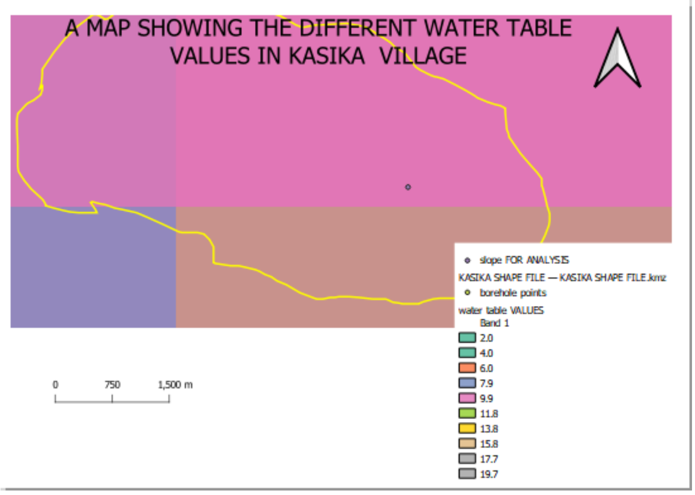


Figure 22: A map showing the different static water levels around Kasika Village obtained through Inverse Distance Weighting (IDW)

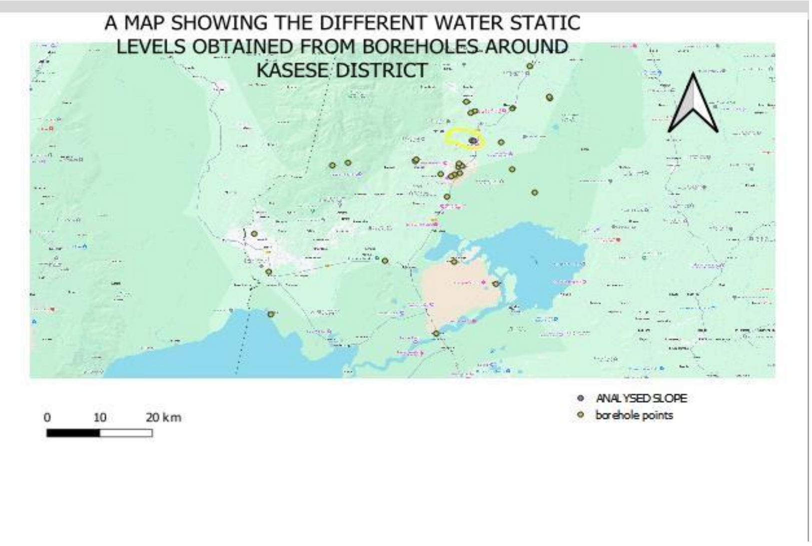


Figure 23: A map showing the different bore hole locations used to obtain the static water levels of Kasika Village.

3.2.4 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. Tools such as the Handy GPS application and Google Earth Prowers were used.

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

3.2.4.1 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 visualize 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 as shown in Figure 24.

Figure 24: Showing the 3D terrain of the endangered slope

After establishing the slope geometrical properties of the slope, the factor of safety of the slope was analyzed 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 Oldeania alpina was the slope stabilization 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)**.

3.3.2 Determining the pullout resistance of the live cuttings under different slope loads.

Pullout resistance tests will be 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).

3.3.3 Evaluation of the pullout resistance

The evaluation of the pullout resistance of live cuttings was conducted using a series of laboratory tests designed to simulate real-world conditions. The procedure involved the following key steps:

3.3.4 Preparation for Test Apparatus:

A steel box measuring 0.3 m × 0.1 m × 0.1 m was filled with soil to create a controlled environment for the tests. This setup allowed for the placement of live cuttings within the soil.

3.3.4.1 Placement of Live Cuttings

Live cuttings, specifically for Bamboo, a species named Oldeania Alpina were inserted into the soil within the test apparatus. Proper positioning ensured that the cuttings were embedded sufficiently to facilitate accurate measurements of pullout resistance.

3.3.4.2 Incorporation of Measurement Devices

The test apparatus featured a circular hole (60 mm wide) in the front side that allowed for the attachment of a clamp to the cutting. This enabled the application of a tensile force directly to the cutting during the test.

3.3.4.3 Application of Pullout Force

A mechanical system involving gears was used to apply a tensile force to the cuttings at a controlled rate of 10 mm/min. This rate was chosen to reflect the rapid nature of slope failure processes.

3.3.4.4 Prevention of Soil Outpouring

To ensure the integrity of the test and prevent soil from spilling out through the hole, a rubber membrane was placed between the hole and the cutting. Care was taken to minimize additional pullout resistance introduced by the membrane.

3.3.4.5 Data Collection

As the force was applied, measurements were recorded to determine the pullout resistance of the cuttings. The experiment aimed to establish the relationship between pullout strength and the normal stress acting on the reinforcement.

3.3.4.6 Analysis of Results

The data collected from these tests were analyzed to derive pullout resistance values, which were then used to understand the effectiveness of the live cuttings as a reinforcement mechanism in soil stabilization.

$$R = \frac{F_{\mathrm{po}}}{\pi \cdot L_{\mathrm{e}} \cdot D_{\mathrm{m}}},$$

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

Dm is the diameter of the bamboo live cuttings used to carry out the pullout resistance tests.

Le is the embedded length of the bamboo live cuttings into the soil.

R is the maximum friction force between the bamboo live cuttings and the soil.

This systematic approach allowed for a comprehensive evaluation of the pullout resistance and the factors influencing the performance of live cuttings in soil environments.

Why is pullout resistance recorded at 5%?

Ultimate pullout resistance is measured at a recommended limit of displacement to ensure consistent and reproducible results, reflecting realistic conditions encountered in real-world applications. By defining a specific displacement limit (such as 5% of the cutting length), the testing method avoids instability that could arise from excessive movement, which might lead to unreliable results, such as total pullout or soil failure. This approach captures the peak resistance values before significant changes occur in the material's behavior, providing critical insights for evaluating performance. Additionally, following established guidelines enhances comparability with other materials, such as geosynthetics, while ensuring that engineering designs incorporate necessary safety factors for stability and safety in slope and soil structure applications.

3.3.5 Quantifying and designing the reinforcement model for the slope.

Excell sheets will be designed to vary the parameters of the brush layers such as spacing, reinforcement density and slope conditions of saturation and normal conditions to see how the factor of safety improves as we vary those parameters under the given standards for reinforcing slopes with brush layering for every slope depth.

This will enable us to achieve the optimum design parameters of the slope to be stabilized and hence achieve 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 causing factors, including slope angle, rainfall, curvature, distance to streams, lithology, land use and land cover, and aspect were ranked using the Analytical Hierarchy Process (AHP). The results revealed that slope angle was the most significant factor contributing to landslides in Kasika Village followed by rainfall, distance to streams land use and land cover, aspect and curvature as shown in **figure 25.**

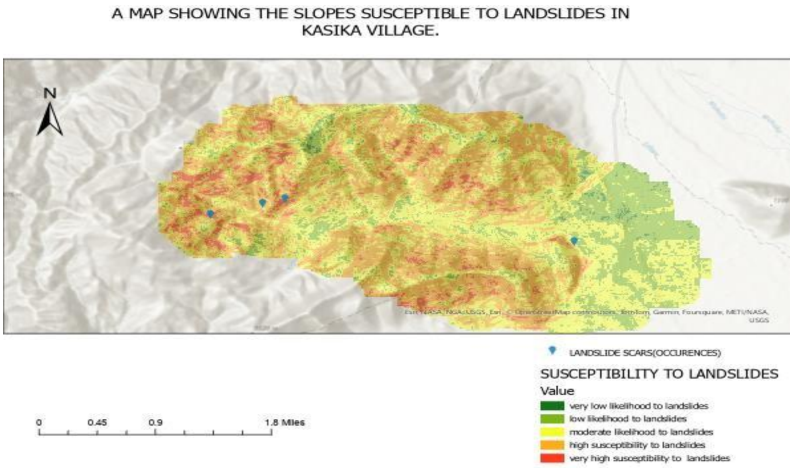


Figure 25: A map showing the slope susceptible to landslides in Kasika village

The landslide susceptibility map of Kasika village was categorized into five classes that is very low susceptibility, low susceptibility, moderate susceptibility, high susceptibility and very high susceptibility 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 susceptibility 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 as shown in **table 6.**

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

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 performance

4.2 Evaluating the suitability of factor of safety of the slope before failure

4.2.1 Particle size distribution

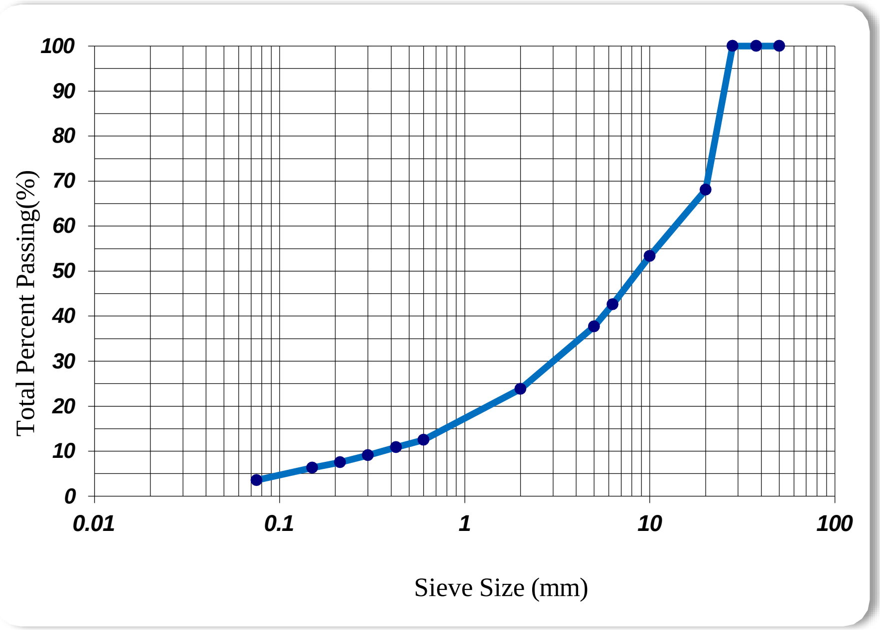


Figure 26: A graph showing sieve size against total percent passing

The shape of the curve in **Figure 26** suggests a well graded soil (if it covers a wide range of sieve sizes) or poorly graded soil (if it is steep or lacks intermediate sizes). From the graph, the curve seems moderately uniform suggesting it is well graded.

According to AASHTO classification system the soil is either granular soils (A-1, A-3, A-2) more than 35% of soil is retained on the no 200 sieve(0.075mm) or fine-grained soils (A-4 to A-7) 35% or more of the soil passes through the 200 sieve.

4.2.1.1 Analysis of the curve

At sieve size 0.075mm (No 200 sieve), approximately 42.87% of the soil passes, since more than 35% passes through the No 200 sieve, the soil falls under the fine-grained soil category.

4.2.2 Atterberg limit tests

4.2.2.1 Plasticity Index

A moderate plasticity indicates that's the soil has some plasticity which means it can deform under load without cracking. IN areas with fluctuating moisture content e.g., heavy rainfall this soil can swell and shrink weaking the slope over time.

4.2.2.2 Liquid limit

The liquid limit indicates the water content at which the soil changes from a plastic to a liquid state. A relatively high LL indicates that the soil becomes weaker and flows under high water content making it susceptible to landslides during heavy rainfall.

4.2.2.3 Linear shrinkage (LS= 10.7%)

High linear shrinkage indicates that the soil is prone to significant volume changes when drying out after saturation. Cracking and weakening of the soil structure can occur leading to a loss of cohesion and increased landslide risk particularly in dry seasons followed by intense rains

According to the graph the liquid limit (LL) of sample is 41.0%, the plastic limit (PL) is 25.0% and the plasticity index PI=(LL-PL) is 16.0%.

4.2.2.4 Classification according to AASHTO

Since42.87% of the soil passes through the sieve No 200 (as per grading curve) the soil is fine grained.

Since the LL is 41% the soil is either A-7 or A-5.

The plastic index of 16.0% places the soil in A-7 (clay) category. A high PI indicates clayey behavior.

Therefore, the soil is classified as an A-7 (clayey soil) under the AASHTO system.

4.2.2.5 Characteristics of A-7 soil

High plasticity

A-6 soils exhibit moderate to high plasticity as shown by the PI of 16.0%. A high plasticity indicates that soil is prone to shrink swell behavior when exposed to moisture changes leading to instability.

Fine grained nature

More than 35% of the particles pass through the no 200 sieve (42.87) indicating a significant proportion of fine particles which retain water and reduce drainage.

Low strength

A-7 soils often exhibit low shear strength especially when saturated. This makes them unstable on steep slopes or under heavy loads

Compressibility

A-7 soils tend to compress significantly under loading leading to settlement problems especially in infrastructure like roads and buildings.

Sensitivity to water content

Water significantly affects the shear strength of A-7soils. Heavy rainfall can saturate the soil leading to increased pore water pressure and a decrease in effective stress which triggers landslides.

Slope Failure Risks

On steep or unstable slopes, the combination of low permeability and high-water retention increases the risk of slope failure due to reduced cohesion and internal friction.

Erosion susceptibility

A-7 soils are prone to erosion because of their fine particle size. Over time surface runoff can wash away soil weakening the slope further

4.2.3 Proctor test

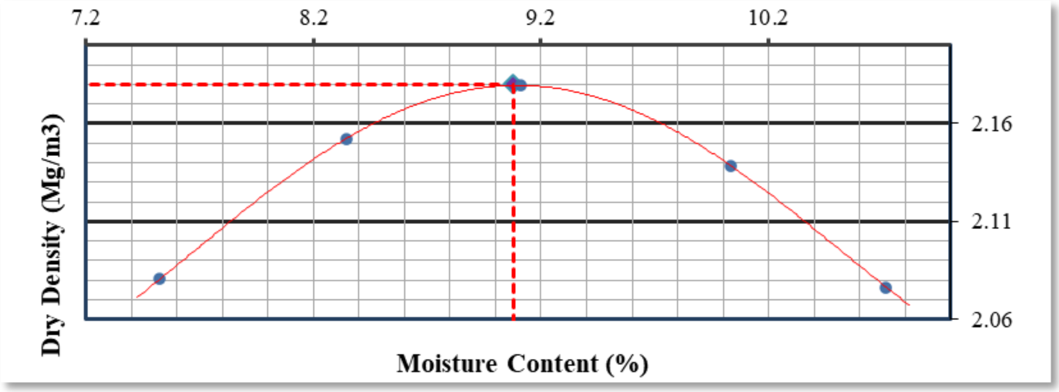


Figure 27: A graph of dry density against moisture content

The proctor compaction test is used to determine the maximum dry density and optimum moisture content of the soil for engineering applications. These parameters help evaluate the soil strength and compaction suitability for stability under field condition. The proctor test provides foundational data on soil compaction and moisture behavior which is critical for determining shear strength and optimizing field conditions. The results from **figure 27** combined with results from Direct shear test enable accurate determination of the factor of safety of the slope.

4.2.4 Consolidation test

Table 7 Showing consolidation test results

Test Standard/ Method: BS 1377-2:2022								
Sample Ref.								
THE CONSOLIDATION TEST RESULTS SUMMARY SHEET ON UNDISTURBED SAMPLES								
Test Point Label	Depth (m)	Saturated Unit weight, γ_{sat} (kN/m^3)	Average Coefficient of Volume Compressibility m_v, (m^2/MN)	Range of Coefficient of Volume Compressibility (m^2/MN)	Elastic Modulus, E_{oed} (MN/m^2)	Settlement (Pc), mm	Compression Index, Cc	Remarks based on average values
TP 01	1.0	17.98	0.260	0.1 - 0.3	3.84	8.448	0.025	Medium compressibility

4.2.4.1 Saturated Unit Weight

The saturated unit weight represents the weight of a fully saturated soil per unit volume. It accounts for both the solid soil particles and the water filling the voids. In this case, the saturated unit weight is 17.98 kN/m^3as shown in **table 7**

The saturated unit weight is a critical parameter in slope stability analysis because it directly affects both the driving forces and the resisting forces in the slope. Here's how it is relevant:

4.2.4.2 Influence on Driving Forces

Driving forces are primarily due to the weight of the soil and water acting on the slope, which creates shear stresses along potential failure surfaces. These forces are proportional to the unit weight of the soil.

A higher saturated unit weight increases the gravitational load, which raises the driving forces that act to destabilize the slope.

The total weight of the soil (including saturation) is factored into the equations for calculating the Factor of Safety (FoS):

Fos= Resisting forces/driving force

As saturated unit weight increases, the driving forces become larger, and the FoS decreases, indicating a higher likelihood of slope failure.

4.2.4.3 Pore Water Pressure and Seepage Forces

In saturated soils, pore water pressure contributes to reducing effective stress. The saturated unit weight determines the total stress exerted by the soil and water, influencing:

The seepage forces in slopes with groundwater flow.

The stability of the slope under fully saturated conditions (e.g., after heavy rainfall).

A higher saturated unit weight increases pore water pressure and seepage forces, which can destabilize the slope.

4.2.5 Direct Shear box test

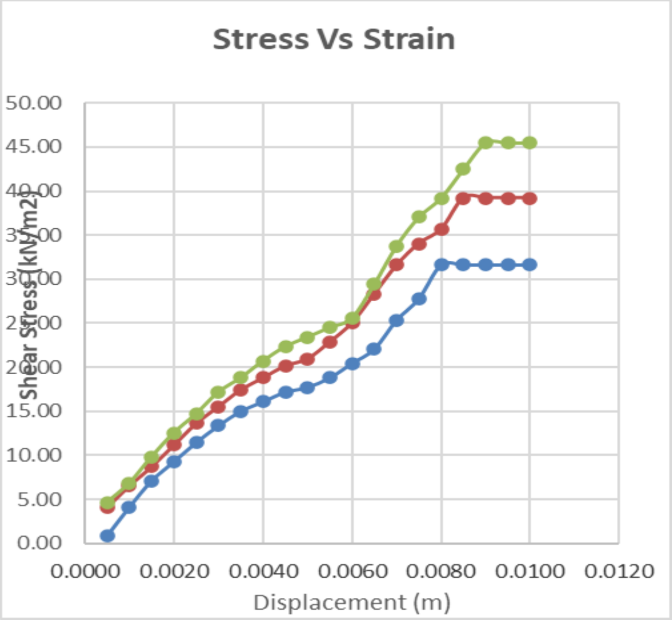


Figure 28: A graph of shear stress vs displacement

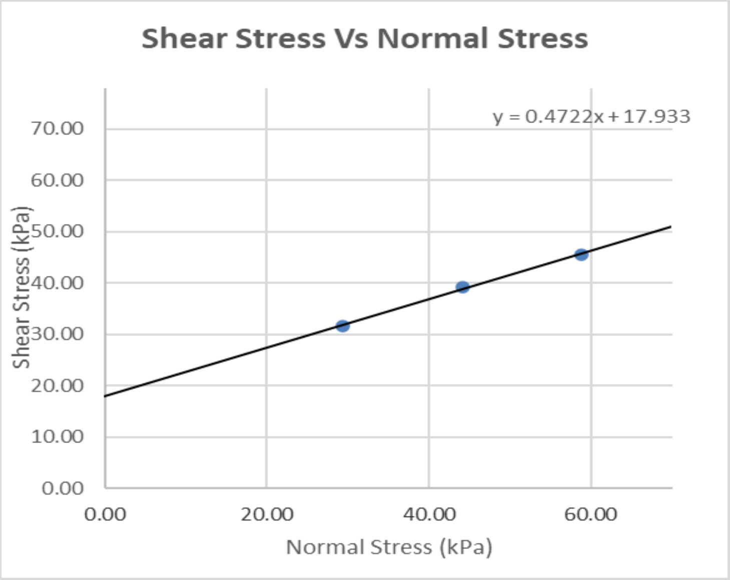


Table 29: A graph of shear stress vs normal stress

The direct shear box test determines the cohesion (the adhesive force between soil particles. And the internal friction which is the resistance due to particle interlocking. Which properties are used in stability analyses to predict the soil capacity to resist shear stress under normal loads.

4.2.6 Determination of factor of safety

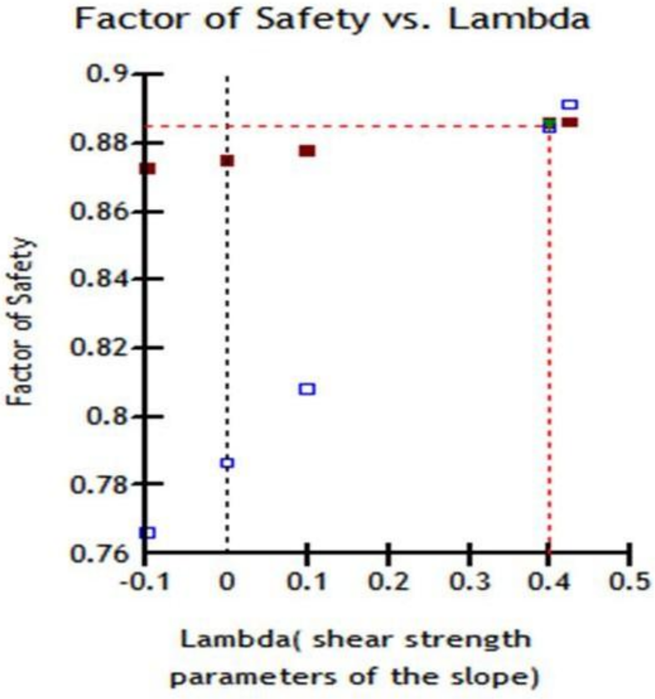


Table30: A graph of Factor of safety against Lamba (normal conditions)

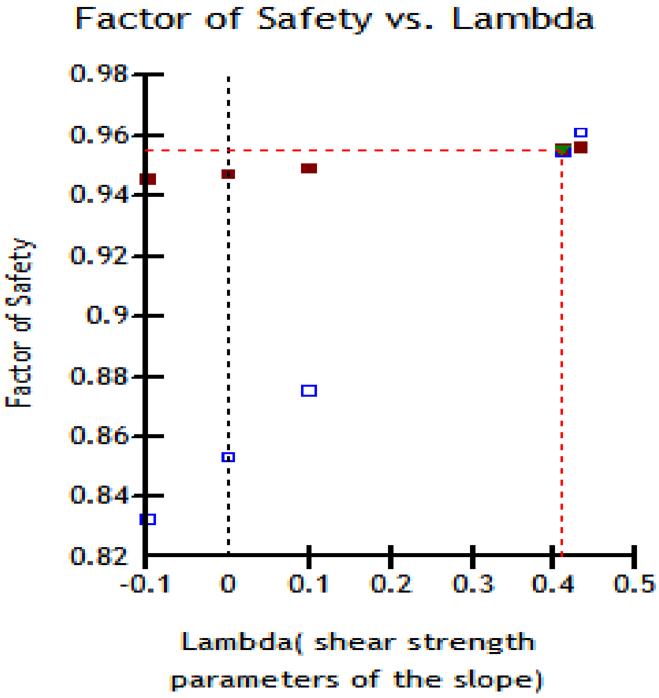


Figure 31: A graph of Factor of safety against Lambda (saturated conditions)

Figure 30 and 31 respectively 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 resisting 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 analyzed conditions and may be prone to failure under certain scenarios.

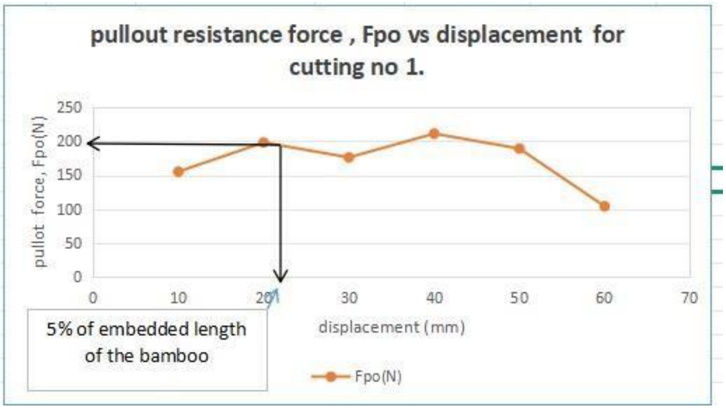
4.3 Assessing the effectiveness of biotechnical slope stabilization techniques for slope stabilization in landslide prone areas

Pullout resistance tests were carried out to assess the actual performance(friction) of the live cuttings of bamboo live cuttings (species: Oldeania Alpina) with the soil materials of the endangered slope. Table 8 shows diameters of bamboo live cuttings considered:

Table 8: Bamboo live cutting specimens with their average diameters

Bamboo live cuttings no.	D1(mm)	D2(mm)	D3(mm)	D(mm)	D(m)
1	28.64	28.62	28.61	28.62	0.0286
2	25.46	20.69	22.85	23	0.0230
3	12.73	12.5	12.43	12.55	0.0125
4	22.28	22.54	22.32	22.38	0.0223

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



Figurega3- 32: pullout resistance of 200 N was observed to pullout 5% of the embedded length of the bamboo live cutting sample no.1.

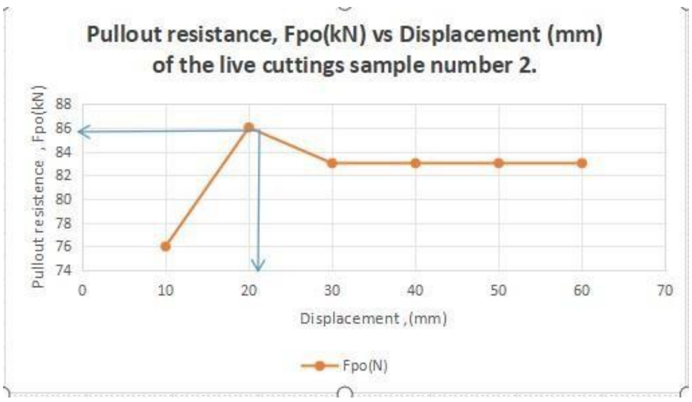


Figure 33: pullout resistance of 85 N was observed to pullout 5% of the embedded length of the bamboo live cutting sample no.2

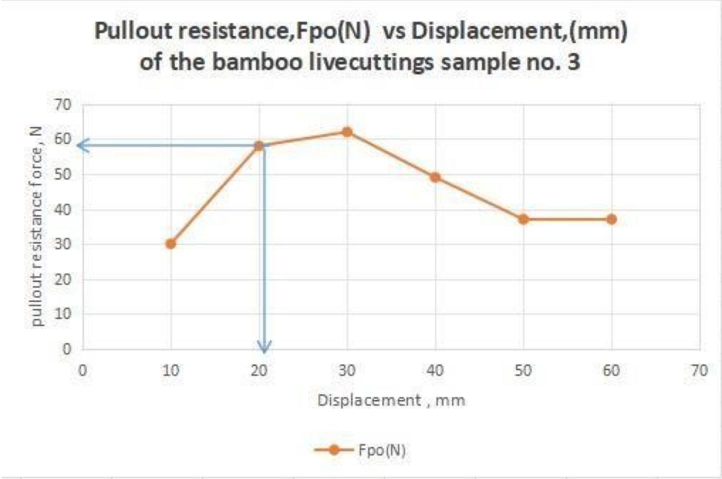


Figure 34: pullout resistance of 58 N was observed to pullout 5% of the embedded length of the bamboo live cutting sample no.3.

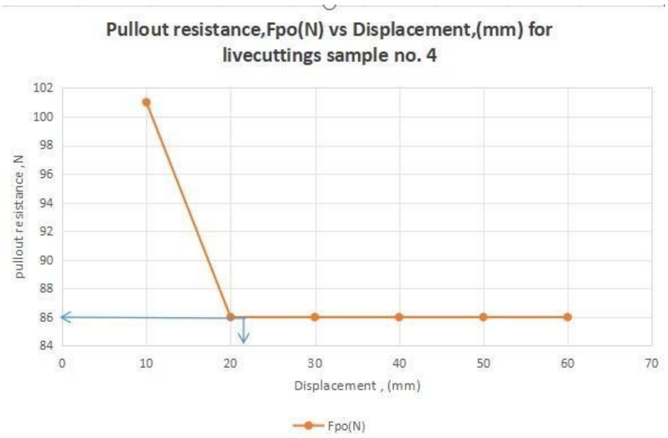


Figure 35: pullout resistance of 86 N was observed to pullout 5% of the embedded length of the bamboo live cutting sample no.4.

4.3.1 Observations as seen in figure 32,33,34 and 35.

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

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

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

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

4.3.2 Reinforcing Model

From the pullout resistance tests, R = 5245.248264 N was taken to be the pull resistance force which was later used to determine the factor of safety.

From the limit equilibrium principle of slope stabilization FS is given as the ratio of shear strength to shear stress. The factor of safety formulae:

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

Shear strength parameters:

$$s=c'l_1+[nR_{\mathrm{po}}(z)\ \sin(\alpha+\beta)+(\gamma_t-\gamma_{\mathrm{w}}m)z\cos^2\beta l_1]\mathrm{tg}\phi',$$

Shear stress parameters:

$$\tau=\gamma_t l_1 z\ \sin\beta\cos\beta-nR_{\mathrm{po}}(z)\cos(\alpha+\beta).$$

Source: (Boschetti G.B. et al 2020)

The calculations were computed and tabulated as showed in **Table 9 and 10**

Table 9: Showing the variation of reinforcement density, brushing layering, depth with factor of safety (normal conditions)

reinforcement density (cutting per meter)	Brush layering spacing (m)	Depth(m)	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	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

Table 10: Table showing the variations of reinforcement density, brush layering, depth with factor of safety (Saturated conditions)

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	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	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

From the results the factor of safety was seen to be most in improved when the parameters were qualified as showed in **Table 14 and 15.**

Table 11: Design for normal conditions

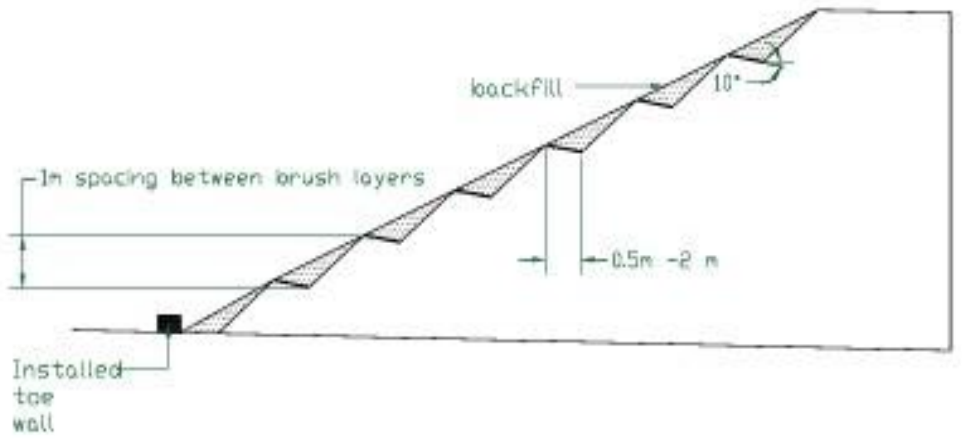
Depth	Spacing	Reinforcement density	Factor of safety
0.5	1	15	2.02
1	1	15	1.9
1.5	1	15	1.8
2	1	15	1.6

Table 12:Design for saturated conditions

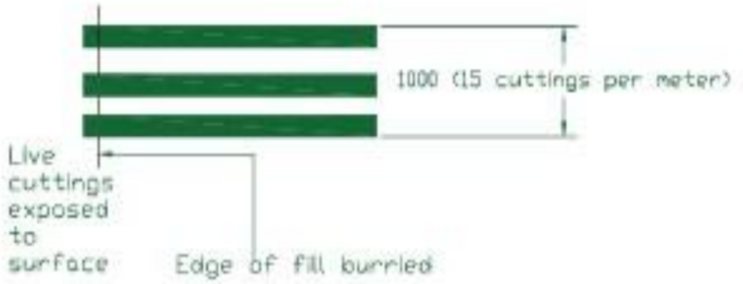
Depth	Spacing	Reinforcement density	Factor of safety
0.5	1	15	1.7
1	1	15	1.6
1.5	1	15	1.4
2.0	1	15	1.8

From tables 14 and 15 it is seen at depth of 0.5, 1,1.5- and 2-meters depth the factor of safety is seen to have increased to a value above the standard value for slope failure most when the reinforcement density of 15 cuttings per meter and spacing of 1 meter apart. Hence this study proves that the best brush layering at every depth (below 2 meter) is quantified to have the reinforcement density of 15 cuttings with a spacing of 1 meter to have the factor of safety increased beyond slop failure.

Cross section of endagered slope to be stabilized



PLAN VIEW



Project Title	ASSESSING THE EFFECTIVENESS OF BIOTECHINICAL SLOPE STABILIZATION METHODS IN LANDSLIDE PRONE AREAS
Drawing	THE BRUSHLAYERING DESIGN
Name	NAKINKUNDA PRISCA
Reg Number	S21B32\084

CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS

5.1 Conclusions

This study comprehensively addressed the challenge of landslide prone areas through advanced mapping, geotechnical analysis and development of a sustainable slope stabilization method.

Landslide prone areas were successfully mapped using the AHP model achieving an AUC of 0.85 (good performance with no false alarms. This method incorporated multiple factors contributing to landslide susceptibility, such as slope gradient, soil type, land use and rainfall intensity. The high AUC demonstrates the model's ability to identity vulnerable areas with high accuracy and reliability.

Geotechnical analysis of slopes (saturated and normal conditions) using the Morgenstern-Price method revealed factors of safety of 0.89 an 0.95 for normal and saturated conditions respectively, indicating high failure especially during heavy rainfall or after prolonged soil saturation. These findings highlight the inherent vulnerability of the slope in their current state, necessitating urgent intervention to mitigate landslides risks.

A bamboo brush layering model for slope stabilization was proposed, accounting for both saturated and normal slope conditions to improve stability. This model integrates bamboo live cuttings into a layered structure along slope contours providing both mechanical and hydrological benefits. Bamboos strong pullout resistance enhances soil reinforcement, while its fibrous roots improve soil cohesion and reduce erosion. the model was specifically designed to improve soil cohesion and reduce erosion. The model was specifically designed to improve slope stability under both saturated conditions (common conditions, ensuring adaptability to varying environmental scenarios. By increasing the slopes factor of safety and reducing failure risks, the proposed bamboo brush layering system offers an effective, ecofriendly, and sustainable stabilization solution.

5.2 Recommendations

The study findings have provided valuable insights into landslide susceptibility and slope stabilization techniques. However further research is recommended to enhance understanding and improve the application of these methods in real world scenarios.

5.2.1 Improving Landslide Susceptibility Mapping

While the Analytical Hierarchy Process (AHP) model demonstrated good performance with an Area Under Curve of 0.85, there is need to explore probabilistic approaches such as the Bayesian probabilistic model and frequency ratio methods. These methods consider the inherent uncertainty and variability of the factors influencing slope properties and vegetation cover. By integrating probability distributions into the analysis, these approaches can provide a more an understanding of the regions susceptibility to landslides enabling more accurate predictions and better-informed mitigation strategies.

5.2.2 Evaluating Brush Layers Under Dynamic Loading Conditions

The bamboo brush layering model has proven effective under static slope conditions; however, its performance under dynamic loading conditions such as earthquakes, heavy vehicular traffic or extreme weather events has yet to be fully assessed. Dynamic loading introduces additional stresses and forces that can affect the integrity of brush layers and the stability of slopes.

5.2.3 Long Term Development of Root Systems in Pullout Resistance Tests

The current pullout resistance tests focus on the immediate stabilization benefits of bamboo live cuttings

However, the long-term development of bamboo root systems and their contribution to slope stability over time require further investigation. Bamboo roots grow and spread extensively over time, significantly enhancing soil cohesion and pullout resistance.

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APPENDIX A: PICTORIAL

Figure36: Showing compaction in proctor test

Figure37: Sample collection

Figure38: sieve analysis test

Figure 27: Sample testing for shear box test

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TEST CERTIFICATE FOR GRAVEL/ SOIL SAMPLE

CLIENT : M/S NAKINKUNDA PRISCA AND VLADIMIR MICHAEL
PROJECT : ASSESSING THE EFFECTIVENESS OF BIOTECHNICAL SLOPE STABILISATION IN LAND SLIDE PRONE AREAS
DATE : 10 FEBRUARY 2025

Test Standard/ Method BS 1377: Part 2 : 2022, BS 1924: 1990 AND MoWT:2005
Material Source and De: Blackish dark brown Trial Pit soil Sample
Job Ref : CML: 003/31/01/25

Sample Description	Grading (%) Passing													Atterbergs Limits			LS %	SP	GC	GM	Bs Heavy Compaction		AASHTO Class	Soaked CBR (%) at 95% MDD; OMC	Material Class MoWT (2005)
	37.5 mm	28.0 mm	20.0 mm	10.0 mm	6.3 mm	5.0 mm	2.0 mm	0.600 mm	0.425 mm	0.300 mm	0.212 mm	0.150 mm	0.075 mm	LL %	PL %	PI %					MDD Mg/m³	OMC %			
TP 01 @ 1.0m (Neat)		100	100	88	67	42	30	25	24	21	19	16	14	41	25	16	11	264	32	2.32	2.18	9	A-2-7(0)	37	GW

Note: The Sample was tested as delivered by the client.

Legend: **LL** - Liquid Limit, **PL** - Plastic Limit, **PI** - Plasticity Index, **LS** - Linear Shrinkage (LS= 100(Initial length-Oven dried length/Initial length)), **SP** - Shrinkage Product (SP= LS*%<425mm), **OMC** - Optimum Moisture Content, **GC**- Grading Coefficient, **MDD** - Maximum Dry Density, **CBR** - California Bearing Ratio, **AASHTO** - American Association of State Highway and Transportation Officials, **MoWT** - Ministry of Works and Transport General Specifications for Roads and Bridges (2005),
GW - Natural gravel for Wearing Course and unpaved shoulders with a Minimum Soacked CBR Value of 25%, **GM** - Grading Modulus (GM= (300-%<2mm-%<0.425mm-%<0.075mm)/100).

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PROJECT : ASSESSING THE EFFECTIVENESS OF BIOTECHNICAL SLOPE STABILISATION IN LAND SLIDE PRONE AREAS
DATE : 10-Feb-25

Test Standard/ Method: BS 1377-2:2022 and BS EN ISO 17892-10: 2018

Ref. CML.003/31/01/25

DIRECT SHEAR BOX TEST RESULTS FOR UNDISTURBED SOIL SAMPLES

Sample Identification	**Test Pit/ BH No.**	**Depth (m)**	**Sample Type**
	TP 01 - Neat	1.0	U-sample

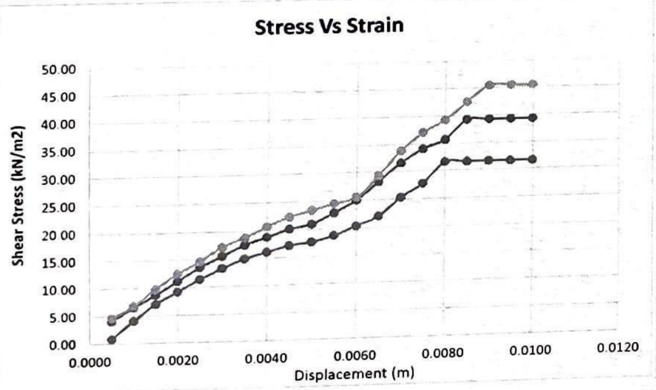
Sample ring Details	Length (mm)	Width (mm)	Height (mm)	Volume (mm^3)	Area (mm^2)
	60	60	25	90000	3600

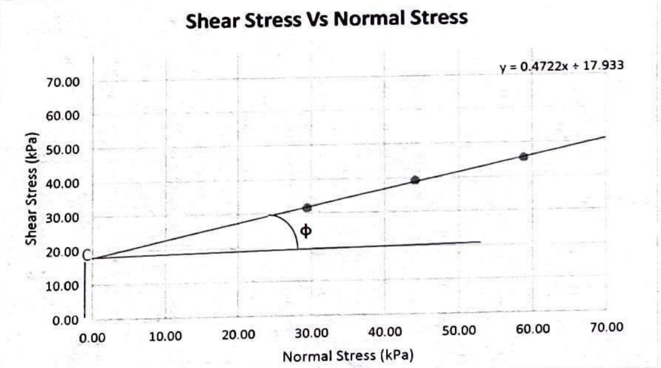
Sample details and Normal stress

Weight of Sample + Ring (g)	**Weight of Ring (g)**	**Weight of Sample (g)**	**Bulk density (Mg/m^2)**	**Overburden Pressure (P_0)**	**Estimated Load (kg)**	**Shearing Stress 1 (kg/cm^2)**		**Shearing Stress 2, if a hanger ratio of 1:5 is used (kg/cm^2)**		**Load 1 (kg/cm^2)**	**Load 2 (kg/cm^2)**	**Load 3 (kg/cm^2)**
336.76	149.7	187.06	2.078	20.39	7.48	0.06	0.06	0.01	0.01	0.30	0.45	0.60

Direct shear pareameters

Normal Stress (kPa)	29.42			44.13				58.84			
Displacement (mm)	**Shear force (kg)**	**Shear Stress (kN/m^2)**	**Displacement (m)**	**Displacement (mm)**	**Shear force (kg)**	**Shear Stress (kN/m^2)**	**Displacement (m)**	**Displacement (mm)**	**Shear force (kg)**	**Shear Stress (kN/m^2)**	**Displacement (m)**
0.5	0.3	0.82	0.0005	**0.5**	1.5	4.09	0.0005	**0.5**	1.7	4.63	0.0005
1.0	1.5	4.09	0.0010	**1.0**	2.4	6.54	0.0010	**1.0**	2.5	6.81	0.0010
1.5	2.6	7.08	0.0015	**1.5**	3.2	8.72	0.0015	**1.5**	3.6	9.81	0.0015
2.0	3.4	9.26	0.0020	**2.0**	4.1	11.17	0.0020	**2.0**	4.6	12.53	0.0020
2.5	4.2	11.44	0.0025	**2.5**	5.0	13.62	0.0025	**2.5**	5.4	14.71	0.0025
3.0	4.9	13.35	0.0030	**3.0**	5.7	15.53	0.0030	**3.0**	6.3	17.16	0.0030
3.5	5.5	14.98	0.0035	**3.5**	6.4	17.43	0.0035	**3.5**	6.9	18.80	0.0035
4.0	5.9	16.07	0.0040	**4.0**	6.9	18.80	0.0040	**4.0**	7.6	20.70	0.0040
4.5	6.3	17.16	0.0045	**4.5**	7.4	20.16	0.0045	**4.5**	8.2	22.34	0.0045
5.0	6.5	17.71	0.0050	**5.0**	7.7	20.98	0.0050	**5.0**	8.6	23.43	0.0050
5.5	6.9	18.80	0.0055	**5.5**	8.4	22.88	0.0055	**5.5**	9.0	24.52	0.0055
6.0	7.5	20.43	0.0060	**6.0**	9.2	25.06	0.0060	**6.0**	9.4	25.61	0.0060
6.5	8.1	22.06	0.0065	**6.5**	10.4	28.33	0.0065	**6.5**	10.8	29.42	0.0065
7.0	9.3	25.33	0.0070	**7.0**	11.6	31.60	0.0070	**7.0**	12.4	33.78	0.0070
7.5	10.2	27.79	0.0075	**7.5**	12.5	34.05	0.0075	**7.5**	13.6	37.05	0.0075
8.0	11.6	31.60	0.0080	**8.0**	13.1	35.69	0.0080	**8.0**	14.4	39.23	0.0080
8.5	11.6	31.60	0.0085	**8.5**	14.4	39.23	0.0085	**8.5**	15.6	42.50	0.0085
9.0	11.6	31.60	0.0090	**9.0**	14.4	39.23	0.0090	**9.0**	16.7	45.49	0.0090
9.5	11.6	31.60	0.0095	**9.5**	14.4	39.23	0.0095	**9.5**	16.7	45.49	0.0095
10.0	11.6	31.60	0.0100	**10.0**	14.4	39.23	0.0100	**10.0**	16.7	45.49	0.0100





Summery				**From Equation (y = mx+c)**			
				c (kPa)	**Slope (m)**	**phi (rad)**	**Angle of Internal friction (ϕ)**
Normal Stress (kPa)	29.42	44.13	58.84	[illegible]	[illegible]	0.441	25
Shear stress at Failure (kPa)	31.60	39.226	45.49				

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

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

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	Width, B	Bulk Density, γb	Effective Vertical Stress, σ	Shear Strength, s_u	Yield Stress Ratio	Adhesion Factor, α	Unit Skin Friction,	Cohesion	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)	ϕ (Degrees)	Nc	Nq	N_γ	q_{ult} (kPa)	(F)	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

$q_{ult} = CN_c sc + q_o N_q + \frac{1}{2}\gamma B N_\gamma s\gamma$

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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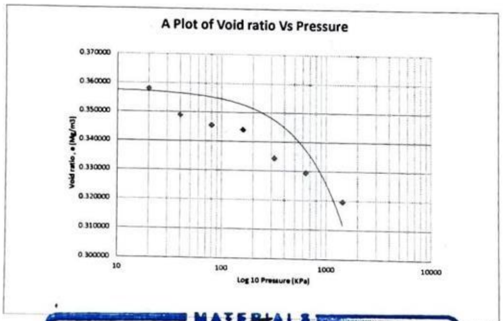
TEST CERTIFICATE FOR CONSOLIDATION OF SOIL

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		$1+e_1$	m_v m^2/MN	Settlement (Pc), mm	Compression Index, Cc
						Vlod ratio	*Pressure*				
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**


A Plot of Void ratio Vs Pressure

CHIEF MATERIALS ENGINEER

11.02.2025

MATERIALS
CHIEF MATERIALS ENGINEER
MINISTRY OF WORKS
AND TRANSPORT
KAMPALA
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 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 RESULTS SUMMARY SHEET ON UNDISTURBED SAMPLES

Test Point Label	Depth (m)	Saturated Unit weight, γ_{sat} (kN/m^3)	Average Coefficient of Volume Compressibility m_v, (m^2/MN)	Range of Coefficient of Volume Compressibility (m^2/MN)	Elastic Modulus, E_{oed} (MN/m^2)	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

11/02/2025

CHIEF MATERIALS ENGINEER

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CENTRAL MATERIALS LABORATORY KIREKA

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	**Sample Receipt Date:** 07/03/2025	**Analysis Start Date:** 07/03/2025
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.		

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.

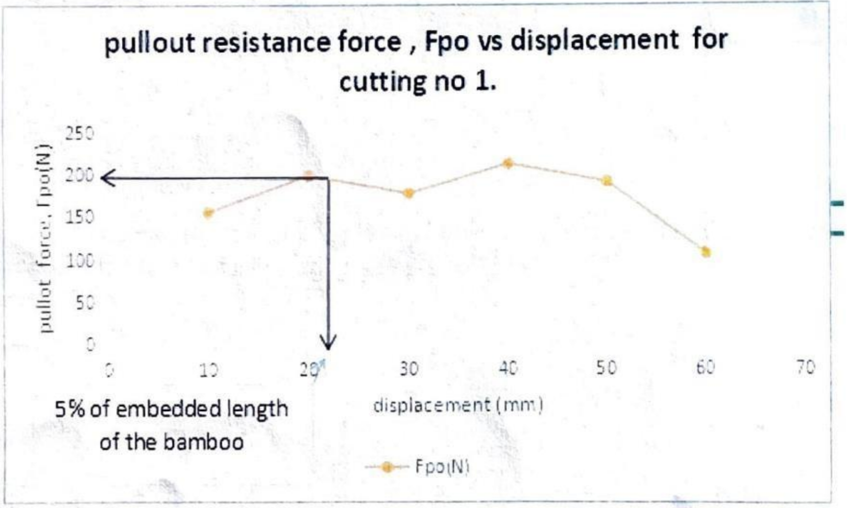


Figure 1 : pullout resistance of 200 N was observed to pullout 5% of the embedded length of the bamboo live cutting sample no.1.

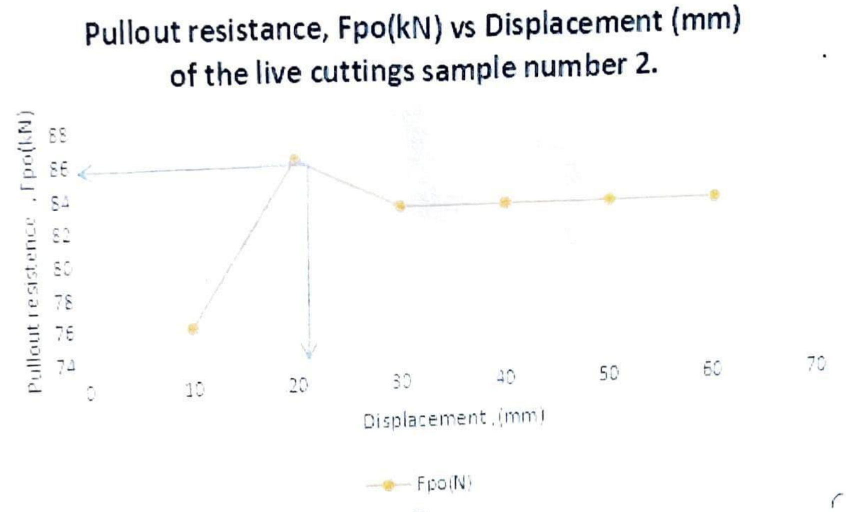


Figure 2 : pullout resistance of 85 N was observed to pullout 5% of the embedded length of the bamboo live cutting sample no.2.

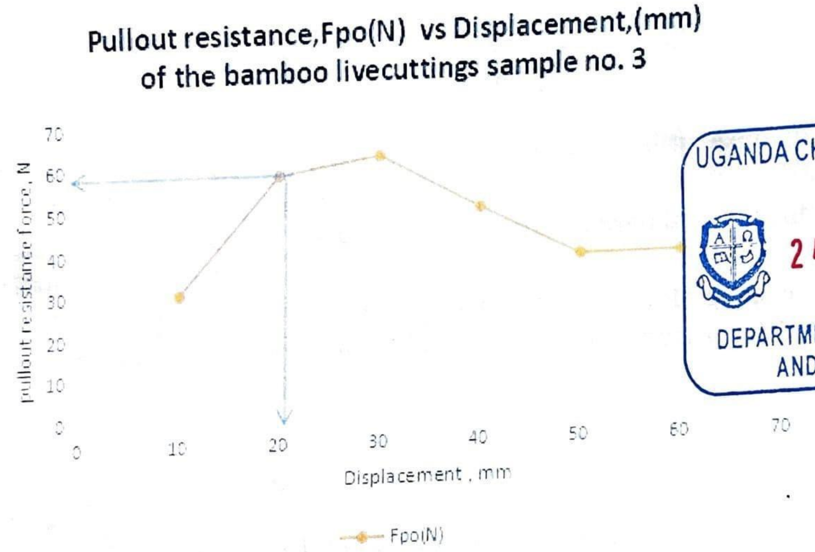


Figure 3 : pullout resistance of 58 N was observed to pullout 5% of the embedded length of the bamboo live cutting sample no.3.

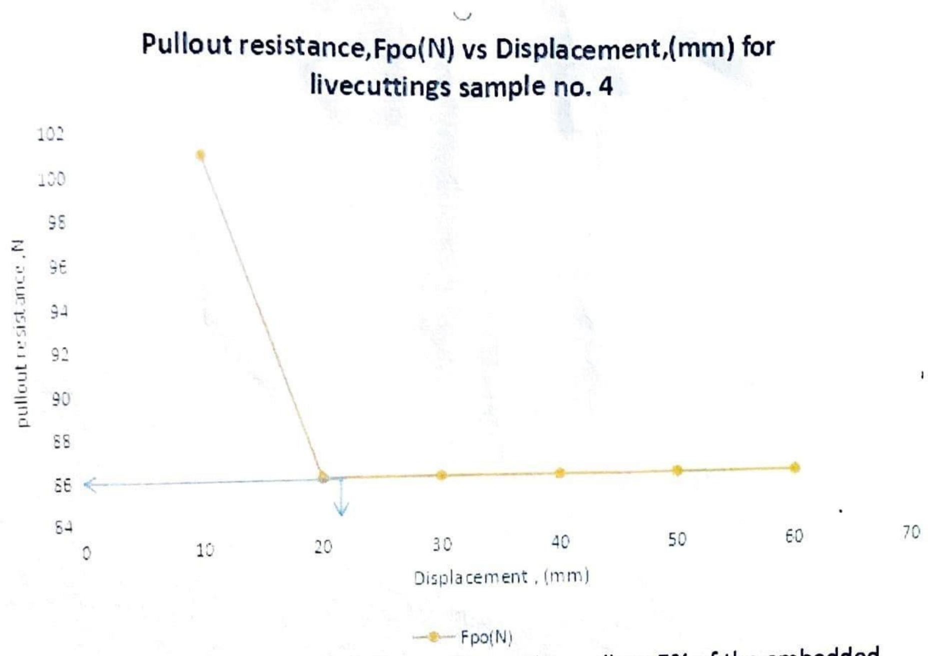


Figure 4 : pullout resistance of 86 N was observed to pullout 5% of the embedded length of the bamboo live cutting sample no.4.

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

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

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

Le is the embedded length of the bamboo livecuttings into the soil.

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

Slope Stability

File Information

- File Version: 9.01
- Title: slope stability analysis
- Comments: SLOPE STABILITY ANALYSIS USING MORGENSTERN PRICE METHOD
- Created By: vladimir michae S21B32/004
- Revision Number: 15
- Date: 02/05/2025
- Time: 10:01:55 AM
- Tool Version: 9.1.1.16749
- File Name: VLADIMIR MICHAEL AND NAKIKUNDA PRISCA.gsz
- Directory: C:\Users\user\Desktop\slope stability trials\
- Last Solved Date: 02/05/2025
- Last Solved Time: 10:02:17 AM

Project Settings

- Unit System: International System of Units (SI)

Analysis Settings

Slope Stability

- Description: MORGENSTERN PRICE LIMIT EQUILIBRIUM METHOD
- Kind: SLOPE/W
- Method: Morgenstern-Price
- Settings
  - Side Function
    - Interslice force function option: Half-Sine
  - PWP Conditions from: Piezometric Line
    - Apply Phreatic Correction: No
    - Use Staged Rapid Drawdown: No
  - Unit Weight of Water: 9.807 kN/m³
- Slip Surface
  - Direction of movement: Left to Right
  - Use Passive Mode: No
  - Slip Surface Option: Entry and Exit
  - Critical slip surfaces saved: 1
  - Optimize Critical Slip Surface Location: No
  - Tension Crack Option: (none)
- Distribution
  - F of S Calculation Option: Constant
- Advanced
  - Geometry Settings
    - Minimum Slip Surface Depth: 0.1 m
    - Number of Slices: 30
  - Factor of Safety Convergence Settings
    - Maximum Number of Iterations: 100

Tolerable difference in F of S: 0.001

Solution Settings

Search Method: Root Finder

Tolerable difference between starting and converged F of S: 3

Maximum iterations to calculate converged lambda: 20

Max Absolute Lambda: 2

Materials

New Material

Model: Mohr-Coulomb

Unit Weight: 17.98 kN/m³

Cohesion': 18 kPa

Phi': 25 °

Phi-B: 0 °

Pore Water Pressure

Piezometric Line: 1

Slip Surface Entry and Exit

Left Type: Range

Left-Zone Left Coordinate: (0.28597, 105) m

Left-Zone Right Coordinate: (18, 105) m

Left-Zone Increment: 8

Right Type: Range

Right-Zone Left Coordinate: (241.17043, 15.99356) m

Right-Zone Right Coordinate: (247, 15.99356) m

Right-Zone Increment: 8

Radius Increments: 4

Slip Surface Limits

Left Coordinate: (0, 105) m

Right Coordinate: (247.50687, 15.99356) m

Piezometric Lines

Piezometric Line 1

Coordinates

	X	Y
Coordinate 1	0 m	95 m
Coordinate 2	20 m	95 m
Coordinate 3	172 m	18 m
Coordinate 4	177.5 m	18 m
Coordinate 5	214.5 m	10 m
Coordinate 6	218.5 m	10 m
Coordinate 7	240.5 m	6 m
Coordinate 8	247.5 m	6 m

Points

	X	Y
Point 1	1 m	105 m
Point 2	20 m	105 m
Point 3	172 m	28 m
Point 4	177.50392 m	28 m
Point 5	214.51054 m	19.99737 m
Point 6	218.50738 m	19.99737 m
Point 7	240.49882 m	15.99356 m
Point 8	247.50687 m	15.99356 m
Point 9	247.50687 m	-0.01392 m
Point 10	0 m	-0.01392 m
Point 11	0 m	105 m

Regions

	Material	Points	Area
Region 1	New Material	1,2,3,4,5,6,7,8,9,10,11	13,841 m²

Slip Results

Slip Surfaces Analysed: 286 of 405 converged

Current Slip Surface

Slip Surface: 3
Factor of Safety: 0.885
Volume: 6,963.7996 m³
Weight: 125,209.12 kN
Resisting Moment: 8,127,801 kN·m
Activating Moment: 9,175,510.6 kN·m
Resisting Force: 35,787.014 kN
Activating Force: 40,441.888 kN
Slip Rank: 1 of 405 slip surfaces
Exit: (241.17043, 15.99356) m
Entry: (0.28597, 105) m
Radius: 206.69066 m
Center: (176.86607, 212.4267) m

Slip Slices

	X	Y	PWP	Base Normal Stress	Frictional Strength	Cohesive Strength	Suction Strength	Base Material
Slice 1	0.642985 m	104.41751 m	-92.35752 kPa	-12.131698 kPa	-5.6571038 kPa	18 kPa	0 kPa	New Material
Slice 2	3.8859925 m	99.41751 m	-43.32252 kPa	38.098828 kPa	17.765775 kPa	18 kPa	0 kPa	New Material
Slice 3	10.078989 m	90.477103 m	44.356054 kPa	148.92811 kPa	48.762749 kPa	18 kPa	0 kPa	New Material

Slice 4	16.692996 m	81.896204 m	128.50893 kPa	270.19576 kPa	66.069657 kPa	18 kPa	0 kPa	New Material
Slice 5	24 m	73.438796 m	191.57865 kPa	358.96439 kPa	78.053252 kPa	18 kPa	0 kPa	New Material
Slice 6	32 m	65.106036 m	233.55387 kPa	417.40995 kPa	85.733495 kPa	18 kPa	0 kPa	New Material
Slice 7	40 m	57.635881 m	267.06952 kPa	465.19307 kPa	92.386529 kPa	18 kPa	0 kPa	New Material
Slice 8	48 m	50.907726 m	293.30838 kPa	504.95234 kPa	98.691201 kPa	18 kPa	0 kPa	New Material
Slice 9	56 m	44.831654 m	313.15225 kPa	538.60092 kPa	105.12844 kPa	18 kPa	0 kPa	New Material
Slice 10	64 m	39.338645 m	327.27804 kPa	567.51817 kPa	112.02581 kPa	18 kPa	0 kPa	New Material
Slice 11	72 m	34.374502 m	336.21723 kPa	592.66158 kPa	119.58196 kPa	18 kPa	0 kPa	New Material
Slice 12	80 m	29.895918 m	340.39455 kPa	614.6313 kPa	127.8787 kPa	18 kPa	0 kPa	New Material
Slice 13	88 m	25.867811 m	340.15404 kPa	633.70564 kPa	136.88536 kPa	18 kPa	0 kPa	New Material
Slice 14	96 m	22.261473 m	335.77723 kPa	649.85919 kPa	146.45882 kPa	18 kPa	0 kPa	New Material
Slice 15	104 m	19.053248 m	327.49614 kPa	662.77204 kPa	156.34172 kPa	18 kPa	0 kPa	New Material
Slice 16	112 m	16.22356 m	315.50273 kPa	671.83787 kPa	166.1618 kPa	18 kPa	0 kPa	New Material
Slice 17	120 m	13.756201 m	299.95597 kPa	676.17882 kPa	175.4356 kPa	18 kPa	0 kPa	New Material
Slice 18	128 m	11.637787 m	280.9871 kPa	674.67554 kPa	183.57993 kPa	18 kPa	0 kPa	New Material
Slice 19	136 m	9.8573504 m	258.70368 kPa	666.02051 kPa	189.93496 kPa	18 kPa	0 kPa	New Material
Slice 20	144 m	8.4060281 m	233.19263 kPa	648.80081 kPa	193.80128 kPa	18 kPa	0 kPa	New Material
Slice 21	152 m	7.2768234 m	204.52259 kPa	621.61188 kPa	194.49193 kPa	18 kPa	0 kPa	New Material
Slice 22	160 m	6.4644296 m	172.74558 kPa	583.19775 kPa	191.39699 kPa	18 kPa	0 kPa	New Material
Slice 23	168 m	5.9651011 m	137.89833 kPa	532.60537 kPa	184.05492 kPa	18 kPa	0 kPa	New Material
Slice 24	174.75 m	5.7651711 m	119.98697 kPa	507.49076 kPa	180.69598 kPa	18 kPa	0 kPa	New Material
Slice 25	177.50196 m	5.737019 m	120.2589 kPa	511.1741 kPa	182.28675 kPa	18 kPa	0 kPa	New Material
Slice 26	181.20353 m	5.8146917 m	111.64824 kPa	496.93934 kPa	179.66419 kPa	18 kPa	0 kPa	New Material
Slice 27	188.60274 m	6.1028095 m	93.133129 kPa	462.48669 kPa	172.23239 kPa	18 kPa	0 kPa	New Material
Slice 28	196.00196 m	6.6573121 m	72.005584 kPa	418.11842 kPa	161.39507 kPa	18 kPa	0 kPa	New Material
Slice 29	203.40118 m	7.4803645 m	48.244372 kPa	364.4548 kPa	147.45135 kPa	18 kPa	0 kPa	New Material

Slice 30	210.80039 m	8.5752239 m	21.817548 kPa	302.48834 kPa	130.87894 kPa	18 kPa	0 kPa	New Material
Slice 31	214.50527 m	9.1920584 m	7.9234829 kPa	269.34835 kPa	121.90442 kPa	18 kPa	0 kPa	New Material
Slice 32	216.50527 m	9.5828391 m	4.0910965 kPa	258.95298 kPa	118.84405 kPa	18 kPa	0 kPa	New Material
Slice 33	218.50369 m	9.9734028 m	0.25425953 kPa	248.49602 kPa	115.75703 kPa	18 kPa	0 kPa	New Material
Slice 34	218.53897 m	9.9806654 m	0.12011867 kPa	248.18846 kPa	115.67617 kPa	18 kPa	0 kPa	New Material
Slice 35	222.22528 m	10.809393 m	-14.580231 kPa	210.41078 kPa	98.116157 kPa	18 kPa	0 kPa	New Material
Slice 36	229.53469 m	12.59487 m	-45.123754 kPa	133.35006 kPa	62.182152 kPa	18 kPa	0 kPa	New Material
Slice 37	236.84411 m	14.666547 m	-78.474043 kPa	53.271205 kPa	24.840771 kPa	18 kPa	0 kPa	New Material
Slice 38	240.49941 m	15.775162 m	-95.863966 kPa	12.911653 kPa	6.0208029 kPa	18 kPa	0 kPa	New Material
Slice 39	240.83522 m	15.884457 m	-96.936866 kPa	10.469974 kPa	4.8822292 kPa	18 kPa	0 kPa	New Material

Slope Stability

File Information

File Version: 9.01
Title: slope stability analysis
Comments: SLOPE STABILITY ANALYSIS USING MORGENSTERN PRICE METHOD
Created By: vladimir michae S21B32/004
Revision Number: 9
Date: 01/29/2025
Time: 10:03:28 AM
Tool Version: 9.1.1.16749
File Name: VLADIMIR MICHAEL AND NAKIKUNDA PRISCA.gsz
Directory: C:\Users\user\Desktop\slope stability trials\
Last Solved Date: 01/29/2025
Last Solved Time: 10:03:54 AM

Project Settings

Unit System: International System of Units (SI)

Analysis Settings

Slope Stability

Description: MORGENSTERN PRICE LIMIT EQUILIBRIUM METHOD
Kind: SLOPE/W
Method: Morgenstern-Price
Settings
    Side Function
        Interslice force function option: Half-Sine
    PWP Conditions from: Piezometric Line
        Apply Phreatic Correction: No
        Use Staged Rapid Drawdown: No
    Unit Weight of Water: 9.807 kN/m³
Slip Surface
    Direction of movement: Left to Right
    Use Passive Mode: No
    Slip Surface Option: Entry and Exit
    Critical slip surfaces saved: 1
    Optimize Critical Slip Surface Location: No
    Tension Crack Option: (none)
Distribution
    F of S Calculation Option: Constant
Advanced
    Geometry Settings
        Minimum Slip Surface Depth: 0.1 m
        Number of Slices: 30
    Factor of Safety Convergence Settings
        Maximum Number of Iterations: 100
        Tolerable difference in F of S: 0.001
    Solution Settings
        Search Method: Root Finder
        Tolerable difference between starting and converged F of S: 3
        Maximum iterations to calculate converged lambda: 20
        Max Absolute Lambda: 2

Materials

New Material

Model: Mohr-Coulomb
Unit Weight: 21.4 kN/m³
Cohesion': 18 kPa
Phi': 25 °

Phi-B: 0 °
Pore Water Pressure
Piezometric Line: 1

Slip Surface Entry and Exit

Left Type: Range
Left-Zone Left Coordinate: (0.28597, 105) m
Left-Zone Right Coordinate: (18, 105) m
Left-Zone Increment: 8
Right Type: Range
Right-Zone Left Coordinate: (241.17043, 15.99356) m
Right-Zone Right Coordinate: (247, 15.99356) m
Right-Zone Increment: 8
Radius Increments: 4

Slip Surface Limits

Left Coordinate: (0, 105) m
Right Coordinate: (247.50687, 15.99356) m

Piezometric Lines

Piezometric Line 1

Coordinates

	X	Y
Coordinate 1	0 m	95 m
Coordinate 2	20 m	95 m
Coordinate 3	172 m	18 m
Coordinate 4	177.5 m	18 m
Coordinate 5	214.5 m	10 m
Coordinate 6	218.5 m	10 m
Coordinate 7	240.5 m	6 m
Coordinate 8	247.5 m	6 m

Points

	X	Y
Point 1	1 m	105 m
Point 2	20 m	105 m
Point 3	172 m	28 m
Point 4	177.50392 m	28 m
Point 5	214.51054 m	19.99737 m
Point 6	218.50738 m	19.99737 m
Point 7	240.49882 m	15.99356 m
Point 8	247.50687 m	15.99356 m
Point 9	247.50687 m	-0.01392 m
Point 10	0 m	-0.01392 m
Point 11	0 m	105 m

Regions

	Material	Points	Area
Region 1	New Material	1,2,3,4,5,6,7,8,9,10,11	13,841 m^2

Slip Results

Slip Surfaces Analysed: 299 of 405 converged

Current Slip Surface

Slip Surface: 3

Factor of Safety: 0.949
Volume: 6,963.7996 m³
Weight: 149,025.31 kN
Resisting Moment: 10,368,379 kN·m
Activating Moment: 10,920,797 kN·m
Resisting Force: 45,527.34 kN
Activating Force: 47,995.369 kN
Slip Rank: 1 of 405 slip surfaces
Exit: (241.17043, 15.99356) m
Entry: (0.28597, 105) m
Radius: 206.69066 m
Center: (176.86607, 212.4267) m

Slip Slices

	X	Y	PWP	Base Normal Stress	Frictional Strength	Cohesive Strength	Suction Strength	Base Material
Slice 1	0.642985 m	104.41751 m	-92.35752 kPa	-10.185612 kPa	-4.7496289 kPa	18 kPa	0 kPa	New Material
Slice 2	3.8859925 m	99.41751 m	-43.32252 kPa	51.028942 kPa	23.795187 kPa	18 kPa	0 kPa	New Material
Slice 3	10.078989 m	90.477103 m	44.356054 kPa	180.96313 kPa	63.700924 kPa	18 kPa	0 kPa	New Material
Slice 4	16.692996 m	81.896204 m	128.50893 kPa	320.13039 kPa	89.354553 kPa	18 kPa	0 kPa	New Material
Slice 5	24 m	73.438796 m	191.57865 kPa	422.64204 kPa	107.74663 kPa	18 kPa	0 kPa	New Material
Slice 6	32 m	65.106036 m	233.55387 kPa	490.78867 kPa	119.95056 kPa	18 kPa	0 kPa	New Material
Slice 7	40 m	57.635881 m	267.06952 kPa	547.10364 kPa	130.58206 kPa	18 kPa	0 kPa	New Material
Slice 8	48 m	50.907726 m	293.30838 kPa	594.51305 kPa	140.45404 kPa	18 kPa	0 kPa	New Material
Slice 9	56 m	44.831654 m	313.15225 kPa	635.1207 kPa	150.13635 kPa	18 kPa	0 kPa	New Material
Slice 10	64 m	39.338645 m	327.27804 kPa	670.42179 kPa	160.01056 kPa	18 kPa	0 kPa	New Material
Slice 11	72 m	34.374502 m	336.21723 kPa	701.42793 kPa	170.30055 kPa	18 kPa	0 kPa	New Material
Slice 12	80 m	29.895918 m	340.39455 kPa	728.73943 kPa	181.08819 kPa	18 kPa	0 kPa	New Material
Slice 13	88 m	25.867811 m	340.15404 kPa	752.58535 kPa	192.31988 kPa	18 kPa	0 kPa	New Material
Slice 14	96 m	22.261473 m	335.77723 kPa	772.8445 kPa	203.80781 kPa	18 kPa	0 kPa	New Material
Slice 15	104 m	19.053248 m	327.49614 kPa	789.05736 kPa	215.22953 kPa	18 kPa	0 kPa	New Material
Slice 16	112 m	16.22356 m	315.50273 kPa	800.43768 kPa	226.12888 kPa	18 kPa	0 kPa	New Material
Slice 17	120 m	13.756201 m	299.95597 kPa	805.89279 kPa	235.92222 kPa	18 kPa	0 kPa	New Material
Slice 18	128 m	11.637787 m	280.9871 kPa	804.06215 kPa	243.9139 kPa	18 kPa	0 kPa	New Material
Slice 19	136 m	9.8573504 m	258.70368 kPa	793.38325 kPa	249.32518 kPa	18 kPa	0 kPa	New Material
Slice 20	144 m	8.4060281 m	233.19263 kPa	772.19165 kPa	251.33937 kPa	18 kPa	0 kPa	New Material
Slice 21	152 m	7.2768234 m	204.52259 kPa	738.85669 kPa	249.16408 kPa	18 kPa	0 kPa	New Material
Slice 22	160 m	6.4644296 m	172.74558 kPa	691.94697 kPa	242.10759 kPa	18 kPa	0 kPa	New Material
Slice 23	168 m	5.9651011 m	137.89833 kPa	630.41072 kPa	229.6623 kPa	18 kPa	0 kPa	New Material
Slice 24	174.75 m	5.7651711 m	119.98697 kPa	599.67467 kPa	223.68205 kPa	18 kPa	0 kPa	New Material
Slice 25	177.50196 m	5.737019 m	120.2589 kPa	603.90888 kPa	225.52969 kPa	18 kPa	0 kPa	New Material
Slice 26	181.20353 m	5.8146917 m	111.64824 kPa	586.59056 kPa	221.46924 kPa	18 kPa	0 kPa	New Material

Slice 27	188.60274 m	6.1028095 m	93.133129 kPa	544.87662 kPa	210.65145 kPa	18 kPa	0 kPa	New Material
Slice 28	196.00196 m	6.6573121 m	72.005584 kPa	491.4583 kPa	195.59401 kPa	18 kPa	0 kPa	New Material
Slice 29	203.40118 m	7.4803645 m	48.244372 kPa	427.10642 kPa	176.66628 kPa	18 kPa	0 kPa	New Material
Slice 30	210.80039 m	8.5752239 m	21.817548 kPa	353.02573 kPa	154.44491 kPa	18 kPa	0 kPa	New Material
Slice 31	214.50527 m	9.1920584 m	7.9234829 kPa	313.47512 kPa	142.48107 kPa	18 kPa	0 kPa	New Material
Slice 32	216.50527 m	9.5828391 m	4.0910965 kPa	301.16208 kPa	138.52647 kPa	18 kPa	0 kPa	New Material
Slice 33	218.50369 m	9.9734028 m	0.25425953 kPa	288.78203 kPa	134.54271 kPa	18 kPa	0 kPa	New Material
Slice 34	218.53897 m	9.9806654 m	0.12011867 kPa	288.41552 kPa	134.43435 kPa	18 kPa	0 kPa	New Material
Slice 35	222.22528 m	10.809393 m	-14.580231 kPa	244.1925 kPa	113.86883 kPa	18 kPa	0 kPa	New Material
Slice 36	229.53469 m	12.59487 m	-45.123754 kPa	154.0234 kPa	71.822292 kPa	18 kPa	0 kPa	New Material
Slice 37	236.84411 m	14.666547 m	-78.474043 kPa	60.308444 kPa	28.122289 kPa	18 kPa	0 kPa	New Material
Slice 38	240.49941 m	15.775162 m	-95.863966 kPa	13.091662 kPa	6.1047422 kPa	18 kPa	0 kPa	New Material
Slice 39	240.83522 m	15.884457 m	-96.936866 kPa	10.238646 kPa	4.7743589 kPa	18 kPa	0 kPa	New Material

significant

not significant

PAIRWISE MATRIX

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	0.333333	1	3.0	0.5	1.0	2.0	1.0
curvature	0.166667	0.333333	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	1.818182	0.333333	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	3.030303	1
SUM	3.45	8.833333	21.81818	4.283333	12.55	17.0303	6.08

STEPS

1. Define objective (likelihood of landslide occurence)

2.Making pairwise comparisons with experts' opinions (experts in disasters that is landslides in this context)

3. define the weights (using the preference scale of saaty(2008))

	slope	lithology	curvature	rainfall	landcover and landuse	aspect	distance to stream	AVERAGE	LEMDA (λ)
Slope	0.289855	0.339623	0.275	0.233463	0.3187251	0.293594	0.328947368	0.29703	7.11201632
Lithology	0.096618	0.113208	0.1375	0.116732	0.079681275	0.117438	0.164473684	0.11795	7.0988079
Curvature	0.048309	0.037736	0.045833	0.046693	0.043824701	0.058719	0.041118421	0.046033	7.0916816
rainfall	0.289855	0.226415	0.229167	0.233463	0.239043825	0.234875	0.164473684	0.231042	7.10066725
landcover and landuse	0.072464	0.113208	0.083333	0.077821	0.079681275	0.058719	0.082236842	0.081066	7.11534504
aspect	0.057971	0.056604	0.045833	0.058366	0.079681275	0.058719	0.054276316	0.058779	7.10279626
distance to stream	0.144928	0.113208	0.183333	0.233463	0.15936255	0.177936	0.164473684	0.168101	7.07903535
SUM	1	1	1	1	1	1	1		7.11534504

SINGOMA JOSEPH
SENIOR PLANNER
DISASTER MGT
FOCAL PERSON

0771621966.

MONTHLY RAINFALL REPORT FORM

Name of Station KASESE MET. STATION Station No. 63674

INSTRUCTIONS

1. Observations are made daily AT 9:00 am.

2. Tear off the card each month and dispatch it as soon as possible after the last entry (that is the fall recorded on the 1st of the next month).

3. Your permanent record is made on reserve side of this card. Please make sure that this has been filled in before sending off the monthly card.

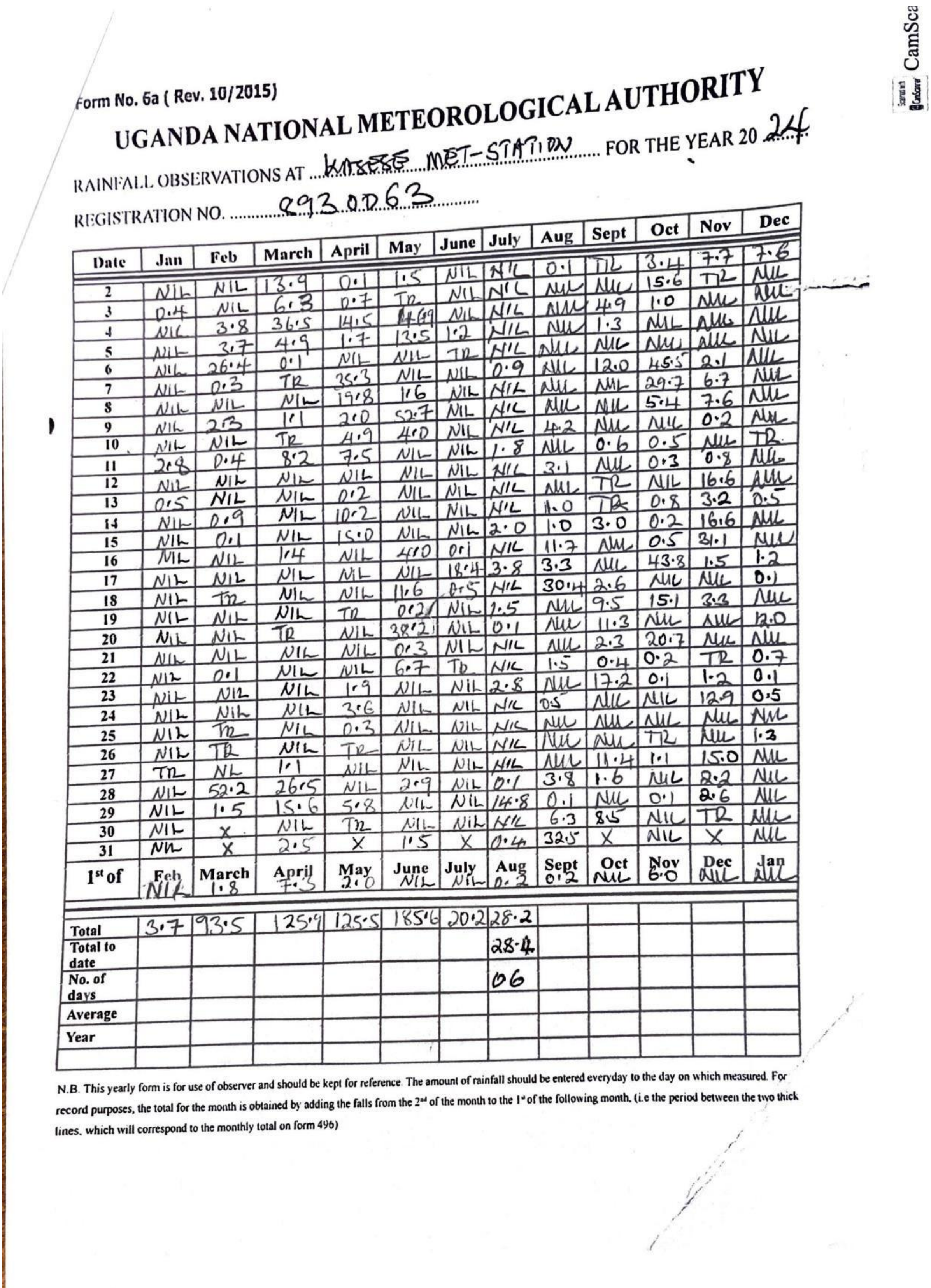
4. The rainfall measured each day must be entered against the date on which it is measured. For example, the rainfall measured at 9:00am on the 2nd of the month is entered in the space marked: 2". Enter "NIL" when no rainfall is found in the gauge. There are spaces for 31 days in each month; for a month having less than 31 days, one or more space must be left blank. For example, February 1971 will have blanks against 29, 30 and 31, etc.

   The space headed "1st" of February of the following month must be completed. The total rainfall for any month is the sum of daily falls as entered, from 2nd of the month to the 1st of the following inclusive.

Instruction books for rainfall observation are available. If you do not already hold a copy, please write for one.

Before sending off the monthly card, please make sure that it bears the name, and the number of your station.

The enclosed cards are franked with a stamp and ready for posting. Great care should be taken to see that they are not lost or destroyed.



Form No. 6a (Rev. 10/2015)

UGANDA NATIONAL METEOROLOGICAL AUTHORITY

RAINFALL OBSERVATIONS AT KASESE MET-STATION FOR THE YEAR 20 24

REGISTRATION NO. 8930D63

Date	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
2	NIL	NIL	13.9	0.1	1.5	NIL	NIL	0.1	TR	3.4	7.7	7.6
3	0.4	NIL	6.3	0.7	TR	NIL	NIL	NIL	NIL	15.6	TR	NIL
4	NIL	3.8	36.5	14.5	46.9	NIL	NIL	NIL	4.9	1.0	NIL	NIL
5	NIL	3.7	4.9	1.7	13.5	1.2	NIL	NIL	1.3	NIL	NIL	NIL
6	NIL	26.4	0.1	NIL	NIL	TR	NIL	NIL	NIL	NIL	NIL	NIL
7	NIL	0.3	TR	35.3	NIL	NIL	0.9	NIL	12.0	45.5	2.1	NIL
8	NIL	NIL	NIL	19.8	1.6	NIL	NIL	NIL	NIL	29.7	6.7	NIL
9	NIL	2.3	1.1	2.0	52.7	NIL	NIL	NIL	NIL	5.4	7.6	NIL
10	NIL	NIL	TR	4.9	4.0	NIL	NIL	4.2	NIL	NIL	0.2	NIL
11	2.8	0.4	8.2	7.5	NIL	NIL	1.8	NIL	0.6	0.5	NIL	TR
12	NIL	NIL	NIL	NIL	NIL	NIL	NIL	3.1	NIL	0.3	0.8	NIL
13	0.5	NIL	NIL	0.2	NIL	NIL	NIL	NIL	TR	NIL	16.6	NIL
14	NIL	0.9	NIL	10.2	NIL	NIL	NIL	1.0	TR	0.8	3.2	0.5
15	NIL	0.1	NIL	15.0	NIL	NIL	2.0	1.0	3.0	0.2	16.6	NIL
16	NIL	NIL	1.4	NIL	4.0	0.1	NIL	11.7	NIL	0.5	31.1	NIL
17	NIL	NIL	NIL	NIL	NIL	18.4	3.8	3.3	NIL	43.8	1.5	1.2
18	NIL	TR	NIL	NIL	11.6	0.5	NIL	30.4	2.6	NIL	NIL	0.1
19	NIL	NIL	NIL	TR	0.2	NIL	1.5	NIL	9.5	15.1	3.3	NIL
20	NIL	NIL	TR	NIL	38.2	NIL	0.1	NIL	11.3	NIL	NIL	12.0
21	NIL	NIL	NIL	NIL	0.3	NIL	NIL	NIL	2.3	20.7	NIL	NIL
22	NIL	0.1	NIL	NIL	6.7	TR	NIL	1.5	0.4	0.2	TR	0.7
23	NIL	NIL	NIL	1.9	NIL	NIL	2.8	NIL	17.2	0.1	1.2	0.1
24	NIL	NIL	NIL	3.6	NIL	NIL	NIL	0.5	NIL	NIL	12.9	0.5
25	NIL	TR	NIL	0.3	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL
26	NIL	TR	NIL	TR	NIL	NIL	NIL	NIL	NIL	TR	NIL	1.2
27	TR	NIL	1.1	NIL	NIL	NIL	NIL	NIL	11.4	1.1	15.0	NIL
28	NIL	52.2	26.5	NIL	2.9	NIL	0.1	3.8	1.6	NIL	8.2	NIL
29	NIL	1.5	15.6	5.8	NIL	NIL	14.8	0.1	NIL	0.1	2.6	NIL
30	NIL	X	NIL	TR	NIL	NIL	NIL	6.3	8.5	NIL	TR	NIL
31	NIL	X	2.5	X	1.5	X	0.4	32.5	X	NIL	X	NIL
1st of	Feb NIL	March 1.8	April 7.3	May 2.0	June NIL	July NIL	Aug 0.2	Sept 0.2	Oct NIL	Nov 6.0	Dec NIL	Jan NIL
Total	3.7	93.5	125.9	125.5	185.6	20.2	28.2					
Total to date							28.4					
No. of days							06					
Average												
Year												

N.B. This yearly form is for use of observer and should be kept for reference. The amount of rainfall should be entered everyday to the day on which measured. For record purposes, the total for the month is obtained by adding the falls from the 2nd of the month to the 1st of the following month. (i.e the period between the two thick lines, which will correspond to the monthly total on form 496)

Form No. 6a (Rev. 10/2015)

UGANDA NATIONAL METEOROLOGICAL AUTHORITY

RAINFALL OBSERVATIONS AT KASESE MET-STATION FOR THE YEAR 2023

REGISTRATION NO. 8930063

Date	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
2	NIL	0.5	NIL	TR	1.1	0.8	NIL	0.6	NIL	2.4	4.2	4.8
3	NIL	NIL	23.5	NIL	17.5	NIL	NIL	TR	NIL	2.6	10.4	NIL
4	5.3	NIL	10.1	3.8	0.8	NIL	NIL	NIL	TR	0.1	11.5	1.7
5	NIL	NIL	0.1	NIL	0.2	NIL	NIL	NIL	1.1	NIL	TR	2.6
6	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	TR	8.8	NIL
7	NIL	NIL	NIL	NIL	NIL	3.3	NIL	NIL	2.6	0.1	NIL	2.5
8	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	TR	1.3	NIL
9	NIL	NIL	NIL	0.5	NIL	NIL	NIL	NIL	TR	TR	20.1	NIL
10	NIL	NIL	NIL	1.7	3.9	NIL	NIL	NIL	NIL	7.9	44.4	0.8
11	4.4	NIL	0.1	NIL	0.5	NIL	NIL	NIL	TR	2.5	TR	2.6
12	NIL	NIL	16.0	1.7	0.2	NIL	9.7	NIL	4.8	23.5	0.2	NIL
13	NIL	NIL	0.5	NIL	NIL	0.7	7.0	0.8	0.8	1.0	17.0	0.1
14	2.0	NIL	2.2	2.3	NIL	0.9	3.6	NIL	1.6	NIL	2.6	13.4
15	NIL	NIL	NIL	NIL	NIL	TR	NIL	NIL	0.5	28.2	0.4	NIL
16	NIL	NIL	2.8	0.3	NIL	NIL	NIL	NIL	10.0	1.3	0.4	13.3
17	NIL	NIL	NIL	0.5	NIL	NIL	NIL	TR	1.4	7.0	22.9	0.1
18	NIL	NIL	6.6	16.3	TR	0.1	NIL	TR	8.0	TR	0.2	5.7
19	NIL	NIL	NIL	0.3	NIL	6.1	NIL	NIL	6.1	2.3	0.5	NIL
20	NIL	NIL	9.0	NIL	NIL	0.3	NIL	NIL	NIL	0.3	1.9	NIL
21	NIL	NIL	14.1	NIL	NIL	8.7	NIL	TR	NIL	NIL	1.8	NIL
22	NIL	NIL	NIL	3.8	NIL	13.2	NIL	NIL	NIL	2.3	3.6	NIL
23	TR	0.2	22.4	6.3	NIL	1.9	NIL	NIL	TR	2.3	6.6	0.5
24	NIL	NIL	24.6	36.4	3.5	4.3	NIL	NIL	NIL	NIL	NIL	NIL
25	NIL	5.4	NIL	0.3	NIL	1.2	NIL	NIL	NIL	1.6	3.6	NIL
26	NIL	NIL	NIL	NIL	28.5	NIL	0.5	NIL	0.3	11.5	1.2	NIL
27	2.3	NIL	0.6	3.7	NIL	NIL	NIL	TR	0.2	1.1	30.2	NIL
28	2.6	3.8	0.8	7.0	2.2	NIL	NIL	NIL	0.1	NIL	0.1	NIL
29	NIL	X	2.8	10.1	NIL	NIL	NIL	NIL	12.7	NIL	NIL	NIL
30	3.1	X	25.3	NIL	NIL	1.7	NIL	NIL	0.1	NIL	24.5	NIL
31	NIL	X	3.2	X	NIL	X	NIL	NIL	NIL	NIL	0.1	10.0
1st of	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan
	TR	2.2	2.4	30.2	0.1	NIL	NIL	4.1	NIL	5.8	0.1	NIL
Total	19.7	12.1	167.1	125.2	58.5	37.2	20.8	5.8	57.6	115.6	218.6	58.1
Total to date	19.7	12.1	167.1	125.2	58.5	37.2	20.8	5.6	5.6	115.6		58.1
No. of days	06	03	14	12	06	08	03	01	18	16		09
Average												
Year												

N B This yearly form is for use of observer and should be kept for reference. The amount of rainfall should be entered every day to the day on which measured. For record purposes, the total for the month is obtained by adding the falls from the 2nd of the month to the 1st of the following month, (i e the period between the two thick lines which will correspond to the monthly total on form 496)

Form No. 6a (Rev. 10/2015)

UGANDA NATIONAL METEOROLOGICAL AUTHORITY

RAINFALL OBSERVATIONS AT KASESE MET-STATION FOR THE YEAR 2022

REGISTRATION NO. 8930063

Date	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
2	NIL	NIL	7.5	NIL	2.2	7.3	NIL	6.0	14.4	0.8	NIL	2.9
3	NIL	NIL	17.0	3.5	NIL	0.6	NIL	NIL	11.7	NIL	2.0	NIL
4	NIL	NIL	NIL	5.4	0.2	NIL	NIL	1.0	NIL	4.9	0.4	15.0
5	NIL	NIL	0.1	0.2	0.3	NIL	NIL	1.0	NIL	1.1	4.8	4.2
6	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	TR	NIL	3.5	0.6
7	NIL	NIL	0.1	15.0	3.0	NIL	NIL	NIL	95.8	15.3	0.4	NIL
8	0.9	NIL	NIL	0.1	NIL	10.0	NIL	NIL	0.3	1.4	1.7	1.0
9	NIL	NIL	NIL	1.1	TR	NIL	NIL	NIL	NIL	4.0	NIL	2.9
10	NIL	19.5	NIL	0.1	NIL	NIL	TR	NIL	7.8	5.6	0.9	1.0
11	NIL	NIL	NIL	13.1	1.0	NIL	NIL	NIL	NIL	NIL	33.6	NIL
12	NIL	NIL	NIL	6.0	1.4	NIL	NIL	NIL	0.5	NIL	NIL	NIL
13	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	4.9
14	NIL	NIL	0.8	NIL	NIL	NIL	NIL	0.9	4.3	1.4	19.7	20.8
15	NIL	NIL	NIL	2.2	TR	NIL	NIL	NIL	0.4	NIL	0.8	NIL
16	1.9	NIL	NIL	21.8	NIL	NIL	NIL	5.7	0.6	5.7	5.2	3.6
17	NIL	NIL	NIL	TR	NIL	TR	NIL	TR	0.3	4.2	1.9	NIL
18	16.7	NIL	NIL	NIL	0.5	1.7	TR	17.5	TR	NIL	16.3	NIL
19	14.2	NIL	NIL	24.7	NIL	TR	TR	1.1	3.1	6.8	3.0	NIL
20	TR	NIL	NIL	NIL	NIL	1.1	NIL	22.0	NIL	0.3	NIL	TR
21	NIL	0.8	NIL	NIL	NIL	0.3	NIL	NIL	NIL	17.3	1.8	TR
22	NIL	NIL	3.7	NIL	NIL	NIL	NIL	NIL	0.5	9.1	1.0	TR
23	NIL	NIL	7.1	20.6	3.2	NIL	NIL	NIL	1.8	NIL	16.4	0.6
24	NIL	NIL	NIL	44.2	NIL	NIL	NIL	NIL	NIL	NIL	1.6	NIL
25	NIL	7.4	2.4	0.1	NIL	NIL	NIL	NIL	NIL	NIL	NIL	0.1
26	NIL	NIL	1.5	0.1	1.4	NIL	NIL	NIL	NIL	NIL	1.0	0.1
27	NIL	NIL	1.8	NIL	4.1	NIL	NIL	NIL	NIL	NIL	NIL	NIL
28	NIL	NIL	NIL	16.7	NIL	NIL	NIL	NIL	NIL	2.1	0.4	0.3
29	NIL	x	16.8	45.3	1.1	NIL	NIL	NIL	8.5	2.3	NIL	0.8
30	NIL	x	2.7	2.5	0.8	NIL	0.1	11.1	NIL	NIL	0.5	0.5
31	NIL	x	0.2	x	8.0	x	11.1	26.4		NIL	x	NIL
1st of	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan
	NIL	4.4	NIL	NIL	0.7	NIL	NIL	5.2	NIL	NIL	3.0	NIL
Total	33.7	32.1	61.7	222.7	27.9	21.0	11.2	98.1	150.0	82.3	119.4	59.3
Total to date	33.7	32.1	61.7	222.7	27.9 ~~28.9~~	21.0	11.2	98.1	150.0	182.3	119.4	59.3
No. of days	03	03	09	14	09	04	01	10	08	14	16	09
Average	1.1	1.1	2.0	7.4	0.9	07	0.4	3.2	5.0	2.3	3.9	1.9
Year												

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

Section 1: General Information

1. Name: (Optional for anonymity)

KOOLI AUGUSTINE 0782544911

DISTRICT ENVIRONMENT OFFICER
KASESE

2. Field of Expertise:

- 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 ~~dur~~ Befor, 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 - ~~Kithobhu~~ Kiraro parish - Kithobhu Subcounty.
③ Kyondo —— Kyondo Subcounty.

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

- [✓ Deforestation]
- Increased rainfall
- New construction
- Other (specify): Steep slope, and other human activities

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

N/A

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

N/A.

1. Very effective

2. Moderate effective

3. Less effective

4. Not effective at all

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]
- Removing weight from the head of the slope
- Other (specify): Planned Settlements.

Section 5: Additional Information

18. Have you noticed any changes in the frequency or severity of landslides i

And what could be the cause?

1. Yes ✓ Land slides in Kacece are triggered both natural and human induced fa

2. No

① ⇒ Intense rainfall and climate change.

② ⇒ Topography and geological factors.

⇒ Increased human activities along steep slopes.

Indiscriminate tree cutting, the ~~Sog~~ Lithology - soil a

18. Are there any other factors or considerations not covered in this questionnaire tha

included in the analysis?

The rain fall pattern and Intensity that may trigger the occurrance ~~a~~ of a land slide in a specific area.

19. Do you have any additional comments or suggestions for improving landsli

assessments in Kasika?

① Use of remote sensing and GIS

⇒ Leveraging ~~Satelight~~ Satelite Imagery and Li

⇒ Use of GIS to overlay data such as slope, Patterns, soil type, vegetation

② Integrate climate data. - Historical and real tim to understand rainfall threshhold. that trigger land slide.

③ Community Driven mapping. Engage local Communities in mapping.

Train Communities to monitor and report early warning signs such as cracks in the ground.

④ Improve early warning systems - Combine Susptability maps with early W System.

- Use SMS Alerts.

⑤ Regular update and Reviews. - Update susptability maps periodically to reflect new data and changes in land use.

- Evaluate the effectiveness of past assessments and refine methodologies accordingly.

② Topographical and geological factors: The districts lies within the Rwenzori mountain ranges X-tericed by steep slopes and unstable soils.

⇒ The loose soils combined tectonic activities in region increases su to Landslide

SECTION 5
NO. 18

③ Hum

* Deffor.

* Poor farming practi cultivation on steep s without proper terr accellerates soil destablises sl

* Un planned Building on slopes fur risk of L

Landslide susceptible

Local community

Section 1 : General information

1. Name of Respondent:

(Optional for anonymity)

MUMBERE WATSON YUNIASI

2. Gender:

- [✓ Male]
- Female

3. Age Group:

- [✓ 18 – 30 years]
- 31 – 50 years
- 50 years and above

4. Occupation:

- Farmer
- Trader
- Civil servant
- [✓ Other (specify): Teacher]

5. How long have you lived in this area?

- Less than 5 years
- 5 – 10 years
- [✓ More than 10 years]

Section 2: Landslide Incidents

6. Have you or your family experienced a landslide in this area?

- [✓ Yes]
- No

7. If yes, how often do landslides occur in your area?

- [✓ Once a year]
- 2 - 5 times a year
- More than 5 times a year

8. When was the last landslide that occurred in your area?

- Less than 6 months ago
- [✓ 6 months to 1 year ago]
- More than 1 year ago

9. What were the main causes of the landslide(s), in your opinion?

- [✓ Heavy rainfall]
- [✓ Steep slopes]
- [✓ Change in land use land cover]
- [✓ Short distance to stream]
- [✓ Soil type]
- Other (specify): ....

Section 3: Environmental and Physical Factors

11. Are there areas nearby where landslides occur frequently?

- [✓ Yes]
- No

12. If yes, please name or describe these areas (e.g., village name, specific landmarks):

.........Rukoki..................

....

....

....

13. What physical features do you notice in these landslide-prone areas? (Check all that apply)

- [✓ Steep slopes]
- [✓ Heavy rainfall]
- Soil type
- Cracks in the ground
- Waterlogged areas
- Proximity to rivers/streams

14. Have there been any changes in land use in these areas?

- Increased farming
- [✓ Deforestation]
- Construction
- Other (specify):........................

15. Have you noticed heavy rainfall before a landslide occurs?

- [✓ Yes]
- No

Section 4: Community Actions and Awareness

16. Are there measures taken by the community to reduce landslide risks?

- Yes
- [✓ No]

17. If yes, what measures are being taken? (Check all that apply)

- 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
- Removing weight from the head of the slope
- Other (specify): ....

18. Are you aware of any government or NGO programs to address landslides in your area?

- Yes
- [✓ No]

Section 5: Additional Information

20. In your opinion, what can be done to prevent landslides in your area?

............Reifarcing the soil............

21. Do you have any other comments or concerns about landslides in your area?

............No............

Landslide susceptible

Local community

Section 1 : General information

1. Name of Respondent:

(Optional for anonymity)

Businessman

2. Gender:

- [✓ Male]
- Female

3. Age Group:

- [✓ 18 – 30 years]
- 31 – 50 years
- 50 years and above

4. Occupation:

- Farmer
- [✓ Trader]
- Civil servant
- Other (specify): ....

5. How long have you lived in this area?

- Less than 5 years
- [✓ 5 – 10 years]
- More than 10 years

Section 2: Landslide Incidents

6. Have you or your family experienced a landslide in this area?

- [✓ Yes]
- No

7. If yes, how often do landslides occur in your area?

- [✓ Once a year]
- 2 - 5 times a year
- More than 5 times a year

8. When was the last landslide that occurred in your area?

- Less than 6 months ago
- 6 months to 1 year ago
- [✓ More than 1 year ago]

9. What were the main causes of the landslide(s), in your opinion?

- [✓ Heavy rainfall]
- Steep slopes
- Change in land use land cover
- Short distance to stream
- Soil type
- Other (specify): ....

Section 3: Environmental and Physical Factors

11. Are there areas nearby where landslides occur frequently?

- [✓ Yes]
- No

12. If yes, please name or describe these areas (e.g., village name, specific landmarks):

....

....

....

....

13. What physical features do you notice in these landslide-prone areas? (Check all that apply)

- [✓ Steep slopes]
- Heavy rainfall
- Soil type
- Cracks in the ground
- Waterlogged areas
- Proximity to rivers/streams

14. Have there been any changes in land use in these areas?

- Increased farming
- [✓ Deforestation]
- Construction
- Other (specify):........................

15. Have you noticed heavy rainfall before a landslide occurs?

- [✓ Yes]
- No

Section 4: Community Actions and Awareness

16. Are there measures taken by the community to reduce landslide risks?

- Yes
- [✓ No]

17. If yes, what measures are being taken? (Check all that apply)

- 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
- Removing weight from the head of the slope
- Other (specify): ....

18. Are you aware of any government or NGO programs to address landslides in your area?

- Yes
- [✓ No]

Section 5: Additional Information

20. In your opinion, what can be done to prevent landslides in your area?

planting trees

21. Do you have any other comments or concerns about landslides in your area?

the gov't should come and help us

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

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

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 in the months between March and may & then between month of August and December as per the data.

However, studying it's 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 BRIAN
Meteorological Supervisor,
Kasese Met station,
08/01/2025.

(115)

~~13~~ (124)

DISTRICT: KASESE

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

Page: 1
07/12/95

SN	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 SEEDS	-	-	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	MOKLEM	-	-	-	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 II	30.1228	0.864	-	54.0	34.99	48.0	-	400
17	WDD3941	MUBUKU	-	-	1040	30.0	6.00	12.0	-	360
18	WDD3942	KABAKA RAILWAY	-	-	930	24.0	2.50	15.0	-	400
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	30.2950	0.1366	-	43.0	-	-	-	-
32	WDD4486	RUHIMI	-	-	-	90.0	46.00	57.0	64.0	-
33	WDD4487	BUGOYE T/C	30.098294	0.305972	-	10.0	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	-	420
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

DISTRICT: KASESE

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

SN	B/H No.	NAME	Coordinates East	South	Alt (m)	Depth (m)	SWL (m)	C.Depth (m)	Yield (m3/h)	Pop
55	WDD1941	KAYANJA NORTH	-	-	-	24.0	2.11	21.0	-	150
56	WDD1942	KAYANJA SOUTH	-	-	1020	24.0	2.02	21.0	1.7	150
57	WDD1943	KANOCHAKA	-	-	1030	30.0	21.56	27.0	-	150
58	WDD1944	BWEHINGO	-	-	-	96.0	DRY	-	-	-
59	WDD1945	KASONGOLO II	-	-	-	36.0	23.90	30.0	-	-
60	WDD1946	KASONGOLO I	-	-	-	96.0	DRY	-	-	-
61	WDD1947	NYAKARANY	-	-	-	42.0	12.00	36.0	-	-
62	WDD1948	KINYAMINAGA	-	-	-	102.0	23.19	36.0	1.1	-
63	WDD1949	KASOZI	-	-	-	60.0	13.82	36.0	1.1	-
64	WDD1950	KINYATSYE	-	-	-	30.0	9.08	21.0	1.5	-
65	WDD1952	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	-	-	-	31.0	8.27	24.0	1.8	-
70	WDD5155	HAMUKUNGU DISP	30.0777083	-0.0090		38.0	12.90	24.0	1.9	-
71	WDD5156	HAMUKUNGU P. S	-	-	-	66.0	18.31	36.0	-	-
72	WDD5157	HAMUKUNGU 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	-	150
81	WDD5166	BLOCK "A" CENT	-	-	-	66.0	26.99	48.0	-	150
82	WDD5167	PROTIC	-	-	-	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	18.0	-	-
86	WDD5171	BWANIKA II	-	-	1020	30.0	24.60	27.0	6.7	-
87	WDD5172	NYABUGASANI	-	-	-	36.0	-	-	-	-
88	WDD5173	BWERA/[illegible]	-	-	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	RUBANDA	-	-	-	60.0	51.70	54.0	-	300
97	WDD5182	RWENSEJU	-	-	-	25.6	-	-	-	-
98	WDD5183	NYAMATOGA III	-	-	-	120.0	-	-	-	-
99	WDD5184	RWETUTU	-	-	-	61.6	-	-	-	-
100	WDD5185	KAGIRIZI	-	-	-	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

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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		-	-	60.0	27.51	39.0	-	-
113	WDD5449	NYAKABONA		-	-	72.0	22.69	63.0	-	-
114	WDD5450	RWABIRINGU	-	-	-	19.2	13.88	36.0	-	-
115	WDD5451	KINYATEKE		-	-	30.0	17.38	27.0	-	-
116	WDD5452	KICHHENDARA	-	-	-	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	-	-	-	33.1	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	525

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

DISTRICT WATER OFFICER
KASESE

For DWO