Thesis for the Degree of Master of Science in Environmental Management

ASSESSING THE PLANT ROOT CONTRIBUTION IN SLOPE STABILITY- "A STUDY OF THE LANDSLIDE IN FIRFIRE DANDA, GODAWARI MUNICIPALITY, LALITPUR, NEPAL"

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Pokhara University, Nepal

May, 2024

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Supervised by Dr.Sanjaya Devkota

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Environmental Management

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DEDICATION

This thesis work has been wholeheartedly dedicated to my beloved Parents **(Father Narendra Prasad Lamichhane and Mother Sita Devi Lmichhane)** and my wife **Shruti Devkota**, who have been my source of inspiration and gave me strength, who continually provided their moral, spiritual, emotional, and financial support. Your belief in me has served as a constant inspiration. I would like to express my gratitude to all of the contributors and participants for giving their time and knowledge to this study. May it enhance public knowledge and have a good effect. Lastly, I present this work with heartfelt gratitude and appreciation to everyone who believes in the power of knowledge and the pursuit of truth.

Bidur Lamichhane

DECLARATION

I hereby declare to School of Environmental Science and Management (SchEMS), affiliated to Pokhara University that this study entitled **Assessing the Plant Root Contribution in slope stability- "A Study of the Landslided in Firfire Danda Godawari Municipality, Lalitpur, Nepal"** is based on my original research work. Related works on the topic by other researchers have been duly acknowledged. I owe all the liabilities relating to the accuracy and authenticity of the data and any other information included hereunder.

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RECOMMENDATION

This is to certify that this thesis entitled **Assessing the Plant Root Contribution in slope stability- "A Study of the Landslided in Firfire Danda Godawari Municipality, Lalitpur, Nepal"** prepared and submitted by **Bidur Lamichhane**, in partial fulfilment of the requirements of the degree of Master of Science in Environmental Science and Management awarded by Pokhara University, has been completed under my guidance and supervision. I hereby recommend the same for acceptance by Pokhara University.

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CERTIFICATION

This thesis entitled **Assessing the Plant Root Contribution in slope stability- "A Study of the Landslided in Firfire Danda Godawari Municipality, Lalitpur, Nepal"**, prepared by **Bidur Lamichhane** has been examined by us and is accepted for the award of the degree of Masters of Science (M.Sc.) in Environmental Science and Management by Pokhara University.

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ACKNOWLEDGEMENT

I would like to sincerely thank **Mr. Ajay Bhakta Mathema** (principal of the SchEMS**),** **School of Environmental Science and Management (SchEMS)**, **Mrs. Bindu Sharma** (Director of SchEMS) and Pokhara University for giving me this opportunity and trusting me.

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I am grateful to all landslide prone areas, Firfire Dada Techo, Godawari Municipality, for providing me their time and remarkable experiences to accomplish this thesis without whom this research would be incomplete.

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LETTER OF APPROVAL

This dissertation paper submitted by Mr. Bidur Lamichhane entitled **Assessing the Plant Root Contribution in slope stability- "A Study of the Landslided in Firfire Danda Godawari Municipality, Lalitpur, Nepal"**, has been accepted for the partial fulfillment of a Master of Science in Environmental Management from Pokhara University.

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Mr. Ajay Bhakta Mathema

Assoc. Professor / Principal

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May, 2024

LIST OF ABBREVIATIONS

AASHTO	American Association of State Highway and Transportation Office
C	Cohesion
CPG	Chapagaon
Cs	cohesion due to suction
Cr	Roots Cohesion
DEM	Digital Elevation Model
DTM	Digital Terrain Model
ESA	Effective Stress Analysis
GD	Godavari
FBM	Fiber Bundle Model
FoS	Factor of Safety
FPR	Factored Pullout Resistance
G	Specific Gravity
GIS	Geographic Information System
GPS	Geographic Positioning System
IS	Indian Standard
LE	Limit-Equilibrium
M-C	Mohr-Coulomb
MDD	Maximum Dry Density
MIT	Massachusetts Institute of Technology
mm	millimeter
NMC	Natural Moisture Content
RA	Root area
RAR	Root Area Ratio
Tr	Tensile strength,
USCS	Unified classification system
UAV	Unmanned Aerial Vehicle
USA	United State of America
WWM	Wu and Waldron model
Φ	Internal friction angle
τ	Shear Stress

ABSTRACT

Slope failure is a common hazard in the mountainous landscape of Nepal. The phenomenon of landslides has increased over the recent past due to an increase in rainfall intensity and human activities such as the construction of unplanned roads. Firfire Danda is located in the Godawari Municipality Ward No. 12, where houses are built without considering slope stability on the top of the hillock, destabilizing the slope due to road excavation. This study focuses on evaluating slope stability and assessing the role of plant roots in slope stability, with a specific investigation. It aims to understand the geotechnical properties of the soil and assess the influence of plant root systems on slope stability to inform future landslide mitigation efforts. Field investigations and plant root contribution to stabilizing the soil slope are employed. By examining soil physical properties such as soil cohesion, internal angle of friction, and unit weight, while the plant root contribution in the form of root cohesion was taken from the literature. Slope stability was assessed by developing two scenarios of the Factor of Safety (FoS) of the slope, firstly without root contribution and secondly with root contribution, implementing Slope/W software of Geo-Studio. The tool implements the Limit-Equilibrium (LE) method of analysis, dividing the slope into a number of slices.

The research aims to assess the contribution of plant roots in preventing slope failure or mitigating slope failures, particularly in landslide-prone areas. The Slope/W software is useful in assessing the slope's Factor of Safety (FoS), facilitating comprehensive analyses through the method of slices. The slope was modeled with the measured physical properties of soil before and after the plantation of Vetiver Grass (Chrysopogon zizanioides) on the slope. Its application in plant root studies involves simulating various scenarios to evaluate how roots influence soil shear strength and stability. By integrating root characteristics, mainly root cohesion, into the slope stability models, the study quantified the Factor of Safety with enhanced soil cohesion due to roots. The plantation on the slope significantly helps to increase soil cohesion in the form of root cohesion. The findings contribute to a broader understanding of eco-friendly slope stabilization methods and offer valuable information for land use planning and risk mitigation in landslide-prone regions.

Keywors: *Slope Stability, Landslide mitigation ,Root Reinforcement,Soil-Root Interaction.*

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CHAPTER 1
INTRODUCTION

1.1 Background

Nepal is a mountainous country, less developed, that straddles the boundary between the Indian and Himalayan tectonic plates. In Nepal, landslides represent a major constraint on development, causing high levels of economic losses and substantial numbers of fatalities each year. There is a general consensus that the impacts of landslides in Nepal are increasing due to the impact of climate change and anthropogenic activities (Thapa *et al.*, 2023).The database suggests that there is a high level of variability in the occurrence of landslides from year to year, but that the overall trend is upward (Dahal *et al.*, 2008).A landslide is a movement of earth material, (e. g. rock, soil or debris) moving downslope under gravity. Landslide can happen suddenly or more slowly over long periods of time. When the forces acting on the earth material on the slope exceeds over the resisting forces the earth material moved downslope, what we called landslides. A landslide may occur because the strength of the material is weakened reduces the power of the 'glue' that binds the rock or soil grains together. Located on a slope, the rock or soil mass is then no longer strong enough to resist the forces of gravity acting upon it and slides downward (Schmidt *et al.*, 2001). The integration of two-dimensional, raster-based, geographic information systems (GIS) and deterministic models, slope stability can be modelled. Over the past deterministic modelling of slope stability is getting popular around the globe; however, in Nepal it is been sued limitedly.

Landslides can be triggered by a variety of factors, including deforestation, road construction, mining activities, improper land use, and heavy rainfall, among others. In Nepal, where steep terrain and monsoon rains are common, human activities such as deforestation for agriculture or infrastructure development can increase the likelihood of landslides by destabilizing slopes. However, without detailed information about the specific landslide event in question, it's difficult to assess the factors that triggere landslides (Moon and Blackstock, 2004).

The area of firfire danda Thecho in Lalitpur District, Godawari Municipality, has experienced a history of landslides. The region's topography, geological composition, and monsoon rains make it susceptible to slope failure. There are cases of slope failure in the hilly terrain of Nepal especially in monsoon season and lossess of the lives, properties, and infrastructres are common. Landslides have been a recurring issue, impacting the local communities, infrastructure, and land use in the area. Efforts in the past may have involved measures to mitigate these risks, such as slope stabilization, reforestation, or land-use planning to minimize the impact of future landslides.

1.2 Statement of the Problem

The practice of non-engineered infrastructure development is dominant in various areas of Nepal (Acharya *et al.*, 2016). Because of which, slope failure is common and has considerable imapcts in the lives, infrastructres, settlments and livelihood activities.

This research addresses the crucial need to understand how geotechnical parameters, especially soil physical properties, interact with plant root systems in assessing slope stability. Geotechnical data, including soil cohesion, internal angle of friction, unit weight, and soil texture, collected from field surveys and laboratory analyses, alongside topographical attributes from high-resolution orthophoto maps, provide the foundation for this study. Root cohesion, a significant contributor to soil stability, is highlighted, with various plant species like vetiver, UrloKhar, Babiyo, Nepiyar, Salim-Khar, Kans, Kush, and Amriso serving as examples due to their roles in soil conservation and erosion control. The research aims to explain how plant roots reinforce soil cohesion and strengthen slopes against erosive forces, reducing the risk of slope failure. Detailed analyses of geotechnical and root characteristics, along with Slope Stability Analysis using specialized software, are conducted to determine the Factor of Safety (FoS) under different conditions. The findings emphasize the importance of comprehensively considering soil physical properties in slope management and engineering to mitigate landslide risks. Integrating advanced monitoring techniques and predictive models can further enhance slope stability assessment, fostering safer and more sustainable infrastructure development in vulnerable areas. Ultimately, the research advocates for incorporating these findings into land-use planning and environmental management policies to minimize landslide risks and protect communities and infrastructure. Additionally, the research suggests exploring physically based deterministic models to assess slope stability in Nepal, as current methods are limited, offering potential improvements in evaluating and managing landslide risks in the region.

1.3 Research Questions

Assessing the Plant Root Contribution in slope stability study area creates many questions. So my research questions are as follows;

- What are the parameters contributing to slope stability?
- How do plant roots contribute in slope stability?

1.4 Research Objectives

The general objective of the study is to assess the contribution of plant roots to slope stability in the Firfire Danda area of Thecho, Godawari Municipality, aiming to enhance understanding and inform potential measures for landslide mitigation.

Specific objectives:

- To perform Slope Stability Modelling of site-specific landslide, which involves identifying and analyzing the parameters influencing slope stability.
- To Compare Factor of Safety with and without considering root cohesion, aiming to specifically evaluate the contribution of plant roots to slope stability.

1.5 Rationale

Quantifying root reinforcement in bio-slope stabilization through laboratory and field studies is essential for assessing stability, comparing different species and conditions, validating models, evaluating long-term performance, and developing best practices. This research provides valuable insights for engineers, researchers involved in slope stabilization projects, ultimately contributing to the sustainable management of slopes and landscapes (Jotisankasa *et al.*, 2018).The major reason for this study lies in addressing the critical issue of slope stability in Firfire Danda ,Thecho, Godawari Municipality. Rationale for Assessing Plant Root Contribution in Slope Stability.in slope stability aligns with the principles of Nature-Based Solutions (NBS), which utilize natural processes and ecosystems to address environmental challenges like slope instability and landslides. Plant roots are pivotal in stabilizing slopes by binding soil particles, reducing erosion, and enhancing soil cohesion. This study aims to evaluate the effectiveness of plant roots in slope stability, offering sustainable and cost-effective solutions compared to traditional engineering methods, thus promoting the adoption of NBS for mitigating landslide risks.

Nepal, is chosen as the study area due to its vulnerability to landslides attributed to steep terrain, frequent heavy rainfall, and geological features. Previous landslide occurrences in the area have endangered human settlements, infrastructure, and ecosystems. The study's focus on Firfire Danda aims to fulfill a crucial need in comprehending and mitigating landslide risks in this vulnerable region, thereby contributing significantly to local disaster risk reduction endeavors.

Various modeling techniques, including numerical models, deterministic models, geospatial analysis, and field-based assessments, are available to evaluate slope stability and assess plant root contributions. Implementing these best practices ensures the generation of robust and reliable results, which are crucial for guiding decision-making and intervention strategies. By leveraging existing modeling tools and methodologies tailored to the specific context of Firfire Danda, the study can enhance the accuracy and applicability of its findings, thereby contributing to a more comprehensive understanding of slope stability dynamics in the area.

1.6 Limitation of the Study

The following are the limitations of the proposed research study.

1. There may be challenges in obtaining comprehensive and accurate data on plant root systems, especially for a diverse range of plant species in the study area.
2. The area covered by the model is limited to the area surveyed or studied. This can result in incomplete information and limited analysis of the surrounding area.
3. The Slope Stability Analysis conducted using the SLOPE/W package of Geo-studio software relies on various assumptions and simplifications. These assumptions may not fully capture the complex interactions between soil, vegetation, and hydrological factors, in the predicted Factor of Safety (FoS).
4. The study indicates that although vetiver roots successfully stabilize slopes in one particular area, extending this approach to different regions should be approached with consideration for differences in soil properties, climates, and plant species.

1.7 Delimitation of study

1. The study may focus specifically on the plant root contribution to slope stability and may not consider other factors such as soil type, rainfall patterns, human activities, or geological factors in depth.
2. The study may be limited to the Firfire Danda area in Godawari Municipality, Lalitpur, Nepal, and findings may not be generalizable to other regions with different geological or environmental conditions.
3. The methodology chosen for assessing plant root contribution to slope stability may have inherent limitations, such as the accuracy of root mapping techniques or the availability of data on root characteristics.

CHAPTER 2
LITERATURE REVIEW

2.1 Landslides in Nepal

Nepal is a mountainous, less developed kingdom that straddles the boundary between the Indian and Himalayan tectonic plates. In Nepal, landslides represent a major constraint on development, causing high levels of economic loss and substantial numbers of fatalities each year. There is a general consensus that the impacts of landslides in countries such as Nepal are increasing with time, but until now there has been little or no quantitative data to support this view, or to explain the causes of the increases. In this paper, a database of landslide fatalities in Nepal has been compiled and analysed for the period 1978–2005 (Petley *et al.*, 2007).

State Flow-like landslides triggered by rainfall are very prominent in Nepal and Shikoku, Japan. In July 2002, many landslides occurred in the southern hills of the Nepalese capital, Kathmandu, because of torrential rainfall. A single flow-like landslide occurred at Matatirtha, a small village situated at the south marginal hill of Kathmandu, killing 16 people who lived at the foot of the hill. Much damage was caused to roads and houses because of landslides and debris flows in small streams. Similarly, in August, September and October 2004, strong typhoon hit the area of northern Sikoku, Japan and extensive damage occurred on hill slopes and some human casualties were also reported. Field observation showed that in northern Sikoku, many flow-like landslides occur in the thin weathering profile of igneous and sedimentary rocks, as well as in old debris materials. However, in the southern hills of Kathmandu, flow-like landslides occurred in weathered debris.

(Dahal *et al.*, 2008) States Landslides are very common occurrences in Nepal that have been affected development infrastructures, lives, and properties of the people every year. Many hill villages are situated on or adjacent to unstable slopes and old landslides are reactivated from time to time. The rapidly increasing construction of infrastructure, such as roads, irrigation canals, and dams without due consideration of natural hazards is contributing to triggering of landslides and debris flows. Thus, this paper has explored the cause and characteristics of landslides occurrences and their mitigation practices in Nepal. Topographic, geologic and triggering factors, and human intervention causing landslides are characterized to suggest the suitable mitigation options that can be implemented in the mountain hill-slopes. Among the wide range of slope stabilization measures which are available to practitioner engineer, the lowering of groundwater level in combination of controlling of surface infiltration (e.g. sealing of tension cracks) of water into landslide are the most cost effective options for mountainous terrain because the rise in pore water pressure is one of the basic cause of landslides during the rainy season. In addition, removing of unstable slope debris, surface drainage, and retaining walls are the useful landslide mitigation measures depending on site conditions, availability of budget, and specific requirements. Various support systems and elements can be crafted for creative solutions of the slope instability problems in Nepal.

2.2 Landslides Susceptibility Modeling

Deterministic models are models that use precise mathematical equations to simulate a system's behavior. These models are used when the relationship between inputs and outputs is well understood and can be expressed through equations. Deterministic models are often used in engineering, physics, and other scientific fields. Geo-studio is a software tool designed for three-dimensional visualization of groundwater flow and solute transport. It is based on MOD FLOW, which is a widely used groundwater flow model. Geo-studio taking into account factors such as geology, hydrology, and other physical properties. In summary, deterministic models like Geo-studio can be useful tools for simulating complex systems and understanding their behavior. However, the effectiveness of any model ultimately depends on its accuracy and how well it can represent the real-world system it is intended to simulate (Dahal *et al.*, 2008).

(Cervi *et al.*, 2010) Deployed a simple rainfall-threshold analytical method that can be used to explain the probability of failure in marginal hills of settlements in the Lesser Himalayan terrain during monsoon rainfall.

(Dahal *et al.*, 2008) To this end, the probability of slope failure in the south-western hills of Kathmandu, Lesser Himalaya in the GIS platform was evaluated by using the criteria for infinite slope failure and topographically-based hydrological model described by Iida (1984). The failure probability calculated in the study addresses only hill slopes. The current practice of settling on the plain area immediately after the base of the hills may need to be evaluated by taking into account the probability of slope failure on the up-hill sections. The resultant failure probability map can be checked against the statistical landslide hazard zonation map. Finally, as mentioned by van Westen and Terlien (1996) and van Westen (2000), there are some limitations in this kind of study, but the results can be used with landslide distribution maps and hazard maps to evaluate the area for settlement.

(Dahal *et al.*, 2008) concentrated on the integration of two-dimensional, raster-based, geographic information systems (GIS) and deterministic models, with emphasis on deterministic hydrological models. Three examples of deterministic landslide hazard zonation are presented; one from Costa Rica and two from Colombia. In the example from Costa Rica, a one- dimensional external hydrological model is used to calculate the height of perched water tables in the upper metre of the soil for different soil types and different rainstorms. In the first example from Colombia, an external two-dimensional hydrological model is used to calculate the maximum groundwater level, for a period, in different slopes with a sequence of volcanic ashes overlying impermeable residual soils. In the second example from Colombia, a three-dimensional hydrologic model is used in a GIS to simulate groundwater fluctuations during one rainy season. In examples 1 and 2 the results of the hydrologic calculations are used in stability calculations to obtain maps which give the spatial distribution of safety factors and the probability of failure, with the use of distribution functions of the input parameters. In example 3 the calculated groundwater levels are exported to an external slope stability model to calculate the safety factor along slope profiles.

Deterministic model are used to assess the potential for mass movement within Hamilton City, New Zealand using sensitivity analysis for critical environmental variables (Moon and Blackstock, 2004). Discrete geomorphic zones are recognized on the basis of material properties and slope characteristics; generic slope profiles are derived for each of these zones by averaging slope profiles determined from a Digital Elevation Model. Stability analysis models are used to derive critical failure surfaces for these profiles using measured or estimated material properties, and sensitivity analysis allows the conditions of water table level and seismic acceleration under which the slopes become unstable to be determined. This method is applied to Hamilton City to assess the citywide hazard associated with mass movement. For the slopes studied, conditions of elevated water table alone may initiate failure, but this is seen as unlikely as the materials are well drained. Combinations of water tables above 10% of the slope elevation together with seismic accelerations of approximately 0.2 g (150 year return period) represent likely failure conditions for many slopes. This information provides emergency management planners with estimates of the likely extent of failure in different regions of the city, and hence facilitates identification of lifelines and infrastructure at risk. The method cannot provide site-specific information, but in combination with knowledge of cultural features gives indications of critical locations where detailed engineering assessments are required.

(Schmidt *et al.*, 2001) Decades of quantitative measurement indicate that roots can mechanically reinforce shallow soils in forested landscapes. Forests, however, have variations in vegetation species and age which can dominate the local stability of landslide-initiation sites. To assess the influence of this variability on root cohesion we examined scarps of landslides triggered during large storms in February and November of 1996 in the Oregon Coast Range and hand-dug soil pits on stable ground. At 41 sites we estimated the cohesive reinforcement to soil due to roots by determining the tensile strength, species, depth, orientation, relative health, and the density of roots ^{3}1 mm in diameter within a measured soil area. We found that median lateral root cohesion ranges from 6.8–23.2 kPa in industrial forests with significant understory and deciduous vegetation to 25.6–94.3 kPa in natural forests dominated by coniferous vegetation. Lateral root cohesion in clearcuts is uniformly £10 kPa. Some 100-year-old industrial forests have species compositions, lateral root cohesion, and root diameters that more closely resemble 10-year-old clearcuts than natural forests. As such, the influence of root cohesion variability on landslide susceptibility cannot be determined solely from broad age classifications or extrapolated from the presence of one species of vegetation. Furthermore, the anthropogenic disturbance legacy modifies root cohesion for at least a century and should be considered when comparing contemporary landslide rates from industrial forests with geologic background rates.

(Cronkite-Ratcliff, Schmidt and Wirion, 2022) although accurate root cohesion model estimates are essential to quantify the effect of vegetation roots on shallow slope stability, few means exist to independently validate such model outputs. One validation approach for cohesion estimates is back-calculation of apparent root cohesion at a landslide site with well-documented failure conditions. The catchment named CB1, near Coos Bay, Oregon, USA, which experienced a shallow landslide in 1996, is a prime locality for cohesion model validation, as an abundance of data and observations from the site generated broad insights related to hillslope hydrology and slope stability. However, previously published root cohesion values at CB1 used the Wu and Waldron model (WWM), which assumes simultaneous root failure and therefore likely overestimates root cohesion. Reassessing published cohesion estimates from this site is warranted, as more recently developed models include the fiber bundle model (FBM), which simulates progressive failure with load redistribution, and the root bundle model-Weibull (RBMw), which accounts for differential strain loading. We applied the WWM, FBM, and RBMw at CB1 using post-failure root data from five vegetation species. At CB1, the FBM and RBMw predict values that are less than 30% of the WWM-estimated values. All three models show that root cohesion has substantial spatial heterogeneity. Most parts of the landslide scarp have little root cohesion, with areas of high cohesion concentrated near plant roots. These findings underscore the importance of using physically realistic models and considering lateral and vertical spatial heterogeneity of root cohesion in shallow landslide initiation and provide a necessary step towards independently assessing root cohesion model validity.

Geo studio slope stability model evaluates slope stability throughout a digital landscape represented by a digital elevation model (DEM). The program uses a three-dimensional (3D) method of columns limit-equilibrium analysis to assess the stability of many potential landslides (typically millions) within a user-defined size range. For each potential landslide, Geo studio assesses the stability of a rotational, spherical slip surface encompassing many DEM cells. It provides the least-stable potential landslide for each DEM cell in the landscape, as well the associated volumes and (or) areas.

The user's manual includes: the theoretical basis for the slope-stability analysis, requirements for constructing a 3D domain, a detailed operational guide and input/output file specifications, practical considerations for conducting an analysis, results of verification tests, and multiple examples illustrating the capabilities of Geo-studio.

2.3 Physically Based Slope Stability Assessment

Statistical and deterministic methods are widely used in geographic information system based landslide susceptibility map- ping. This paper compares the predictive capability of three different models, namely the Weight of Evidence, the Fuzzy Logic and SHALSTAB, for producing shallow earth slide susceptibility maps, to be included as informative layers in land use planning at a local level. The test site is an area of about 450 km2 in the northern Apennines of Italy where, in May 2004, rainfall combined with snowmelt triggered hundreds of shallow earth slides that damaged roads and other infrastructure. An inventory of the landslides triggered by the event was obtained from interpretation of aerial photos dating back to May 2004. The pre-existence of mapped landslides was then checked using earlier aerial photo coverage.

(Terlien, Van Westen and Van Asch, 1995) States Hydrological landslide-triggering thresh- olds separate combinations of daily and antecedent rainfall or of rainfall intensity and duration that triggered landslides from those that failed to trigger landslides. They are required for the development of landslide early warning systems. When a large data set on rainfall and landslide occurrence is available, hydrological triggering thresholds are determined in a statistical way. When the data on landslide occurrence is limited, deterministic models have to be used. For shallow landslides directly triggered by percolating rainfall, triggering thresh- olds can be established by means of one-dimensional hydrological models linked to the infinite slope model. In the case of relatively deep land- slides located in topographic hollows and triggered by a slow accumulation of water at the soil-bedrock contact, simple correlations between landslide occurrence and rainfall can no longer be established.

Shanmugapriya Dewdree and Siti Norafida Jusoh , 2019, “Slope stability analysis under different soil nailing parameters using the SLOPE/W software” For determining the most appropriate value for stabilization of soil slope using software Slope/W ,Soil nailing system was studied in terms of inclination of soil nailing . The best factor of safety found at (60°,50° and 40° respectively) with the horizontal . Soil nailing FOS varies very minute where the soil nails varies (5°-20°) respectively.

(Mr. Digvijay P. Salunkhe *et al.*, 2017) “An overview on methods for slope stability analysis” For different soil type and slope condition the FOS find out with the principle of L.E. and F.EM. . The various factor of safety and various parameters used by the author and reviewed and disscuss . Ass s suggestion , same mathematical tools are suggested for analysis of slope.

(De Baets *et al.*, 2008) “Slope Stability Prediction of Homogeneous Earth dam caused by fluid particles seeps by using artificial neural networks” C, Φ,ϒ are used as input parameter of dam and find out the FOS by using entry and exit method , Here time series method used for analysis . Slip surfaces eliminated in Upstream and Downstream side of the dam to find out the FOS.

CHAPTER 3

MATERIALS AND METHODOLOGY

3.1 Study Area

The study area, Firfire Danda Thecho, is situated within the Godawari Municipality ward no-12 . Godawari Municipality is located in the Lalitpur District of Bagmati Province.Here's some introductory information about firfire dada ,Thecho Geographic Location (GPS) is 27°37'14.80"N,85°18'57.30"E,1413.9m .Firfire dada Thecho is situated in the southern part of the Lalitpur district, approximately 7 kilometers south of the capital city, Kathmandu. It is part of the Kathmandu Valley and shares its geographical features with other towns and cities in the valley. Haphazard urbanization, unplanned excavation and deforestation are found to be the major triggering factors of multi-hazards. Though the local People is continuously focusing to the reconstruction of firfire dada Prone areas, local communities seems to be highly affected by the landslides .

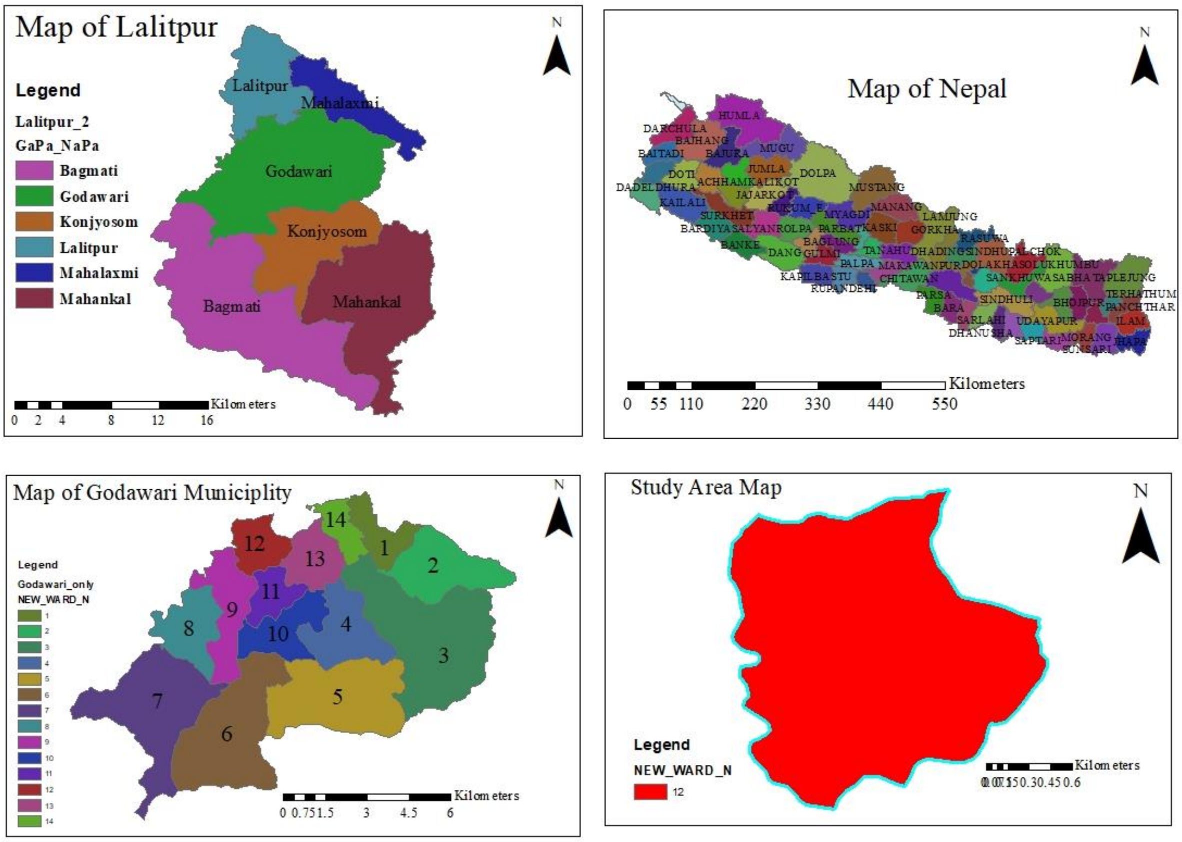

Figure 3-1: Map of Study Area

Figure 3-2: Google Photograph of the study area (note the hosue under the threat of slope failure)

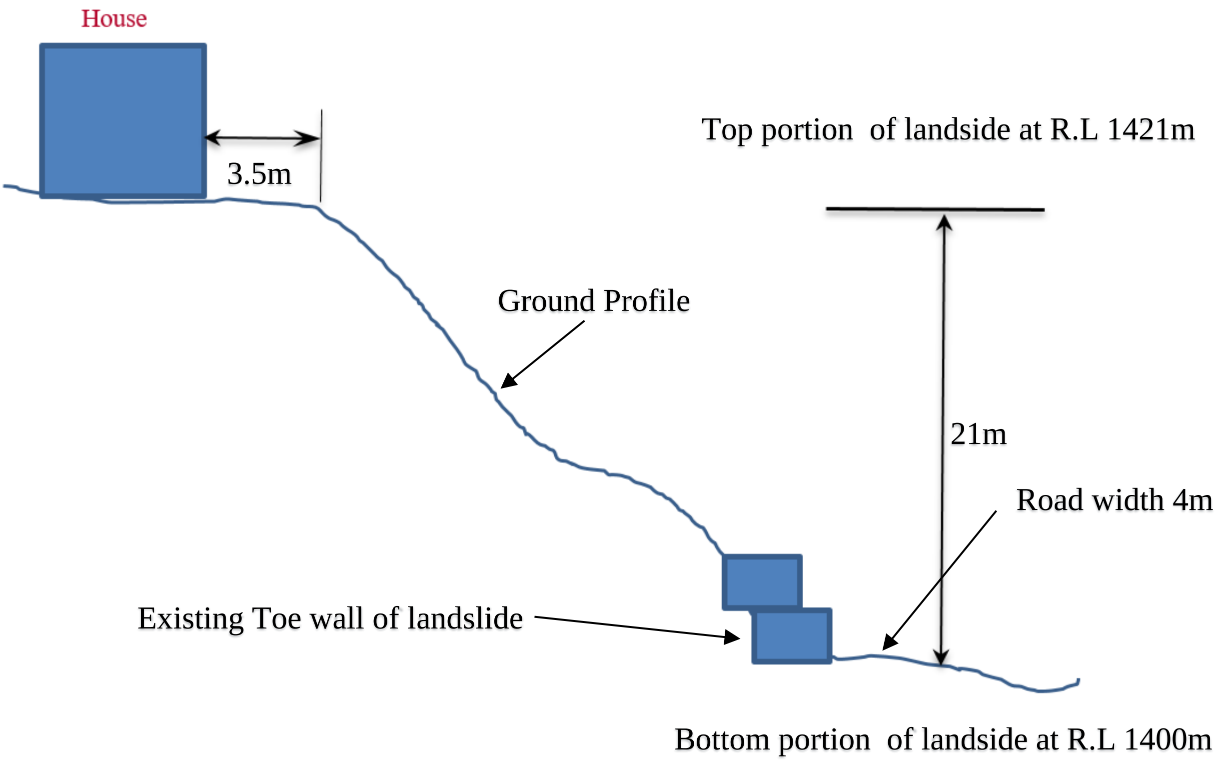

Figure 3-3: Firfire danda Landslide X-Section on Ground profile

3.2 Climate

Firfire danda ,Thecho, situated in the Bagmati Province, Lalitpur District, under Godawari Municipality-6 in Nepal, exhibits a diverse topography, encompassing both urban and rural landscapes. Influenced by elevation, the region experiences distinct seasons. Spring brings warm and pleasant weather, attracting outdoor activities and tourism. Summer is characterized by elevated temperatures, particularly in lower elevations, making it an ideal period for exploring cultural and historical sites. However, the monsoon season, prevalent from June to September, introduces heavy rainfall, triggering potential landslides and flooding. Rainfall patterns are influenced by various factors such as geography, topography, and climate change. Here's a summary along with some graphs to illustrate the trends as Figure 3-3 and Figure 3-4 of different Two Rainfall Stations as below.

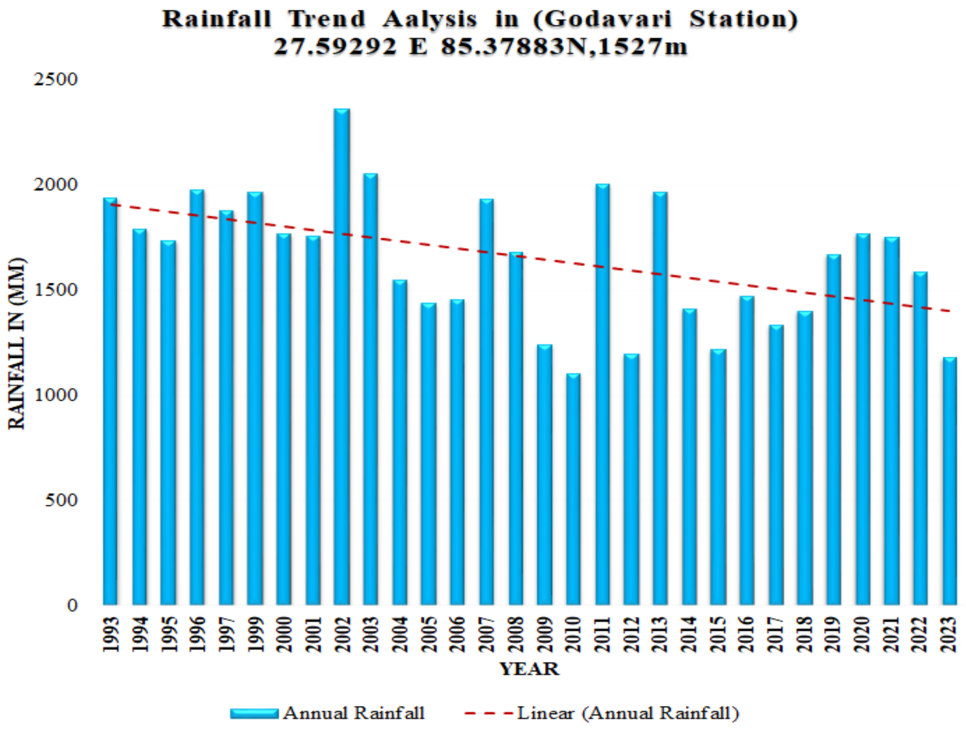

Figure 3-4: Rainfall Trend Analysis (Rainfall vs Year) on Godawari Station

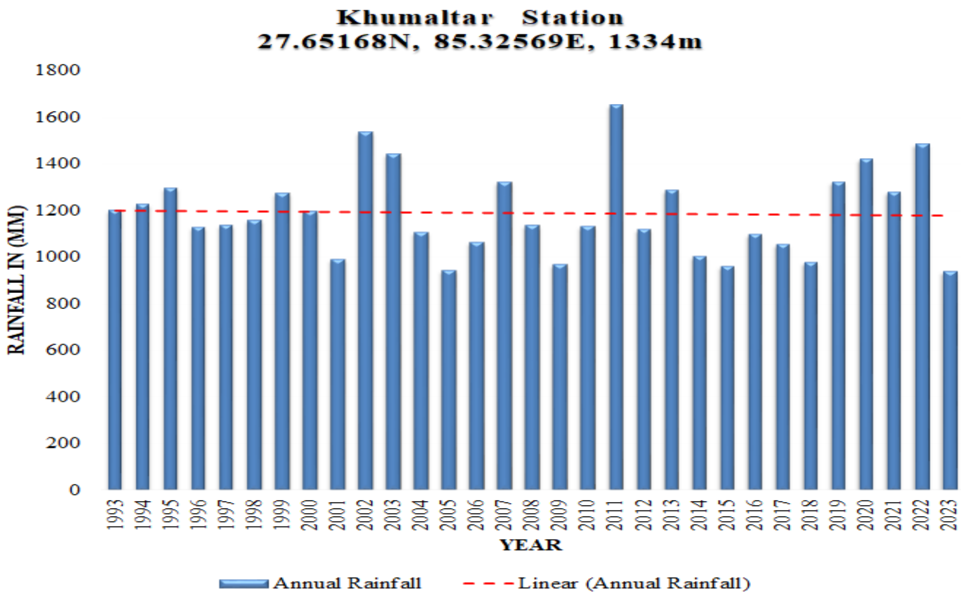

Figure 3-5: Rainfall Trend Analysis (Rainfall vs Year) on Godawari Station

In Godawari Rainfall station analized the rainfall data from 1993 to 2023 shows a fluctuating trend. The highest recorded rainfall occurred in 2002 with 2366.6 mm and the lowest in 2010 with 1104.8 mm. Over the years, there seems to be some variability, with peaks in 2002, 2011, and 2019, and troughs in 2010 and 2013. On average, the annual rainfall hovers around 1600-1800 mm, with occasional deviations. A more detailed analysis could identify patterns or potential factors influencing these variations in the rainfall trend.. similarly next khumaltar station the rainfall data from 1993 to 2023 shows varying trends. There is a general increase in rainfall from 1993 to 2002, peaking in 2002 at 1535.3 mm. Subsequently, there is a fluctuating pattern with both increases and decreases until 2011, where a significant spike is observed with 1653.1 mm. Post-2011, there's a mix of higher and lower values, and by 2023, the rainfall has decreased to 937.11 mm. Overall, the data suggests a period of elevated rainfall in the early 2000s, followed by a more erratic pattern in the subsequent years, emphasizing the importance of considering longer-term trends for comprehensive rainfall analysis as below. especially in higher elevations, with clear skies but chilly conditions, occasionally approa especially in higher elevations, with clear skies but chilly conditions, occasionally approaching freezing temperatures, especially during the night.

The rainfall pattern in Lalitpur, specifically in the Firfire Danda area, over the last 30 years shows fluctuations in precipitation levels. Analyzing data from rainfall stations in Godawari and Khumaltar, there's evidence of varying trends. In Godawari, from 1993 to 2023, rainfall has fluctuated, with peaks observed in 2002, 2011, and 2019, and troughs in 2010 and 2013. On average, annual rainfall ranges between 1600-1800 mm, with occasional deviations. Similarly, in Khumaltar, there was a general increase in rainfall until 2002, followed by a fluctuating pattern until 2011, where a significant spike occurred. Post-2011, there's a mix of higher and lower values, with rainfall decreasing by 2023. Overall, the data suggests elevated rainfall in the early 2000s, followed by a more erratic pattern in subsequent years. These fluctuations in rainfall highlight the importance of considering longer-term trends for comprehensive rainfall analysis, especially in assessing the impact on landslide susceptibility in areas like Firfire Danda in Lalitpur.

The relationship between rainfall patterns and landslides is complex but significant. In Lalitpur, fluctuations in rainfall, as observed over the past 30 years in areas like Firfire Danda, can directly influence landslide occurrences. Here's a summary of their relationship:

1. **Intensity and Duration**: Heavy rainfall, particularly when prolonged or intense, can saturate the soil, reducing its stability and increasing the likelihood of landslides. Peak rainfall events, such as those observed in 2002, 2011, and 2019, may coincide with higher landslide occurrences.
2. **Precipitation Variability**: Fluctuations in rainfall, as seen in the data from Godawari and Khumaltar stations, can lead to periods of both elevated and reduced precipitation. These variations can impact soil moisture levels, affecting slope stability and potentially triggering landslides.
3. **Rainfall Trends**: Long-term trends in rainfall, such as the increase observed until 2002 in Khumaltar, followed by fluctuating patterns, can influence landscape conditions over time. Changes in rainfall patterns may alter soil erosion rates, vegetation growth, and other factors contributing to landslide risk.
4. **Cumulative Effects**: Landslides often result from a combination of factors, including rainfall, slope steepness, soil type, and land use practices. While individual rainfall events may trigger landslides, cumulative effects of multiple rainstorms over time can exacerbate soil instability and increase landslide susceptibility.
5. **Monitoring and Prediction**: Understanding the relationship between rainfall patterns and landslides is crucial for effective monitoring and prediction efforts. Analyzing historical rainfall data, as done in Godawari and Khumaltar stations, helps

identify trends and patterns that inform landslide risk assessments and early warning systems.

3.2 Geomorphology

The Geomorphology of the landslide site at Firfire Danda is influenced by its location geological morphometric processes that have shaped the region. Following section presents an overview of the morphological features the landslide location.

Valley setting:- which is a synclinal valley formed by the tectonic collision of the Indian and Eurasian plates. The valley is characterized by its flat and relatively low-lying terrain surrounded by hills and mountains.

Alluvial deposite:-The valley floor and its surrounding areas are covered with alluvial deposits, which are sediments transported and deposited by rivers over time. These deposits contribute to the fertile soil of the region, making it suitable for agriculture.

River Systems:- Lalitpur District in Nepal is known for its rich cultural heritage and beautiful landscapes, including several river systems. Here are some of the notable rivers that flow through or near Lalitpur District:

1. Bagmati River: The Bagmati River is one of the major rivers in Nepal, and it flows through Lalitpur District. It is highly revered by both Hindus and Buddhists and holds significant cultural and religious importance.
2. Bishnumati River: Another important river in Lalitpur District is the Bishnumati River. It originates from the Shivapuri Hills and flows through Kathmandu Valley, including parts of Lalitpur.
3. Manohara River: The Manohara River is a tributary of the Bagmati River and flows through Lalitpur District. It originates from the Shivapuri Hills and joins the Bagmati River near Thapathali in Kathmandu.
4. Lalitpur Khola: Lalitpur Khola is a smaller river that flows through Lalitpur District. It originates from the hills surrounding the district and adds to the natural beauty of the region.The Bagmati River and its tributaries flow through Lalitpur District. The rivers have played a significant role in shaping the landscape through erosion, sediment transport, and deposition.

Terraces:- The region is characterized by terraced fields, particularly on the hillsides. These terraces are a result of human intervention and traditional agricultural practices, where farmers have modified the landscape to create flat surfaces for cultivation.

Hills and Uplands:- Lalitpur District is surrounded by hills and uplands, which have been shaped by erosion and weathering over time. These features contribute to the overall topography of the district as well as thecho area and provide scenic landscapes.

Geology:- The Kathmandu Valley, including Lalitpur Thecho, is seismically active due to the ongoing tectonic collision. This activity has led to the development of fault lines and geological structures that influence the geomorphology of the region.

Erosional Landforms:- Various erosional landforms can be found in the district, including gullies, ravines, and river-cut valleys. These features are a result of the continuous action of water and weathering processes.

Figure 3-6: Soil Profiles in Firfire Dada Landslide area after the plantation.

soil profile for firfiredada,Techo, Lalitpur. However, I can provide a generalized overview of the soil types commonly found in Lalitpur District based on the region's geological characteristics and climatic conditions.

Lalitpur District, located in the Kathmandu Valley of Nepal, exhibits diverse soil profiles influenced by its topography, parent material, climate, and land use practices. The region's soils are primarily formed from alluvial deposits, colluvial material, and residual weathered rock.In the valley bottoms and along riverbanks, alluvial soils dominate, characterized by their fine texture and high fertility resulting from the deposition of sediments carried by rivers and streams. These soils are often well-drained and suitable for agriculture, supporting crops like rice, wheat, and vegetables.

In upland areas and slopes, colluvial soils predominate, formed from the accumulation of weathered material transported downslope by gravity. These soils may vary in texture and fertility depending on the parent material and the degree of weathering.Additionally, residual soils derived from the weathering of underlying bedrock are found in some areas, contributing to the soil diversity of Lalitpur District. These soils often exhibit characteristics influenced by the parent rock type, such as clayey soils derived from shale or sandy soils derived from sandstone.Land use practices, such as agriculture, urbanization, and deforestation, can further influence soil characteristics and profiles in Lalitpur District. Conservation measures and sustainable land management practices are essential for preserving soil quality and mitigating erosion and degradation in this region, emphasizing the importance of ongoing soil surveys and monitoring efforts.

The soil profile of Lalitpur, Nepal, based on general characteristics of the region. However, without specific soil data for Lalitpur as follow:

1. Surface Layer (O Horizon): This layer consists of organic matter such as leaf litter, decomposing plant material, and humus. In Lalitpur, this layer might be relatively thin due to the high levels of human activity and agricultural practices in the region.
2. Topsoil (A Horizon): This layer is rich in organic matter, minerals, and nutrients. It's where most plant roots are found. In Lalitpur, the topsoil might vary depending on land use, but it's likely to be fertile due to agricultural practices and vegetation cover.
3. Subsoil (B Horizon): This layer contains minerals leached from the topsoil and often has a different texture and color from the layers above. In Lalitpur, the subsoil might have characteristics influenced by the underlying geology of the region, which could include various types of rock formations.
4. Parent Material (C Horizon): This layer consists of partially weathered rock fragments and minerals. It's less affected by biological activity and contains the base

material from which the soil developed. In Lalitpur, the parent material might include weathered rock from the surrounding hills and mountains.

5. Bedrock (R Horizon): This is the solid rock layer that underlies all the other soil horizons. In Lalitpur, the bedrock might consist of various types of sedimentary, igneous, or metamorphic rock formations common to the region.Overall, the soil profile of Lalitpur likely reflects a combination of natural processes and human activities, with variations influenced by factors such as topography, climate, vegetation, and land use practices.

3.3 Geology and Geotechnology

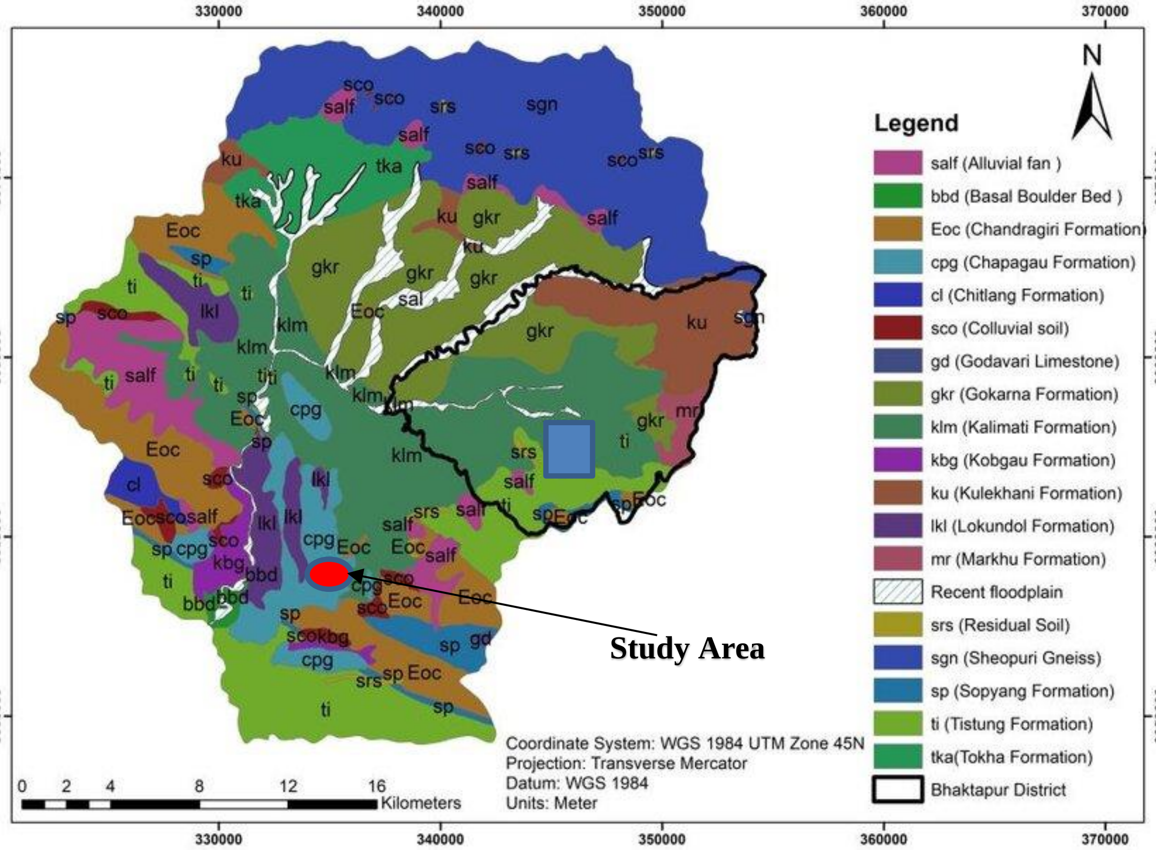

Figure 3-7: Geological map of the Kathmandu Valley (redrawn and modified after Shrestha et al., (1998)). (Source: Department of Mines and Geology, Nepal).

The geology and geotechnology of Lalitpur, Nepal, are influenced by its location within the Kathmandu Valley and its surrounding geological features. Lalitpur district is situated in the southern part of the Kathmandu Valley, which is formed within the Kathmandu nappe, a geological structure within the lesser Himalaya belt . Lalitpur district, one of the smallest districts of Nepal, lies in the Southern part of the Kathmandu Valley covering an area of 385 km^2.

Lalitpur is situated in a Average geological structure with numerous fault lines, low bearing capacity, and loose soil structure. The study area is majorly formed from the cpg ,gd Formation, in our study area is lies cpg (chapagaon formation) as shown in Figure 3-7.

The predominant geological formation in Lalitpur is the CPG-GD Formation, specifically the Chapagaun Formation within it. This geological formation plays a significant role in shaping the landscape and geotechnical properties of the area.The charactertistics of CPG and GD formation as following below.

Chapagaon Formation (CPG):

- Geological Formation: Part of the Lesser Himalayan Sequence.
- Composition: Primarily consists of phyllites, schists, and quartzites.
- Color: Varied colors including shades of grey, green, and purple.
- Texture: Exhibits strong foliation and banding due to metamorphism.
- Fossils: Typically lacks fossils due to intense metamorphism.
- Occurrence: Found in the southern part of the Kathmandu Valley, Nepal.
- Structural Features: Shows complex folding and faulting due to tectonic activities.
- Economic Importance: Limited economic significance, mainly used for construction materials locally.

Godavari Limestone (GD):

- Geological Formation: Part of the Siwalik Group.
- Composition: Composed predominantly of calcium carbonate (calcite).
- Color: Usually light to medium grey.
- Texture: Generally fine-grained with occasional fossil fragments.
- Fossils: Abundant fossil content including marine mollusks, foraminifera, and coral fragments.
- Occurrence: Found in the Godavari region of Nepal.
- Depositional Environment: Formed in shallow marine environments.
- Economic Importance: Significant as a source of limestone for construction, cement production, and agriculture (as a soil conditioner).

3.4 Firfiredada Landslide

The Firfire Danda landslide, situated in the southern part of Lalitpur district, approximately 7 kilometers south of the capital city, Kathmandu, was studied for research purposes. This landslide was triggered by excavation at the toe of the access road. Geology and topography are causal factors, while rainstorms act as triggering factors for this landslide. It occurred in July of 2020 and covered 400 m^2-500m^2 area tentatively. Although there was no severe damage, there was a loss of private land, and one house nearby remains at risk. Despite continuous efforts by the local community to focus on the reconstruction of Firfire Danda and prone areas, local communities continue to be highly affected by landslides.

The Firfire Danda Landslide in Lalitpur is a significant event that has drawn attention due to its impact on the local community and environment. The landslide poses a threat to houses and agricultural land in the area. The terrain in this region is known for its susceptibility to landslides, especially during periods of heavy rainfall or seismic activity. Efforts to mitigate the risks associated with such natural disasters are crucial for ensuring the safety and well-being of residents living in landslide-prone areas like Firfire Danda. Major species such as vetiver, urokhar, babiyo nepiyar, salimkhar, kans, kush, and amriso were planted by communities in order to mitigate the causes of landslides. According to this study, the recommended species to mitigate the causes of landslides is vetiver.

3.5 Research Plan and Design

3.5.1 General Term

This term to ensure the high-quality delivery of the thesis result. This was achieved by adhering to relevant national and international codes, practices, guidelines, and standards in slope stability analysis and slope stability model. Additionally, engaged with local communities to gain a better understanding of the history and significant impacts of slope failure landslides and potential debris flows. Here conducted a thorough review of topographical and geological maps, remote sensing data, and related guiding documents. Furthermore, the implemented an internal quality control mechanism, which was led by senior experts working in landslides. This mechanism helped to ensure the high-quality delivery of the thesis project deliverables.

3.5.2 Technological Terms

The study area's topography was studied through image captured once using state-of-the-art UAV (Drone) technology by FEED (P) Ltd./Institute of Himalayan Risk Reduction. This image data provided valuable insights into recent land use patterns, settlement distribution, and topographical features that aided in the identification of unstable landscapes. Also, helped to gain a better understanding of the materials present in the study area and their characteristics. To gather primary data, a variety of methods were utilized, including the use of UAV(Drone) surveys to obtain a digital terrain model, soil physical properties, and land use information. Soil sampling was also conducted to collect additional data. In the laboratory, the collected soil samples were analyzed to determine their physical properties, including soil cohesion and internal angle of friction.

Finally, the Geo-Studio software was used to evaluate the slope stability of the study area. By combining these various techniques, a comprehensive understanding of the area's soil properties, topography, and slope stability was obtained.

3.5.3 Methodological Framework

The primary and secondary data collected were used in the formation of maps relevant to the designing of structures required for the stabilization of the slope. The desk study comprised mostly of literature review of published and articles to understand the history and progression of the slope failure. Similarly, previously applied design and mitigation efforts were studied to comprehend the existing scenario in a more effective manner. The field visit comprised of the application of UAV DRONE to collect the required data from the subsurface and the aerial methods.

The research design and plan for assessing plant root contribution to slope stability in the Firfire Danda Thecho landslide of Godawari Municipality involve a comprehensive approach. The study aims as

1. Field observation and Mapping
2. Review of previous stuidy report and collection of data (e. g. Drone images)
3. Field consultaitona and soil smapling for geotechnical properties
4. Laboratory analysis of the soil and obtained C, phi, root cohesion, etc.
5. Selection of model –Geo-stodio
6. Model setup and implementation
7. Interpretation of results

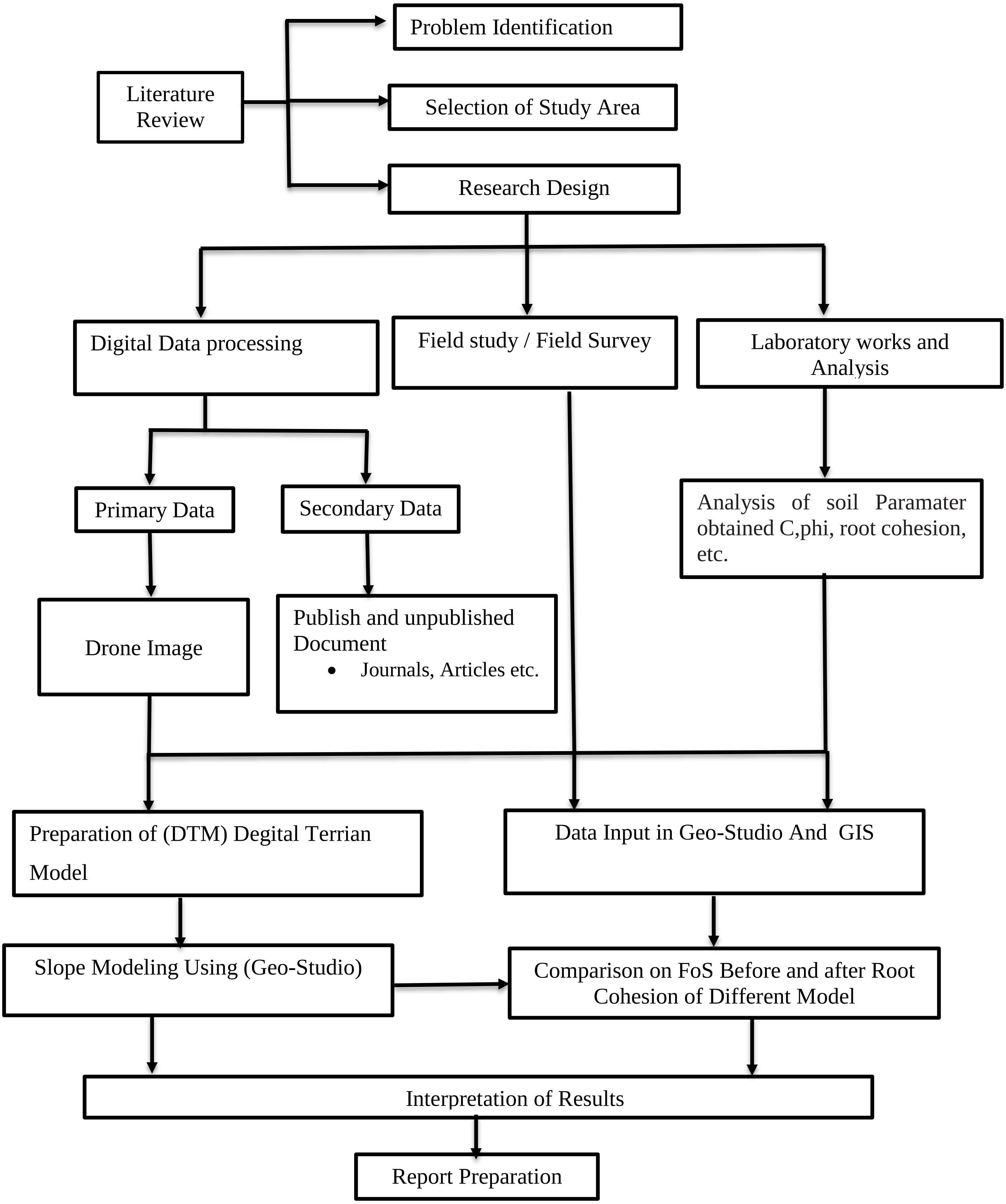

Figure 3-8: Methodological Framework

3.6 Field observation and Creating a Digital Terrain Model (DTM)

A Digital Terrain Model (DTM) and visualizing it in 3D to indicate landslide locations involves several steps. Here's a general process:

1. Data Collection: Gather elevation data for the landslide area. This data can come from Drone satellite imagery, or aerial surveys.
2. DTM Creation: Process the elevation data to generate a DTM. This typically involves removing noise, interpolating elevation values, and creating a continuous surface representing the terrain.
3. Landslide Detection: Identify landslide locations using relevant data sources such as historical records, satellite imagery analysis, or field surveys. This step may involve remote sensing techniques and image processing algorithms to detect changes in terrain morphology associated with landslides.
4. Integration: Overlay landslide location data onto the DTM. This involves spatially referencing the landslide locations to the DTM coordinate system.
5. 3D Visualization: Use software tools like GIS (Geographic Information Systems) or 3D modeling software to visualize the DTM and overlay landslide locations in a 3D environment. You can represent landslides as specific symbols or markers in the 3D scene.
6. Analysis: Analyze the 3D visualization to understand the spatial relationships between the terrain and landslide locations. This step may involve measuring distances, slopes, or other terrain attributes to assess landslide risk and potential impacts.
7. Documentation and Reporting: Document the findings of the analysis and create reports or visualizations to communicate the results effectively to stakeholders or decision-makers.

For each of these steps, there are various software tools and techniques available depending on the specific requirements of your project and the available data sources. GIS software such as ArcGIS, QGIS, or specialized landslide analysis software can be useful for processing elevation data, detecting landslides, and visualizing the results in 3D.

Figure 3-9:Firfire Danda Landslide Image

Figure 3-10: Firfire Danda Landslide Image

A slope map of Firfiredada landslide Techo in Lalitpur would likely display the topographical variations in the area, showing the degree of steepness or incline across the terrain. This type of map is essential for various purposes such as urban planning, environmental assessment, and land management. It provides valuable information about the landscape's susceptibility to erosion, landslide risks, and suitability for development or agriculture. A slope map typically uses color gradients or contour lines to represent different slope angles, with steeper areas usually depicted in darker shades or with closely spaced contour lines. Understanding the slope characteristics of Techo Firfiredada in Lalitpur is crucial for making informed decisions regarding infrastructure development, conservation efforts, and disaster risk reduction in the region.

3.7 Method of Data Collection

The study was based on primary and secondary data as described below:

3.7.1 Primary Data

1. **Field Survey**
   Conduct field surveys to gather information directly from the study area. This includes collecting data on plant species, their distribution, root characteristics, and the slope conditions.
2. **Root Sampling**
   The root samples of Vetiver plant species I referenced are from secondary sources such as Devkota et al. (2006) and Howell (1999). The root samples from Vetiver plant species in the study were assessed for root length, diameter, and depth to understand the potential impact on slope stability (Devkota, Shakya and Sudmeier-Rieux, 2019).
3. **Slope Measurements**
   Measure the slope angle and topography of the study area to identify the slope conditions and potential landslide-prone areas.
4. **Soil Sampling**
   Collect soil samples at different depths to analyze soil composition and stability. Assess factors such as soil moisture (NMC), cohesion(C), and shear strength(φ) . Six sample have taken from study area to know the current physical and geotechnical

propertis of the study area. The soil sample collection location is shown in table below.

Table 3- 1: Soil Sample Collection Details

S.N.	Sample	Date	Location	Remarks
1	Sample-1	2023/11/08	27°37'14.80"N,85°18'57.30"E,1417 m	Bottom area of landslide
2	Sample-2	2023/11/08	27°37'14.80"N,85°18'57.30"E, 1417 m	
3	Sample-3	2023/11/08	27°37'14.6"N,85°18'56.40"E,1424 m	Middle area of landslide
4	Sample-4	2023/11/08	27°37’14.6”N,85°18’56.40”E,1424 m	
5	Sample-5	2023/11/08	27°37’15.56”N,85°18’59.6”E,1430 m	Top area of landslide
6	Sample-6	2023/11/08	27°37’15.56”N,85°18’59.6”E,1430 m	

5. **Photographic Documentation**

   Take photographs of the study area at regular intervals to document changes in vegetation, slope conditions, and potential signs of instability.

3.7.2 Secondary Data

1. **Previous Studies**

   Review existing literature and studies related to landslides in the region. Identify any previous research on the Firfire Dada Landslide or similar cases.
2. **Geological Maps**

   Utilize geological maps to understand the geological features and potential geological hazards in the study area.
3. **Climate Data**

   Obtain historical climate data for the region, including temperature, precipitation, and extreme weather events.
4. **Satellite Imagery**

   Analyze satellite imagery to observe changes in vegetation cover, land use, and potential signs of slope instability.
5. **Government Reports**

   Consult government reports on environmental and geological conditions in the region, as they may contain valuable information on slope stability.

3.8 Geotechnical parameter

The geotechnical properties of the soil samples are derived in the laboratory using following methods.

Table 3- 2: Type and number of laboratory tests performed in this study

Tests	**Sieve Analysis**	**Hydrometer**	**NMC**	**Specific. Gravity**	**Direct Shear**
No.	6	6	6	6	6
Standard	IS: 2386 (Part 1) - 1963	IS: 2720 (Part 4)	IS: 2720 (Part 2)	IS: 2720 (Part 3)	IS: 2720 (Part 15)-1986

3.8.1 Soil classification

Soil classification is a separation of soil into classes or groups each having similar characteristics and potentially similar behavior. A classification for engineering purposes should be based mainly on mechanical properties. The classification to which a soil belongs can be used in its description.

In general, there are two major categories into which the classification systems can be grouped.

1. The textural classification is based on the particle-size distribution of the percent of gravel, sand, silt, and clay size fractions present in a given soil. Such as Massachusetts Institute of Technology classification system (MIT classification) and the U.S. Department of Agriculture.
2. The other major category is based on the engineering behavior of soil and takes into consideration the particle-size distribution and the plasticity (i.e., liquid limit and plasticity index). Under this category, there are two major classification systems in extensive use now.
    a. The American Association of State Highway and Transportation classification system (AASHTO), and
    b. The Unified classification system (USCS).

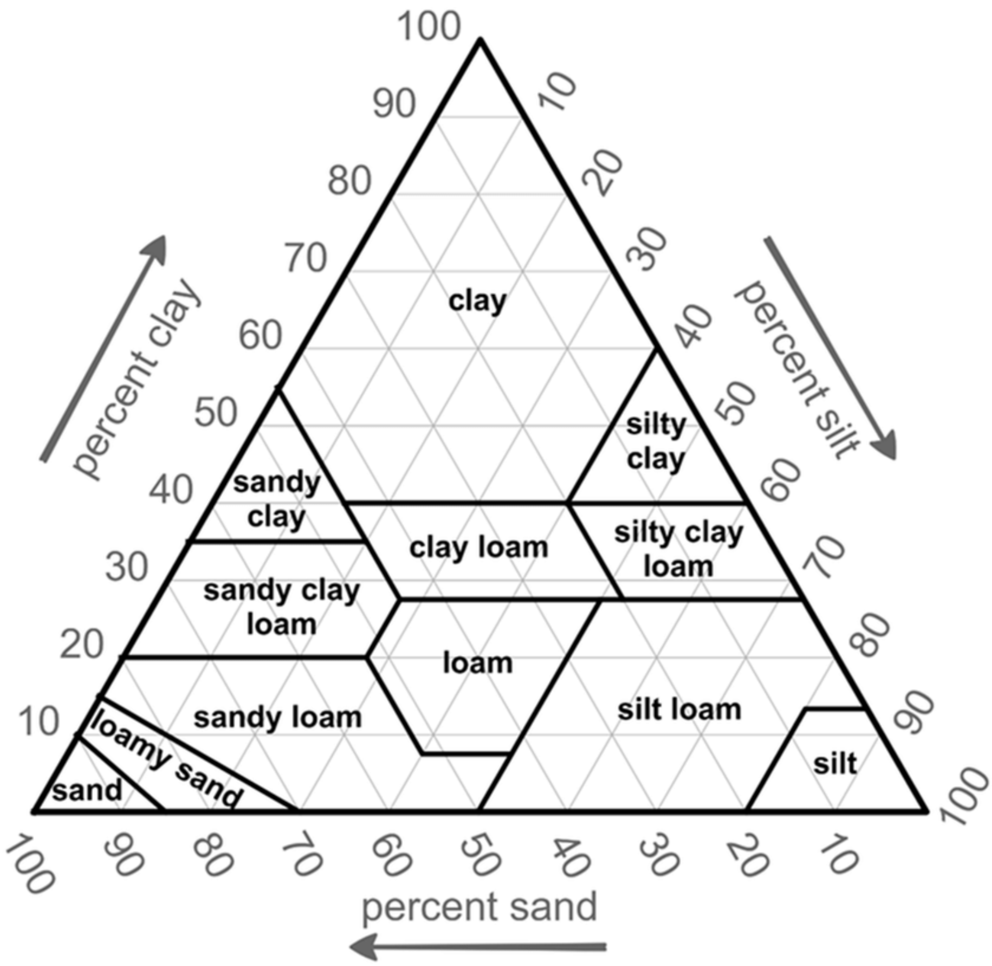

Figure 3-11: Soil textural triangle and textural classes (sources of image from USDA-NRCS).

3.8.2 Sieve Analysis

Table 3- 3: Soil Texture and Sieve Sizes IS 2386 (Part I) – 1963

Soil Texture	**Description**	**Sieve Size (mm)**
Sandy	Mostly sand particles	4.75
Silty	Fine particles, smooth to the touch	0.075
Clayey	Sticky, fine particles	0.002

To determine the particle size distribution of fine and coarse aggregates by sieving IS 2386 (Part I) – 1963 is brought in practice. The test is carried out by passing the sample downward through a series of standard sieves, each of decreasing size openings. The aggregates are separated into several groups, each of which contains aggregates in a particular size range. A set of IS Sieves are of sizes – 80 mm, 63 mm, 50 mm, 40 mm, 31.5 mm, 25 mm, 20 mm, 12.5 mm, 10 mm, 4.75 mm, 7 2.36 mm, 1.18 mm, 600 mm, 300 mm, 150 mm and 75 mm.

Balance or scale with an accuracy to measure 0.1 percent of the weight of the test sample is maintained. For sandy soils, the designation used number, i.e as shown in Table 3-4 US Standard Sieve as below.

Table 3- 4: U.S Standard Sieve

U.S. Standard Sieve Number	Opening Size (mm)	U.S. Standard Sieve Number	Opening Size (mm)
4	4.76	50	0.297
5	4.00	60	0.250
6	3.36	70	0.210
7	2.83	80	0.177
8	2.38	100	0.149
10	2.00	120	0.125
12	1.68	140	0.105
14	1.41	170	0.088
16	1.19	200	0.074
18	1.00	230	0.063
20	0.841	270	0.053
25	0.707	50	0.297
30	0.595	60	0.250
35	0.500	70	0.210
40	0.420	80	0.177
45	0.354	100	0.149

Figure 3-12: IS Sieve set from 4.75 mm to 75 micron.

3.8.3 Hydrometer Analysis

Hydrometer analysis is based on the principle of sedimentation of soil grains in water. When a soil specimen is dispersed in water, the particles settle at different velocities, depending on their shape, size, weight, and the viscosity of the water. For simplicity, it is assumed that all the soil particles are spheres.A hydrometer analysis is a measurement method used to determine soil particle size in a sample. It is carried out as per Indian Standard, Code IS: 2720 (Part 4). The hydrometer analysis is a widely used method of obtaining an estimate of the distribution of soil particle sizes from the 200 (0.075 mm) sieve to around 0.001 mm. The data are plotted on a semi-log plot of percent finer versus grain diameters to represent the particle size distribution. Both sieve analysis and hydrometer analysis are required to obtain the complete gradation curve of the coarse and fine fraction of many natural soils.

Figure 3-13: Hydrometer Analysis Test Appratus

Particle-Size Distribution Curve

The results of mechanical analysis (sieve and hydrometer analyses) are generally presented by semi-logarithmic plots known as particle-size distribution curves. The particle diameters are plotted in log scale, and the corresponding percent finer in arithmetic scale. When the results of sieve analysis and hydrometer analysis are combined, a discontinuity generally occurs in the range where they overlap. This is because soil particles are generally irregular in shape. Sieve analysis gives the intermediate dimension of a particle; hydrometer analysis gives the diameter of a sphere that would settle at the same rate as the soil particle.The percentages of gravel, sand, silt, and clay-size particles present in a soil can be obtained from the particle-size distribution curve. According to the(UCS) soil.

Gravel (size limit - greater than 4.75 mm)

Sand (size limits - 4.75 to 0.075 mm) = percent finer than 4.75 mm diameter - percent finer than 0.075 mm diameter

Silt and clay (size limit - less than 0.075 mm)

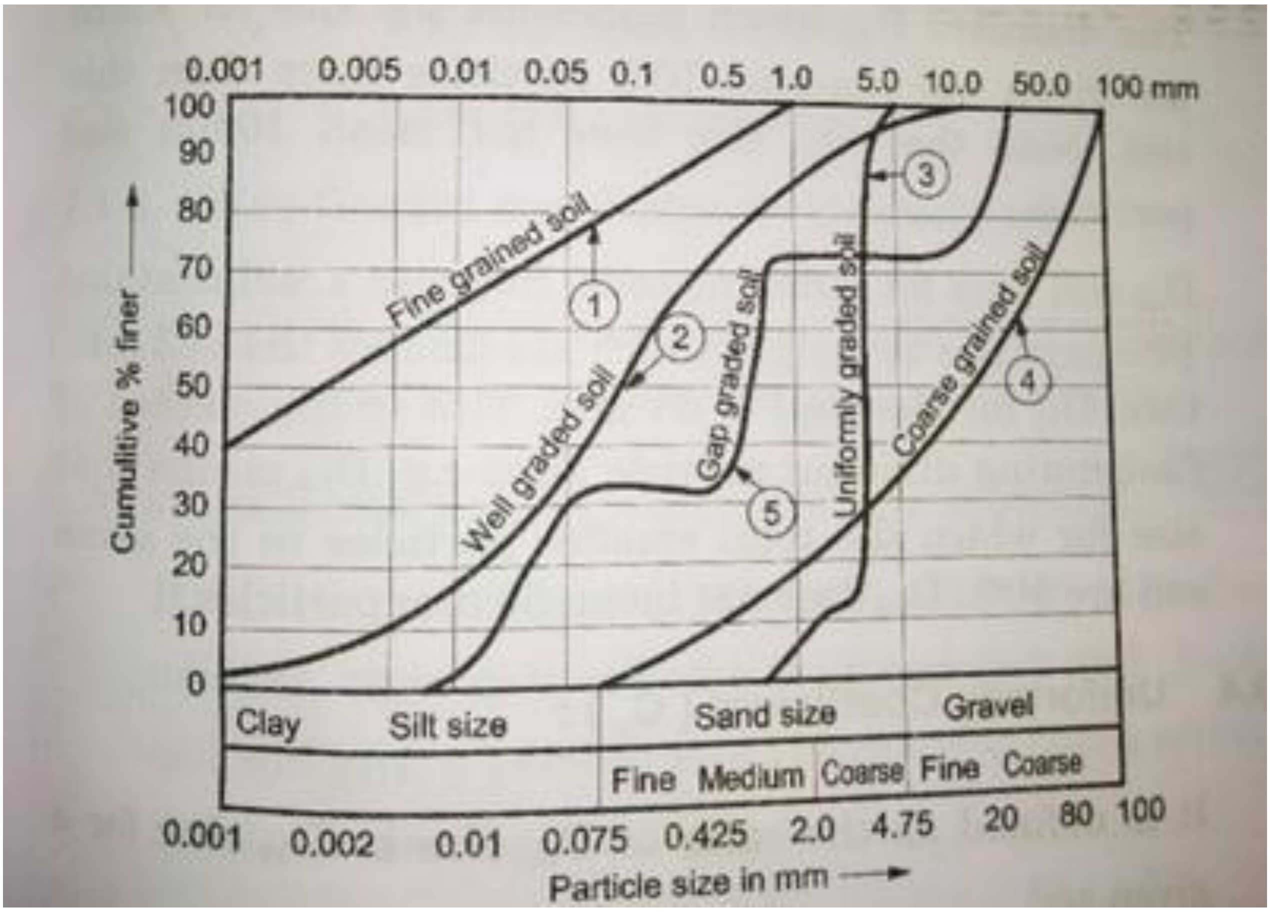

Figure 3-14: Particle Size Distribution Size Curve (2019 by vicky Geotechnical Engineering Note Book)

3.8.4 Natural Moisture content (NMC)

Natural Moisture content (NMC) is the ratio of the weight of water to the weight of the solids in a given mass of soil. This ratio is usually expressed as percentage.

3.8.5 Specific Gravity

Specific gravity is the ratio of the weight in air of a given volume of a material at a standard temperature to the weight in air of an equal volume of distilled water at the same stated temperature. To determine the specific gravity of fine-grained soil by density bottle IS: 2720 (Part III/Sec 1) – 1980 method is used.

The specific gravity of the soil particles lie with in the range of 2.65 to 2.85. Soils containing organic matter and porous particles may have specific gravity values below 2.0. Soils having heavy substances may have values above 3.0

3.8.6 Direct Shear Test

A direct shear test, also known as shear box test is a laboratory test used by geotechnical engineers to measure the shear strength properties of soil or rock material or of discontinuities in soil or rock masses. The direct shear test is carried out as per the method described in IS: 2720 (Part 13) – 1986.

Test is an experimental procedure conducted in geotechnical engineering practice and research that aims to determine the shear strength of soil materials. Shear strength is defined as the maximum resistance that a material can withstand when subjected to shearing.

Generally, the Direct Shear Test is considered one of the most common and simple tests to derive the strength of a soil and can be performed on undisturbed or remoulded samples.
In soil mechanics, the shear strength is evaluated using the Mohr-Coulomb (M-C) Failure Criterion. The M-C (Mohr-Coulomb) Criterion is a fundamental concept in soil mechanics that relates shear strength to effective stress. It assumes that the shear strength of a soil mass depends on three factors: cohesion (c), friction angle (φ), and normal stress (σ).

The Mohr-Coulomb equation is given by Equation 1:

$$\tau = c + \sigma \tan(\phi) \quad \ldots\ldots\ldots\ldots\ldots\ldots 1$$

(Jotisankasa *et al.*, 2018)

Where,

τ is the shear strength,

c is the cohesion of the soil (the intercept on the shear stress axis)

σ is the normal stress (the vertical stress applied to the soil), and

ϕ is the friction angle (the angle of internal friction).

Figure 3-15: Direct Shear Test Appratus

3.9 Plant Root parameter

3.9.1 Root reinforced soil strength

A simplified model for shear strength of root-reinforced soil in a variably saturated state can be expressed as follows;

$$\boldsymbol{\tau = c' + (\sigma n - ua)\tan\emptyset' + cs + cr}\text{..................}\mathbf{1}$$

(Jotisankasa *et al.*, 2018)

Where,

c' is the effective cohesion intercept of non-reinforced soil,

σ is normal stress,

u is pore-air pressure (normally equal to zero for soil near root zone),

$\phi'$is the effective angle of friction of non-reinforced soil,

cs is the cohesion due to suction,

and cr is the cohesion due to roots.

The cohesion due to suction, cs can be estimated as a function of suction and
a normalized wetted area index around soil particles, which can be expressed in several forms

$$\boldsymbol{c_s = x(ua - uw)\tan \emptyset'} \text{.................................}\mathbf{2}$$

where u_a is pore-water pressure, (u_a-u_w) is the soil matric suction, and the Bishop's parameter,χ, represents the effective wetted area over which the soil suction effectively contributes to shear strength. The parameters x can be approximated to be equal to degree saturation the roots, c_r can be expressed as follows;

$$\boldsymbol{c_r = \sigma_t \left(\frac{AR}{A}\right)[\sin\theta + \cos\theta \tan\emptyset]} \text{..........................}\mathbf{3}$$

Where,
σ_t = the moilized tensile stress of root fibers developed at the shear plan;
$\frac{AR}{A}$= the root area ratio: AR is the root area and A is total area of soil and
θ=the angle of shear distortion in shear Zone.

To calculate the root cohesion specific to individual species, we carried out tensile strength tests for thread diameters up to 6.5 mm for 12 species of vegetation characteristic of the field area. We trimmed 15– 20 cm long root segments from the plant, measured diameters including bark, clamped one end of the roots to a calibrated spring, and loaded roots to failure in tension similar to the procedure described in Wu et al. (1979). The load registered on the spring at failure determined the maximum tensile force provided by the root. Regression curves of the thread strength versus root diameter data were subsequently used to extrapolate root tensile strength for threads >6.5 mm in diameter.('Trisuli landslide_Final Print_Check.pdf', no date)

3.9.2 Root Area Ratio (RRA)

Root-Area-Ratio is a measure of the root surface area relative to the total land surface area. It is often used in ecological studies to quantify the extent of root development in relation to the overall plant or land area. The formula for Root-Area-Ratio (RAR) is given by:

RAR= Total Land SurfaceArea/Total Root Surface Area

$$\mathbf{RRA}=\frac{\mathbf{Ar}}{\mathbf{As}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\mathbf{4}$$

Where,

Ar = Total Root Surface Area is the sum of the surface areas of all the roots.

As = Total Land Surface Area is the total area of the land or soil

3.9.3 Root Tensile Strength(τ):

Root tensile strength is the force per unit cross-sectional area required to pull a root out of the soil. It is an important parameter in soil mechanics, indicating the ability of plant roots to stabilize soil. The formula for root tensile strength is given by:

$$\text{Root Tensile Strength} = \frac{\textbf{Force required to Breakl the root}}{\textbf{cross−sectional area of the root}}$$

$$\mathbf{Tr}= \frac{\mathbf{Fmax}}{\frac{\pi(D)^2}{4}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\mathbf{5}$$

Where,

Fmax is the maximum force (N) needed to break the root

D is mean root diameter (mm) near the point of rupture before stretching. Before testing, root diameter was measured at three points, i.e. near the upper clamp, halfway the root clamps and near the bottom clamp, using a digital calliper.

3.9.4 Factor of safety (FOS):

Modified Bishop's method is found in 1955, it is invented by Bishop. This method is slightly different from the ordinary method of slices. In this normal interaction forces between adjacent slices are assumed to be collinear and the resultant inter slice shear force is zero. The method has been shown to produce factor of safety values within a few percent of the "correct" values. Factor of safety appears both on the left and right hand sides of the equation.

This method satisfies vertical force equilibrium for each slice and overall moment equilibrium about the center of the circular trial surface. Since horizontal forces are not considered at each slice, the simplified Bishop method alsoassumes zero inter slice shear forces (Agbelele *et al.*, 2023).

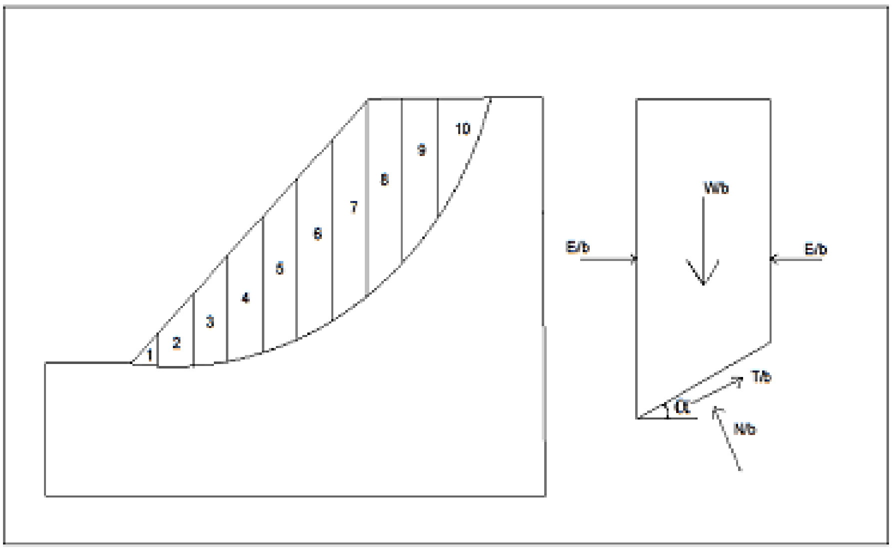

Figure 3-16: Modified Bishop's method of analysis

Neglecting side forces (OMS) produces FS too low (conservative)Assume side shear forces are zero but account for side normal forces.Effective Stress Analysis (ESA).

$$F_s = \frac{\left\{ \dfrac{mc' + \left[\left({}^{W}/_{b}\right) - um\right] \tan \emptyset'}{\psi} \right.}{\sum\left[\left({}^{W}/_{b}\right)\right] \sin \alpha}$$

$$\psi = \cos \alpha + \frac{\sin \alpha \tan \phi'}{F_s}$$

Total stress analysis,

$$F_s = \frac{\sum(\frac{ms_u}{\cos \alpha})}{\sum\left[({}^{W}/_{b}) \sin \alpha\right]}$$

3.9.5 KPI of the Plant Species

The perennial grass species that were recommended by the community were also recommended by (Maffra *et al.*, 2019) implying that species selection through local knowledge is useful. Altogether, nine indicators as following below:

1. **Survival Rate**: The percentage of planted or seeded individuals that successfully establish and survive to maturity, indicating the effectiveness of planting efforts and habitat suitability.
2. **Growth Rate**: Measure of the increase in size or biomass of plant species over a specified period, indicating healthy growth and ecosystem productivity.
3. **Reproduction Rate**: Assessment of the capacity of plant species to produce viable seeds or offspring, essential for maintaining population numbers and genetic diversity.
4. **Population Size and Density**: Monitoring changes in population size and density to assess the overall health and abundance of plant species within a given area.
5. **Genetic Diversity**: Evaluation of the variety of genetic traits within a population, which enhances resilience to environmental stressors and disease.
6. **Habitat Suitability**: Analysis of environmental conditions necessary for the growth and survival of plant species, including soil quality, moisture levels, and light availability.
7. **Ecosystem Services**: Quantification of the ecological services provided by plant species, such as carbon sequestration, soil stabilization, and habitat provision for other organisms.
8. **Invasive Species Control**: Monitoring the effectiveness of control measures against invasive plant species, crucial for preserving native plant communities and biodiversity.
9. **Response to Climate Change**: Assessment of how plant species respond to shifting climate conditions, including changes in phenology, distribution ranges, and abundance patterns.

These nine indicators provide a comprehensive framework for evaluating the performance, conservation status, and ecological significance of plant species within diverse ecosystems. were quantified to evaluate the performance of the Vetiver plant (Table 3-4). Among the model and the same observation was valid for the canopy cover.

According to the model plant species can be divided into three classes as per the root depth: (1) deep, (2) moderately deep, and (3) shallow, according to which Vetiver (C. zizanioides) has the deeper and stronger roots chracteristics.The root tensile strength is one of the important indicators contributing to increase soil cohesion, known as root cohesion. Vetiver

(C. zizanioides) demonstrated the highest tensile strength (Tr) from its root cohesion (cr), (Devkota *et al.*, 2019).

Table 3- 5: Summary of KPIs of the model vetiver plant species

Species Local	Species Name	RAR-Deep	RAR-Shallow	Rooting Depth (cm)	Tr (MPa)	cr (kPa)
Vetiver	*C.zizanioides*	0.0018	0.0241	0-100	45.4	14.08

Note: RAR-deep = root area ratio of deep roots, RAR-shallow = root area ratio of shallow roots, Tr = tensile strength, cr = root cohesion (Devkota, Shakya and Sudmeier-Rieux, 2019).

3.10 Geo-Studio Software Package and the respective method Used

The history of Geo-Studio software tools dates back to the early 1990s when the first version of the software was developed by Dr. Ross Boulanger at the University of California, Berkeley (Agbelele *et al.*, 2023).The software was initially created to analyze geotechnical problems such as slope stability, retaining walls, and foundation design.

Over the years, Geo-Studio has evolved into a comprehensive suite of software tools that are widely used by geotechnical engineers, researchers, and students around the world. The software is known for its user-friendly interface, powerful modeling capabilities, and accurate analysis results. Over the period the software package is evolving and released new version in 2021 (‘SLOPE Modeling.pdf’,2021-2024).

For slope stability analysis Slope/W is generally used that implement the Limit Equilibrium method for computing the Factory of Safety (FoS) of the earth slopes. The the model uses the geotechnical principles which involved in the analysis and the final judgment is necessary to ensure that actual soil properties are used to find the FOS. The model primerely uses the soil unit weight (ϒ), Soil cohesion C and soil internal anagle of frinction (Φ) to assess the slope stability.

3.10.1 Limit Equilibrium Method (LE)

The most widely used approach is Limit Equilibrium for solving geotechnical engineering problems like slope stability failures . The limit Equilibrium method requires criteria of Mohr Coulomb where the material failure is on account of the combination of the maximum normal stress and maximum shear stress.. The principle of Mohr Coulomb criteria is slope stability by comparison of the forces causing failure against resisting forces .With the help of static equilibrium equation FOS can be analyzed. The basic assumption of the failure is that failure occurs by sliding of mass or block along the slip surface (Bishop, 1955).

3.10.2 Morgenstern-Price Method

This method was generated by N.R. Morgenstern, E. Spencer, which consider not only the normal and tangential equilibrium but also the moment equilibrium for each slice in circular and non-circular slip surfaces. It is solved for the factor of safety using the summation of forces tangential and normal to the base of a slice and the summation of moments about the center of the base of each slice. The equations were written for a slice of infinitesimal thickness. The Combination of Moment and Force equilibrium and a modified numerical technique of Newton Raphson was used to solve for the factor of safety satisfying force and moment equilibrium. The requirement of solution an self made assumption regarding the direction of the resultant of the interslice shear and normal forces (Bishop, 1955).

The factored pullout resistance FPR per length of grouted section or nail behind the slip surface is calculated from the specified pullout resistance PR as

$$\boldsymbol{FPR = \frac{PR(\pi D)}{RRF(S)FS}} \text{..} \mathbf{6}$$

The pullout force (*PF*) that could be applied to the free body is calculated as

$$\boldsymbol{PF = FPR(1)} \text{ ....} \mathbf{7}$$

where l is the length of the grouted section or nail behind the slip surface. The maximum pullout force must not exceed the factored tensile capacity

FTC:

$$\mathbf{FTC} = \frac{\mathbf{TC}}{\boldsymbol{RF(S)FS}} \text{..............................} \mathbf{8}$$

where the factor of safety FS is only included if the “F of S Dependent” option is selected to be “Yes”. The pullout force that is applied to the free body is the lesser of PF or FTC. These equations make it apparent that the reduction factors should generally be specified as 1.0 if the “F of S Dependent” option is selected to be “Yes” (Bishop, 1955).

3.10.3 Slope/W analysis of Firfiredada soil with Bishop Slice Method

In the 1950's Professor Bishop at Imperial College in London devised a method which included interslice normal forces, but ignored the interslice shear forces. Bishop developed an equation for the normal at the slice base by summing slice forces in the vertical direction. The consequence of this is that the base normal becomes a function of the factor of safety. This in turn makes the factor of safety equation nonlinear (that is, FOS appears on both sides of the equation) and an iterative procedure is consequently required to compute the factor of safety('SLOPE Modeling.pdf', no date a). A simple form of the Bishop's Simplified factor of safety equation in the absence of any pore-water pressure is:

$$\boldsymbol{Fs} = \frac{1}{\sum W \sin\alpha} \sum \frac{c\beta + w\tan\varphi - \frac{c\beta}{Fs}\sin\alpha\tan\varphi}{m_a} \text{.........................9}$$

FOS is on both sides of the equation as noted above. The equation is not unlike the Ordinary factor of safety equation except for the ma term, which is defined as:

$$m_a = \cos\alpha + \frac{\sin\alpha\tan\varphi}{FS} \text{.......................................10}$$

To solve for the Bishop's Simplified factor of safety, it is necessary to start with a guess for FOS. In SLOPE/W, the initial guess is taken as the Ordinary factor of safety. The initial guess for FOS is used to compute mα and then a new FOS is computed. Next the new FOS is used to compute mα and then another new FOS is computed. The procedure is repeated until the last computed FOS is within a specified tolerance of the previous FOS. Fortunately, usually it only takes a few iterations to reach a converged solution.

Now if we examine the slice free body diagrams and forces polygons for the same slices as for the Ordinary method above, we see a marked difference (Figure 3-9). The force polygon closure is now fairly good with the addition of the interslice normal forces. There are no interslice shear forces, as assumed by Bishop, but the interslice normal forces are included.('SLOPE Modeling', 2023)

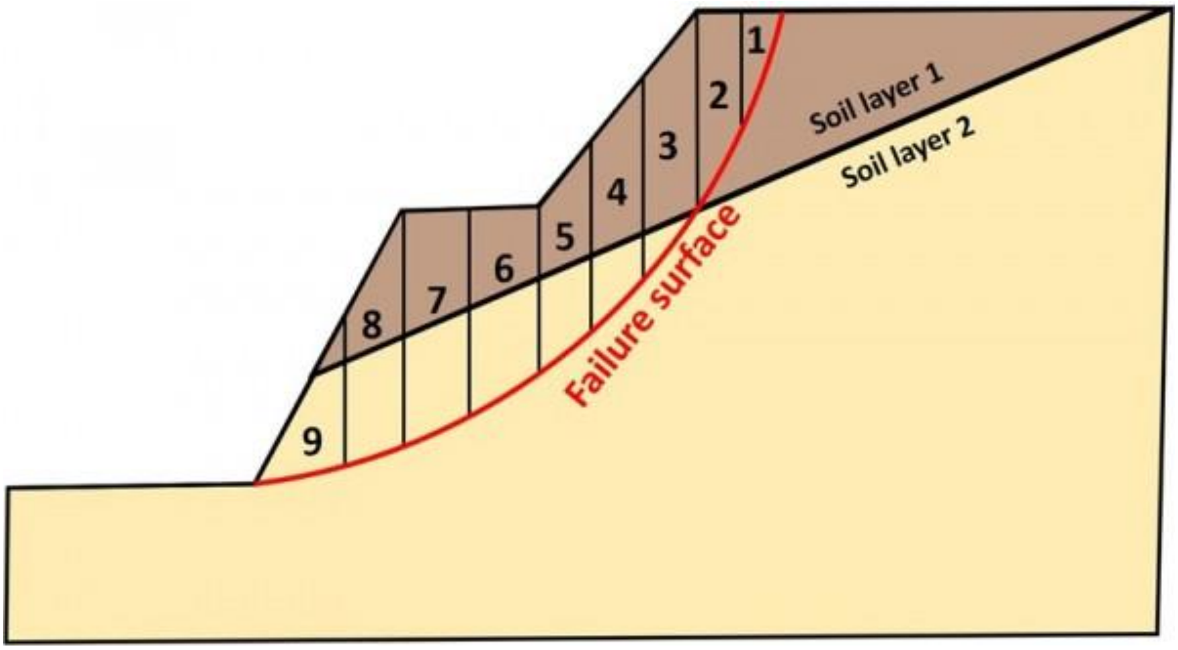

Figure 3-17: An example of slice division for a model with more than one soil layer and a complex slope geometry.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Results

4.1.1 Geotechnical properties of soil

The results of physical properties of soil samples collected from various location on the terrain are presented in Table 4-1 given below. Natural moisture content of the soil varies from a minimum value of 9.64 % to a maximum value of 19.90%. The share stress on selected samples shows the values in the range of 51.3kN/m^2 to 118.8kN/m^2. Specific Gravity value range 2.42 to 2.62, soil internal angle of friction is varying from 28.4 to 34 degrees (~ 30) degrees) and C value range (17 -24)kN/m^2 Similarly, soil texture is mostly Silty-Clay.

Table 4-1: Test results of Physical Parameter of Soil sample after plantation

Sample No.	Description (USCS Group Name)	NMC (%)	Particle Size Distribution			Specific Gravity	Directc shear	
			Slit& Clay %)	Sand(%)	Gravl (%)		C (kN/m2)	φ
Top soil 1	Well Graded Gravelly Sand with silt	14.5	23.01	51.06	25.93	2.62	17.6	34.0
Top soil 2	Well Graded Gravelly Sand with silt,	9.6	23.48	64.51	12.01	2.58	20.9	32.4
Top soil 3	Poorly Graded Sand With Silt	14.7	1.00	80.41	18.59	2.55	24.5	28.4
Top soil 4	Poorly Graded Sand With Silt	12.0	2.76	59.43	37.81	2.56	21.6	29.8
Top soil 5	Poorly Graded Sand With Silt	15.7	9.87	90.00	0.13	2.42	29.9	29.0
Top soil 6	Poorly Graded Sand With Silt	19.9	4.45	76.49	19.06	2.41	24.3	30.7

The results of cohesion (c) value compare the before and after vetiver plantations as shown in table 4-2 as below.

Table 4-2: Test Results of Cohesion (c) Value of Before and After Vetiver Plantations

Sample No.	C values of after plantations (kN/m2)	C values of before plantations (kN/m2)
Sample 1	17.6	2.8
Sample 2	20.9	6.1
Sample 3	24.5	9.7
Sample 4	21.6	6.8
Sample 5	29.9	15.1
Sample 6	24.3	9.5

Table 4-3: Comparision of Soil Cohesion before plantations of Vetiver Plant Species

Vetiver Plant						
Parameters	**Sample 1**	**Sample 2**	**Sample 3**	**Sample 4**	**Sample 5**	**Sample 6**
Φ (°)	34.02	32.4	28.37	29.85	28.96	30.71
Cs (kN/m^2)	2.8	6.1	9.7	6.8	15.1	9.5
Vetiver (Cr)	14.08	14.08	14.08	14.08	14.08	14.08
C=Cs+Cr	16.88	20.18	23.78	20.88	29.18	23.58

Here initial value of soil parameters Φ (28-34°), and C_s of different soil (2-16) shown in above table and adding vetiver roots cohesion (Cr) than new cohesion value indicate (C) as above table.

4.1.2 Mapping of Landslide Slope

The slope was mapped using the UAV/Drone and visual inspection. With the data obtained the slope inventory was prepared.Terrain was prepared form the DTM accordingly cross-sectional profile of the terrain was constructed and the landslide alignment was overlaid

Figure 4-18: The Digital-photo of the study area shows Newly plan constructed to mitigate the hazard

To export the ground profile data on Firfire Dada through GIS, begin by loading the elevation data or ground profile information into GIS software. Navigate to the Firfire Dada on the map, and using GIS tools, whether it's a point, line, or polygon representing the ground profile. Access the export functionality in the GIS software, choosing the desired file format such as shapefile, GeoTIFF. Using GIS software, such as ArcGIS or to expertly analyze the ground profile of Firfire Dada involves several steps. First, the elevation or ground profile data for the area is loaded into the GIS platform. Then, Firfire Dada is located on the map, and the desired ground profile area is selected using GIS tools. Next, the user exports the selected ground profile data, choosing the appropriate file format and output location. Finally, the exported data is reviewed to ensure accuracy, providing valuable insights into the terrain characteristics of Firfire Dada for various applications, including land use planning, environmental assessment, and infrastructure development.

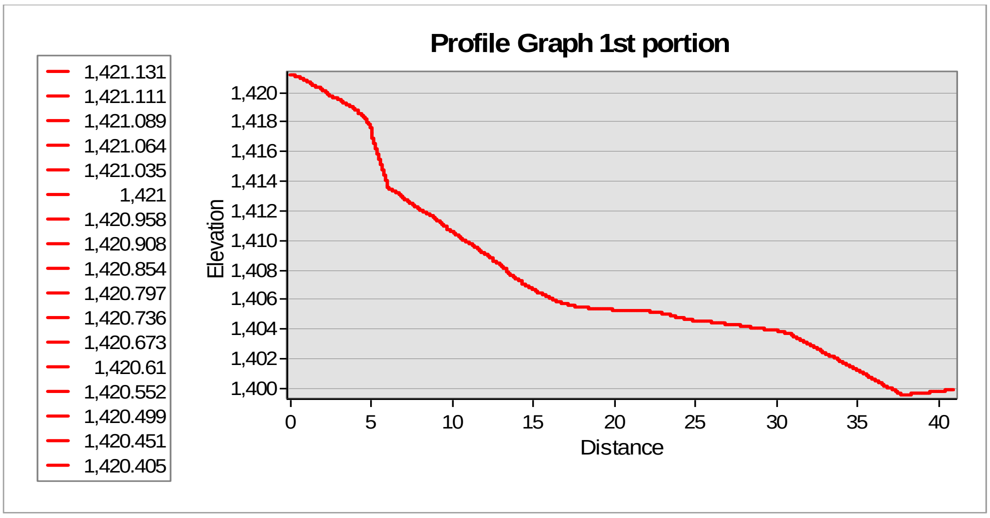

Figure 4-19: Geographic Profile on Firfiredada 1St Portion

The above graph represents the geographic profile graph of 1st portion of study area. The vertical column represents the elevation from1400m to 1430m and horizontal column represent the horizontal distance varaying from 0m to 40m. This profile was extracted from DTM using arc GIS.

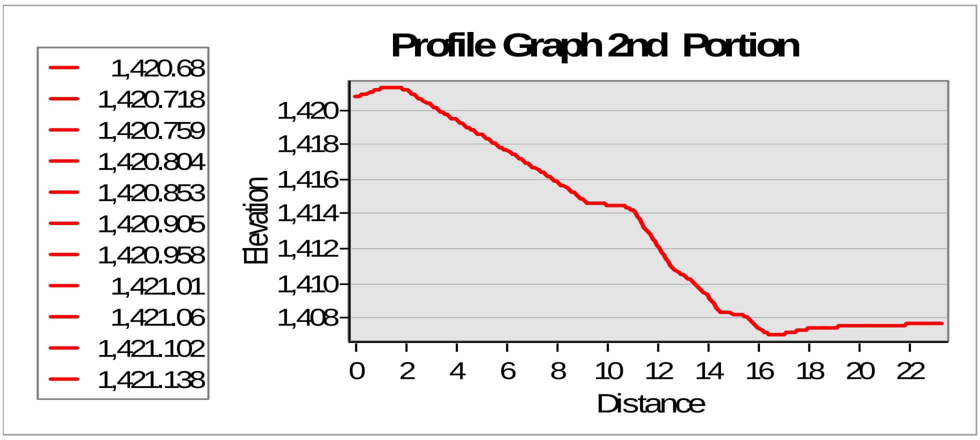

Figure 4-3 : Geographic Profile on Firfiredada 2nd Portion

Similarly, The above graph represents the geographic profile graph of 2st portion of study area. The vertical column represents the elevation from1400m to 1430m and horizontal column represent the horizontal distance varaying from 0m to 40m. This profile was extracted from DTM using arc GIS.

4.1.3 Modelling of Slope Stability with out root cohesion (Before) plantations

The stability model was implemented for the Single profiles on the Firfiredada (Figure 4-5) Before root cohesion depicted that the slope has FoS less than 1 (i. e. o.535) meaning that the slope is unstable.

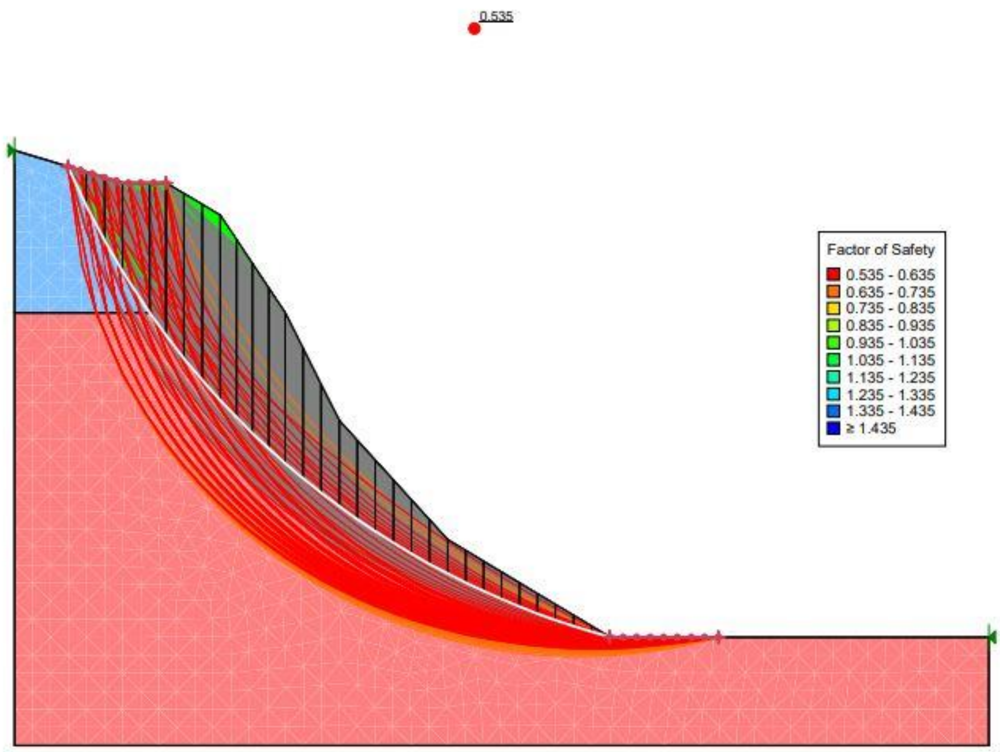

Figure 4-4 :-. Limit Equilibrium Analysis (FoS) on Firfire Dada of the slope profile,(note the FoS is less than 1).

4.1.4 Free body diagram and force polygon for the Morgenstern-Price before root cohesion

Examining the free body diagrams of the slice and forces polygons for the same slice as for the Morgenstern-Price method, it can be see a marked difference (Figure 4-5). The force polygon closure is now fairly good with the addition of the interslice normal forces. There are no interslice shear forces, as assumed by Bishop, but the interslice normal forces are included. In a factor of safety versus lambda plot, as in Figure 4-5, the Bishop's Simplified factor of safety falls on the moment equilibrium curve where lambda is zero (*FS* = 0.535).

Recall that

$$\boldsymbol{X} = \mathbf{E}\boldsymbol{\lambda}\boldsymbol{f}(\boldsymbol{x})\ldots\ldots\ldots\ldots\ldots\ldots\ldots\mathbf{11}$$

The Morgenstern-Price method without considering root cohesion, a comparison of free body diagrams and force polygons reveals significant distinctions. While the force polygon closure notably improves with the incorporation of interslice normal forces, unlike Bishop's assumption, interslice shear forces are absent. Consequently, in a factor of safety versus lambda plot, Bishop's Simplified factor of safety aligns with the moment equilibrium curve at lambda zero, resulting in a factor of safety of 0.535.

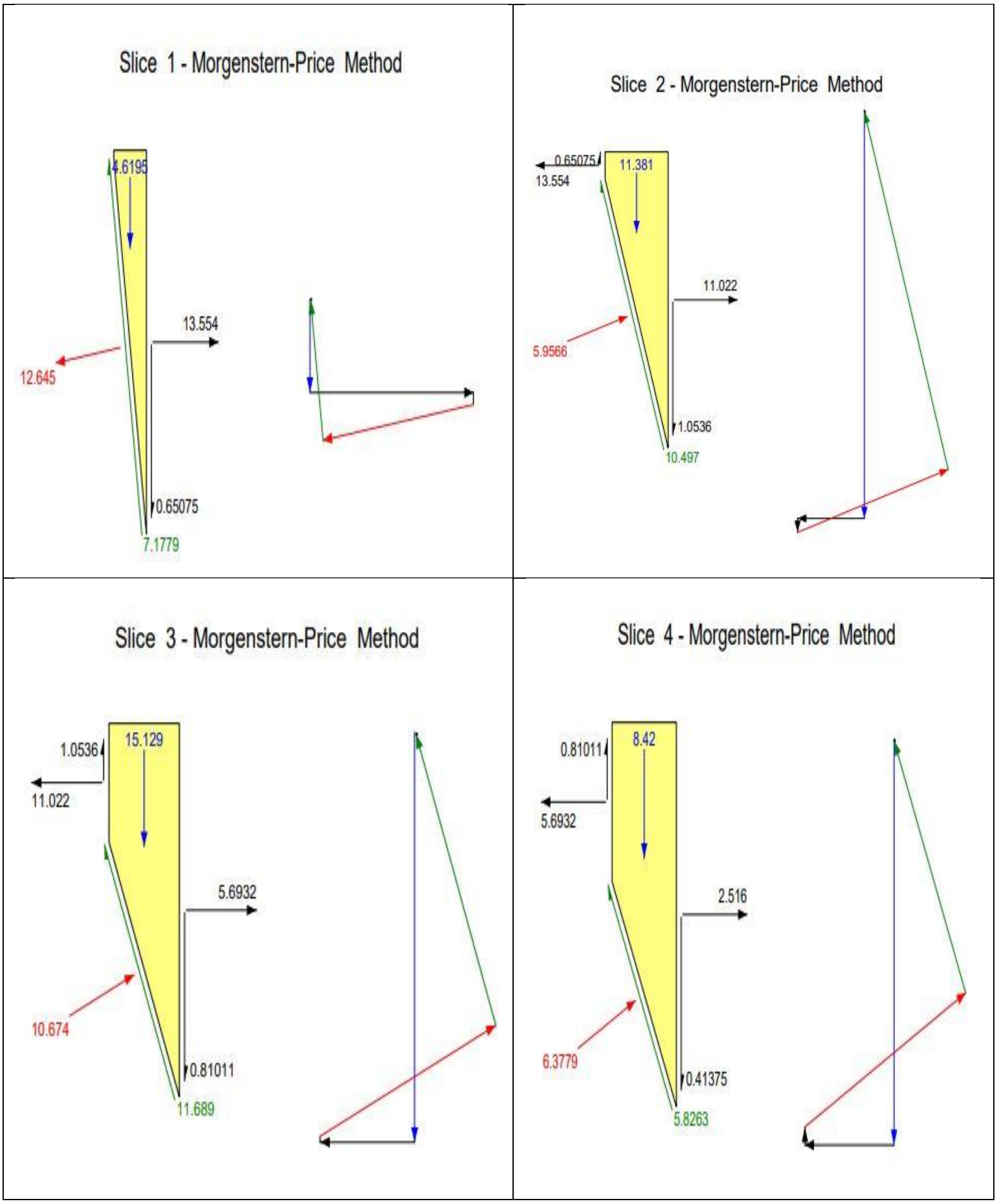

Figure 4-5 : Example of Free body diagram and force polygon for the before root cohesion of different Slices - Morgenstern-Price method

4.1.5 Modelling of Slope Stability with root (After plantation) cohesion

The stability model was implemented for the Single profiles on the Firfire Danda (Figure 4-6) with root cohesion depicted that the slope has FoS is more than 1 (i. e. 1.173) meaning that the slope is stable.

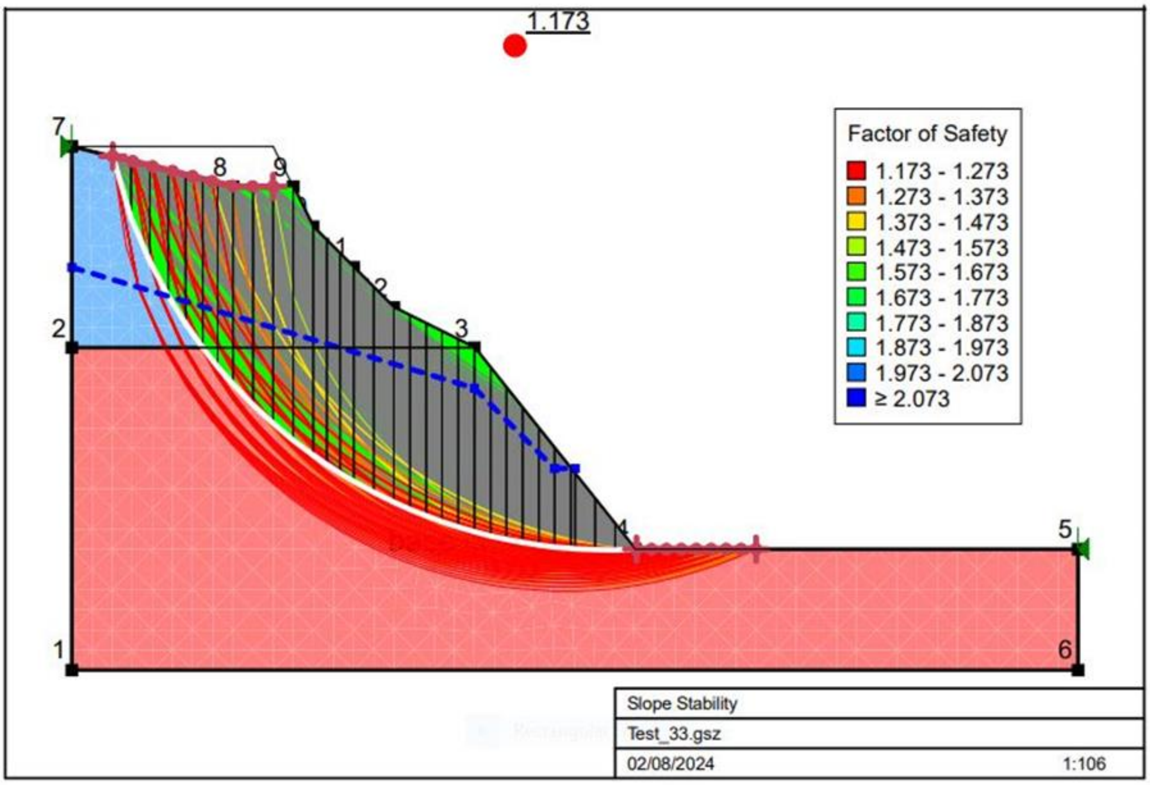

Figure 4-6 : Limit Equilibrium Analysis (FoS) on Firfire Dada of the slope profile,(note the FoS is more than 1).

4.1.6 Free body diagram and force polygon for the Morgenstern-Price After plantation root cohesion

Now if we examine the slice free body diagrams and forces polygons for the same slices as for the Morgenstern-Price method, we see a marked difference (Figure 4-7). The force polygon closure is now fairly good with the addition of the interslice normal forces. There are no interslice shear forces, as assumed by Bishop, but the interslice normal forces are included.

In a factor of safety versus lambda plot, as in Figure 4-7, the Bishop's Simplified factor of safety falls on the moment equilibrium curve where lambda is zero (*FS* = 1.173).

where Bishop's Simplified factor of safety aligns with the moment equilibrium curve at lambda zero, resulting in a factor of safety of 1.173. This factor is determined by the equation X = Eλf(x), emphasizing the nuanced interplay between various factors in slope stability analysis.

$$X = E\lambda f(x)$$

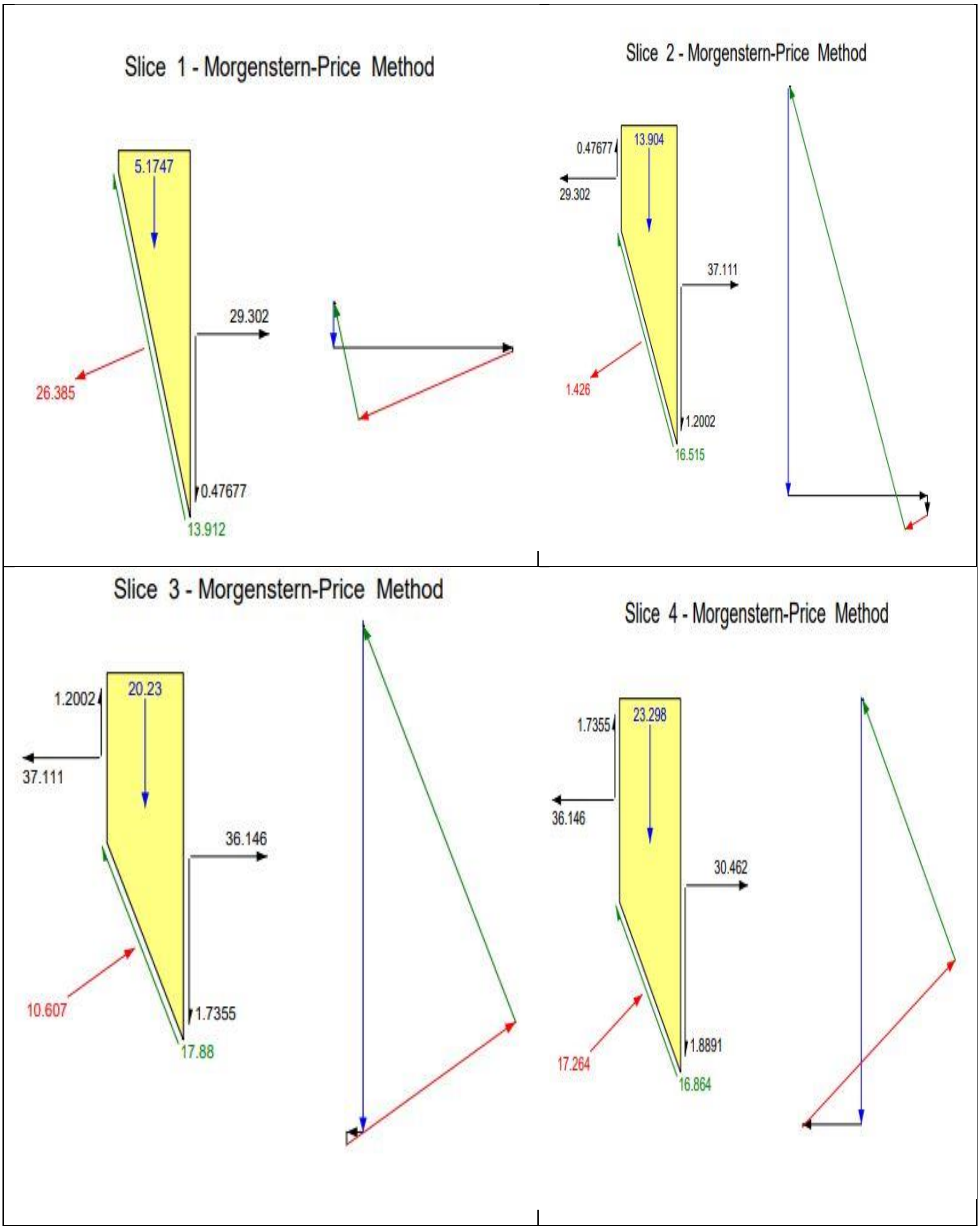

Figure 4-7 : Free body diagram and force polygon for the after root cohesion of different Slices - Morgenstern-Price method

4.1.7 Root cohesion and its Important

Root cohesion refers to the binding strength provided by plant roots within soil, which plays a crucial role in slope stability and erosion control. Here's why root cohesion is important and how it has been addressed by

1. **Slope Stability:** Plant roots mechanically reinforce the soil, increasing its shear strength and resistance to erosion. Root networks act like a natural reinforcement system, anchoring soil particles and reducing the likelihood of slope failure or landslides, especially on steep slopes or in areas with shallow soils.
2. **Erosion Control:** Root systems help to stabilize soil by reducing surface runoff and enhancing infiltration, thereby minimizing soil erosion caused by water flow. The intertwining of roots creates a network that binds soil particles together, preventing them from being washed away by rainwater or surface runoff.
3. **Vegetative Cover:** Vegetation provides surface cover that protects soil from direct exposure to erosive forces such as rainfall and wind. In addition to root cohesion, the presence of vegetation helps to intercept rainfall, reduce soil surface sealing, and promote soil moisture retention, all of which contribute to improved slope stability and erosion control.

Table 4-4: Different aspect of Stability Model before and after Root Cohesion

Aspect	**Before Root Cohesion**	**After Root Cohesion**
Factor of Safety (FoS)	Low	High
Slope Stability	Unstable	Stable
Risk of Landslides	High	Reduced
Soil Erosion	Pronounced	Minimized
Vegetation Stability	Vulnerable	Reinforced
Surface Runoff	High	Low
Soil Moisture Retention	Limited	Enhanced
Human Infrastructure	At Risk	Protected
Maintenance Requirement	High	Low

Before root cohesion, the slope stability was low, resulting in unstable conditions prone to landslides, pronounced soil erosion, and vulnerability of vegetation. Soil moisture retention and nutrient cycling were limited, impacting biodiversity support and putting human infrastructure at risk, requiring high maintenance. However, after root cohesion, significant improvements are observed across all aspects. Slope stability becomes high, reducing the risk of landslides and minimizing soil erosion. Vegetation stability is reinforced, enhancing soil moisture retention and nutrient cycling, leading to improved biodiversity support.

Human infrastructure is better protected, requiring lower maintenance efforts to maintain stability and safety

In sufurface runoff also stability models evaluate soil erosion and runoff potential, considering conditions before and after interventions like root cohesion, such as species or plantation. Before such measures, there's a higher risk of erosion due to soil detachment and increased surface runoff, as lack of vegetation provides fewer barriers to slow water flow, reducing soil stability. After root cohesion, soil stability improves as roots bind particles, reducing runoff volume and enhancing infiltration, thus decreasing erosion risk.

The key difference between the two models lies in the consideration of root cohesion the pre-root cohesion model evaluates stability without accounting for root reinforcement, while the post-root cohesion model incorporates the additional strength provided by roots, offering a more accurate assessment of slope stability in landslide areas.

4.2 Discussion

Assessing the plant root contribution in slope stability is a crucial aspect of understanding and mitigating landslide risks, especially in areas prone to slope failure. The study of the Firfire Dada landslide offers valuable insights into how plant species contributes in slope stability.

Firstly, identifying the types of plant species present in the area and their root characteristics is essential. Different plant species have varying root depths, densities, and tensile strengths, all of which influence their effectiveness in stabilizing slopes. Deep-rooted plants, such as trees and shrubs, tend to provide more significant stability compared to shallow-rooted grasses or herbs.

Secondly, assessing the distribution and density of Specisis across the slope helps in determining the overall impact of plant roots on slope stability. Areas with dense species cover may exhibit better soil cohesion and resistance to erosion, thus reducing the likelihood of landslides.

Furthermore, studying the soil properties, including its texture, composition, and moisture content, in conjunction with plant species analysis, provides a comprehensive understanding of slope stability dynamics. Plant roots not only mechanically reinforce the soil but also play a crucial role in regulating soil moisture through transpiration, which affects soil shear strength.

In conclusion, studying the plant root contribution in slope stability, as exemplified by the Firfire Dada landslide in Thecho, Godawari Municipality, Lalitpur District, requires a multidisciplinary approach integrating ecological, geological, and engineering principles.

Likewise, (Johnson and Wilcock, 2002) A simple stability model evaluated the relative influences of soil moisture changes and root strength decline on slope stability. The findings suggest that in areas with shallow soil depth (<0.7 m), the loss of root strength plays a significant, possibly dominant role in slope instability. In deeper soils (>1 m), changes in pore pressure have a greater influence on stability. Landslides are most likely when decline reaches a certain stage, approximately 50 years after tree death, where most of the root strength is lost, and secondary growth root strength has yet to develop.

(De Baets *et al.*, 2008) Root reinforcement effects of 25 Mediterranean plant species were evaluated using a model developed by root distribution data were collected in SE-Spain, and laboratory tests were conducted to determine root tensile strength. Results indicated variations in root strength among different plant species, with shrubs like Salsola genistoides and Atriplex halimus exhibiting the strongest roots. Grasses such as Brachypodium retusum showed significant soil reinforcement effects. Additionally, the rush Juncus acutus provided maximum soil reinforcement. While Wu's model may overestimate root cohesion values, the study's findings are valuable for ranking species according to their potential for soil reinforcement. This research underscores the importance of considering both above-ground and below-ground biomass in erosion control strategies in Mediterranean environments.

In paper Sidle, (1991) emphasizes the crucial role of plant root systems in maintaining stability on steep, vegetated slopes prone to shallow landslides. Two functional relationships are proposed to simulate the effects of vegetation removal on root cohesion: decay of existing roots and regrowth of new vegetation. The developed root strength model is adaptable to various silvicultural systems such as clearcutting, partial cutting, shelterwood cutting, and thinning Specifically, shorter clearcut or partial cut rotations may lead to a steady decline in root strength, while longer intervals between shelterwood cuttings can promote greater rooting strength.

Results are consistent with Hydrometer analysis provide the foundation for understanding soil properties, which in turn influence root development, shear strength, and moisture content.Root reinforcement contributes to the shear strength of soil, impacting the results of direct shear tests and factor of safety calculations.Natural moisture content affects both soil properties and root growth, thereby influencing soil stability and erosion control.Specific gravity influences soil density and porosity, which indirectly affect root penetration and soil reinforcement.The effectiveness of vegetation in stabilizing soil (as indicated by root area ratio, root tensile strength, and species-specific KPI) directly impacts slope stability and erosion control, ultimately affecting factor of safety and overall stability assessments.

CHAPTER 5
CONCLUSIONS AND RECOMMENDATION

5.1 Conclusions

Geotechnical parameters of soils of the research site was obtained either from field surveys or laboratory analyses and the topographical attributes such as slope were obtained from high-resolution orthophoto maps (DTM) derived from drones. Soil physical properties are crucial in slope stability such as soil cohesion, internal angle of friction, unit weight, soil texture. Soil-cohesion is further contributed by plant roots known as root cohesion. Small variation in soil cohesion can have considerable implection in slope stability.

The root systems of plants effectively bind soil particles, increasing cohesion, and enhancing mechanical strength, thereby fortifying slopes against erosive forces. The root cohesion of the vetiver plant is essential for soil conservation, erosion control, and slope stabilization, making it a valuable tool in sustainable land management practices. Through careful analysis of detailed geotechnical and root characteristics, the study demonstrates that plant roots act as natural reinforcement, binding soil particles, and enhancing slope stability. Furthermore, this study highlights that Slope Stability Analysis was performed using the SLOPE/W package of Geo-studio software to better understand the Factor of Safety (FoS) under different conditions. The model required geotechnical parameters such as soil cohesion, angle of friction, soil profile, soil depth, and the presence of groundwater, among others.

This research underscores the importance of comprehensive considering of soil physical properties in slope management and engineering practices to mitigate the risks of slope failure and associated hazards. By integrating advanced monitoring techniques and predictive models, practitioners can enhance their ability to assess and manage slope stability, thereby promoting safer and more sustainable infrastructure development in vulnerable areas. It is imperative to incorporate these findings into land-use planning and environmental management policies to minimize the risk of landslides and protect affected houses.

5.2 Recommendations

- Further research is to be carried out to better understand the plant root cohesion on slope stability in different physio-climatic region to better understand the plant root contribution in slope stability.
- Collaborate with local communities to raise awareness about the importance of preserving natural Plant species for slope stability and disaster risk reduction.
- To explore innovative techniques such as bioengineering and eco-engineering to enhance slope stabilization using native plant species.
- Further researcs is to be carried out by assess the sensitivity anaiysis of the slope stability parameters.

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ANNEX I: GENERAL INFORMATION PEOPLE'S PERCEPTION ON FIRFIRE DANDA LANDSLIDE ,TECHO,12,GODAWARI MUNICIPALITY

Name of respondent: Sraban Shrestha

Age: 45

Gender:Male

Occupation:Journalist

1. How long have you been living in Thecho?
    a. Less than 1 year
    b. 1-5 years
    c. 6-10 years
    d. More than 10 years
2. Were you aware of the Firfire Dada Landslide before participating in this survey?
    a. Yes
    b. No
3. How would you describe your level of concern regarding landslide risks in Firfire dada Thecho?
    a. Very concerned
    b. Somewhat concerned
    c. Neutral
    d. Not very concerned
    e. Not concerned at al
4. Have you or anyone you know personally experienced the effects of the Firfire Dada Landslide?
    a. Yes
    b. No
5. How satisfied are you with the government's response to the Firfire Dada Landslide?
    a. Very satisfied
    b. Somewhat satisfied
    c. Neutral
    d. Somewhat dissatisfied

e. Very dissatisfied

6. Do you think the community has been adequately informed about landslide risks and safety measures?
   a. Yes
   b. No
   c. Not sure
7. Are there any measures you believe could be taken to reduce the risk of landslides in Thecho?
8. How prepared do you feel personally in the event of another landslide in your area?
   a. Very prepared
   b. Somewhat prepared
   c. Neutral
   d. Not very prepared
   e. Not prepared at all
9. What additional information or support do you think the community needs to better understand and address landslide risks?
10. Is there any other information or feedback you would like to provide regarding slope stability, landslides, or vegetation management in your area?

ANNEX II: PHOTOGRAPHS

Photo Plate-1: Firfire dada Landslide Site photo

Photo Plate-2: : Firfire dada Landslide Site photo

Photo Plate-3: Soil sample collection time Photo

Photo Plate-4: Soil sample collection time Photo

Photo Plate-5:Arranging the different samples

Photo Plate -6: Sieve analysis of soil work on Lab

	
Photo Plate -7: Hydrometer Anlysis Test Work	**Photo Plate -8: Dirct share Test Work**

Soil Sample Photographs

		
Photo plate - 9: Sample 1	**Photo plate – 10 : Sample 2**	**Photo plate – 11 : Sample 3**
		
Photo plate - 12: Sample 4	**Photo plate - 13: Sample 5**	**Photo plate - 14: Sample 6**

ANNEX III: RESULTS OF LEM-FOS SLOPE STABILITY (WITH AND WITH OUT ROOTS COHESION)