AN INTEGRATED APPROACH TO SLOPE STABILITY ANALYSIS: A CASE STUDY OF THE HUMARRI LANDSLIDE IN NAGAR

Moadat Hussain

2020-KIU-BS2128

Hussain Shah

2020-KIU-BS2125

Department of Earth Science Karakorum International University, Gilgit

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بسم الله الرحمن الرحيم

IN THE NAME OF ALLAH WHO IS THE MOST BENEFICIENT AND MERCIFUL

CERTIFICATION

This is to certify that the thesis entitled An Integrated Approach to Slope Stability Analysis **"A Case Study of the Humarri Landslide in Nagar**." submitted by **Moadat Hussain (2020-KIU-BS2128) and Hussain Shah (2020-KIU-BS2125)** in fulfillment of the requirements for the award of Bachelor of Science in Geology at the Karakoram International University Gilgit. is authentic work carried out by me under my supervision and guidance. To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other university/Institute for the award of any degree.

Project Supervisor ______________________

Dr. Asghar Khan

Chairperson/Chairman/HOD ______________________

Dr. Sher Sultan Baig

External Examiner ______________________

Prof. Rahat Hussain

DEDICATION

Allah Almighty our creator, our strong pillar and master, the greatest messenger Muhammad (PBUH), and his revered Ahl-e-Bait (A.S). Our beloved parents and esteemed teachers, The KIU; Our second magnificent home; Our beloved siblings, who constantly lead with the light of hope and support and always stand by us when things look bleak, our friends who encourage and support us and all the people in life who touch our heart.

DECLARATION

We hereby declare that this thesis is a presentation of our work and has not been submitted anywhere for any award. We also warrant, that we have not received outside assistance or were involved in the external contributions, if received/involved we will acknowledge in a written statement to authorities, otherwise, we will be liable for the cancellation of our thesis thereby the degree that will be awarded.

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ACKNOWLEGMENTS

Alhamdulillah!

Together, with our hearts filled with profound gratitude, we first and foremost raise our hands in thanks to Allah Almighty, the Most Gracious, and the Most Merciful. His omnipotent grace, boundless blessings, and undying guidance have illuminated our academic and personal paths. We remain humbled by His benevolence and seek His pleasure in our endeavors. Furthermore, our reverence is directed to the Holy Prophet Muhammad and his progeny (peace be upon them), whose teachings and way of life serve as an unerring compass for humanity.

Our journey to this milestone would have remained incomplete without the anchor of our parents' unwavering love, faith, and countless sacrifices. To them, we owe our very essence and our deepest gratitude. Their dreams became our mission and their prayers our armor. Equally, our siblings have been silent cheerleaders, providing relentless support, encouragement, and prayers at every twist and turn.

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We are eternally grateful for all these blessings, seen and unseen, spoken and silent. This thesis stands as a testament to a collective effort, and while penned by our hands, it carries the imprints of many hearts.

Moadat Hussain

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ABSTRACT

Landslides are dangerous natural events that can cause serious damage to buildings and put lives at risk, especially in areas with complex ground conditions. It is important to understand and manage slope stability. The focus of the review is on the challenges in the Humarri region. The techniques covered are traditional, like the limit equilibrium method, and newer ones, like finite element analysis. Slope stability can be affected by factors like soil properties and water content. It stresses the importance of combining real-world data with advanced modeling for more accurate predictions, as it looks at recent advances in stabilization methods. The goal of this review is to encourage more in-depth studies that take into account geological, hydrological, and soil related factors in order to improve safety in landslide prone areas.

CHAPTER 1

INTRODUCTION

1.1 Study Area

The Nagar region exhibits a complex geological structure that heightens the risk of landslides, posing significant threats to safety and property. The predominant soil type is sandy silt, which tends to lose stability when saturated. Understanding the elements that influence slope stability, such as soil composition and climatic conditions is crucial. Researchers employ a range of methodologies, from traditional to contemporary, to assess slope stability. Findings from these investigations can inform

Figure 1. Sample collection during field

protective measures. Implementing monitoring systems is vital for safeguarding both infrastructure and residents in this vulnerable area.

1.2 Significance of study

Investigating slope stability in Hamari Nagar is essential for recognizing and mitigating landslide hazards that endanger lives and assets. By gaining insights into the geological characteristics of the region, this research can facilitate the safe construction of buildings and infrastructure. It also contributes to the development of early warning systems and emergency preparedness plans. Moreover, the study supports land-use planning and enhances community awareness regarding safety protocols, ultimately making Humari Nagar a safer living environment.

1.3 Research Gape

1.3.1 Limit Equilibrium Methods (LEM):

Techniques such as Fellenius, Bishop's Simplified, and Janbu's Method are commonly utilized to determine the Factor of Safety (FoS) for slopes under varying conditions, including soil strength, load, and water pressure.

1.3.2 Finite Element Analysis (FEA):

More sophisticated approaches employ finite element modeling to replicate slope behavior under intricate conditions, taking into account diverse soil characteristics, groundwater movement, and seismic activity.

1.3.3 Seismic Slope Stability:

Numerous studies focus on how seismic events affect slope stability. Researchers utilize dynamic load models and safety factor analyses in these contexts

1.3.4 Soil and Geotechnical Surveys:

Regular soil surveys and sample analyses are conducted to ascertain soil strength, cohesion, and friction angles, which are essential for precise slope stability assessments. Example of Slope Stability Research: To exemplify the types of investigations that can be undertaken, consider the following study in the broader field of slope stability.

1.4 Aims and Objectives

Examine the Influence of Slope Geometry on Stability:

This goal focuses on assessing how various geometric aspects of slopes—such as angle, height, and shape—impact stability and the likelihood of failure under different geological scenarios.

Conduct In-Depth Field Studies on Local Geology and Its Impact on Rock Slope Stability:

This objective emphasizes mapping local geological features, including rock types, structures, and discontinuities. It also involves determining the physical and mechanical properties of rock samples to evaluate their effects on rock slope stability.

Investigating the Correlation Between Peak Ground Acceleration (PGA) and Geotechnical Structure Responses:

This aim includes collecting and analyzing field data on PGAs and their effects on structural and soil behavior during past seismic events. It also seeks to formulate strategies to alleviate the negative impacts of high PGA on geotechnical structures, such as foundations, slopes, and retaining walls.

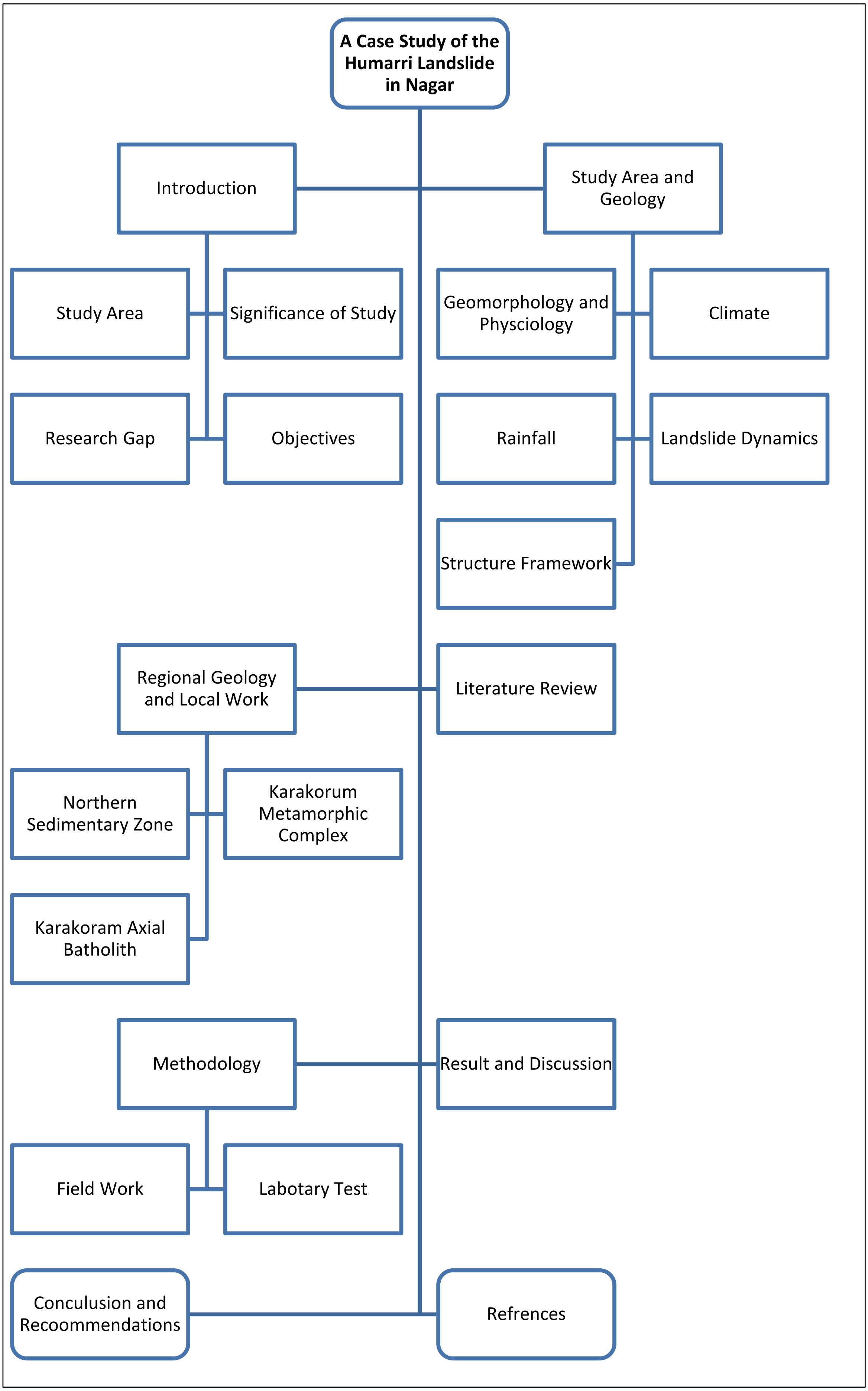


Figure 2. Research Desing

CHAPTER 2

STUDY AREA AND GEOLOGY

2.1 Study Area

The Humarri landslide is situated in the Nagar district, which features intricate topography and diverse geological conditions. The region is susceptible to landslides due to steep inclines, substantial rainfall, and varying soil types. The area encompasses multiple land uses, including agriculture, residential zones, and natural landscapes, necessitating an understanding of the factors that contribute to slope instability. The local climate, heavily influenced by monsoon rain, plays a significant role in the area's hydrology.

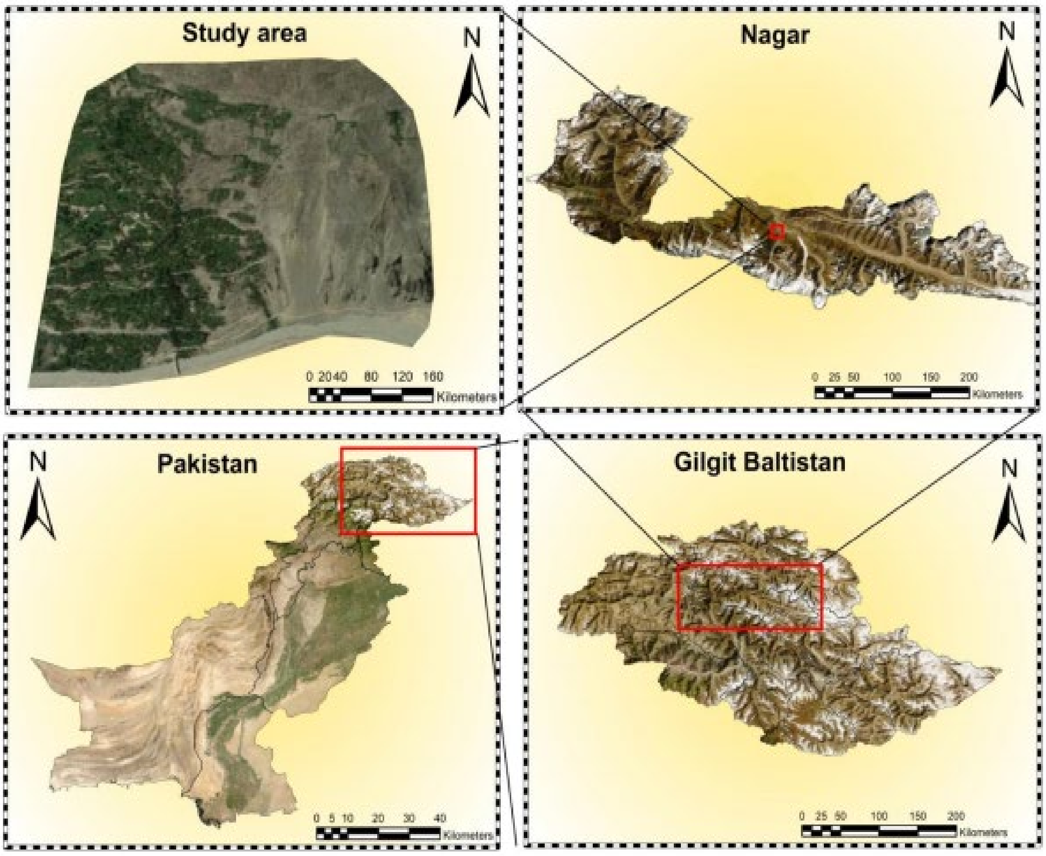


Figure 3. Map of Study Area

2.2 Geology

The geological makeup of the Humarri region primarily consists of sedimentary rocks, including sandstone, silt stone, and clay stone, often interspersed with alluvial deposits. The predominant soil type is sandy silt, which is prone to erosion and instability, particularly when saturated. Key geological characteristics include:

2.2.1 Soil Composition:

The soil is mainly sandy silt with varying cohesion and moisture levels, crucial for assessing slope stability.

2.2.2 Rock Formations:

The underlying sedimentary rock layers can affect slope mechanical behavior. Fractures and faults within these rocks may also contribute to landslide occurrences.

2.2.3 Hydrology:

The area experiences significant rainfall, which increases pore water pressure in the soil, potentially compromising slope stability. Understanding groundwater levels and their fluctuations is vital for predicting landslide risks. In summary, the interplay of geological factors, soil characteristics, and hydrological conditions in the Humarri area creates a complex environment that necessitates comprehensive investigation and analysis to effectively mitigate landslide risks.

2.3 Geomorphology and Physiology

The geomorphology of the Humarri region in Nagar is marked by a diverse and intricate landscape, including steep slopes, rolling hills, and complex drainage systems. The area displays notable elevation changes that contribute to its vulnerability to landslides, especially during heavy rainfall. The topography is shaped by both natural processes, such as erosion and sediment deposition, and human activities that alter the land surface. The presence of various landforms, including ridges and valleys, significantly influences the region's hydrological dynamics. Water runoff from elevated areas can lead to increased soil saturation, further destabilizing slopes. Additionally, drainage patterns are affected by the underlying geological formations, which consist of sedimentary rocks that can influence water flow and soil stability. Overall, the geomorphological features of Humarri Nagar create a unique environment that demands careful monitoring and management to mitigate landslide risks and ensure the safety of the local population and infrastructure. Understanding these geomorphological attributes is crucial for developing effective land-use planning and erosion control measures in the region.

2.4 Climate

The climate in the Humarri Nagar area significantly impacts the frequency of landslides and the stability of slopes. This region is marked by a temperate climate, which features noticeable seasonal changes, particularly during the monsoon season. The heavy rains associated with this period can lead to increased soil saturation, thereby elevating the risk of landslides. Typically, the monsoon brings intense rainfall over a brief time frame, causing rapid absorption of water and raising pore water pressure in the soil, which can undermine its shear strength. Furthermore, dry periods can result in soil drying out, reducing its cohesion and making slopes more vulnerable to collapse when subsequent rain occurs. Yearly temperature variations also influence soil moisture levels and can initiate freeze-thaw cycles that affect slope stability.

Moreover, climate change introduces further complications by potentially altering rainfall patterns, increasing the occurrence and severity of extreme weather events, and impacting groundwater levels, all of which may heighten the risk of landslides. Grasping the relationship between climate and landslide behavior is crucial for formulating effective risk management approaches and ensuring the safety of local communities.

2.5 Rainfall

Rainfall serves as a pivotal element in the dynamics of landslides within the Humarri Nagar region, as it has a direct impact on soil moisture levels and the stability of slopes. The area receives considerable precipitation, especially during the monsoon season, when heavy and sustained rainfall can quickly saturate the soil. This saturation raises pore water pressure, diminishing the effective stress in the soil and weakening its cohesion, which can trigger slope failures. The characteristics of rainfall events, such as their intensity and duration, are vital; sudden, heavy storms can lead to immediate landslides, while extended periods of rain can gradually weaken slopes over time. Additionally, the region's topography can amplify the effects of rainfall, as steep inclines may experience increased runoff, further destabilizing the soil. Understanding rainfall trends, including seasonal changes and potential shifts due to climate change, is critical for forecasting landslide occurrences and implementing effective monitoring and mitigation measures to safeguard at-risk areas and communities.

2.6 Landslide Dynamic

Landslide dynamics encompass the various processes and elements that lead to the initiation and movement of landslides, which are intricate natural events shaped by numerous geological, hydrological, and environmental factors. In the Humarri

Nagar area, the primary driving force behind landslide dynamics is gravity acting on slope materials, which is balanced by the natural shear strength of the soil and rock. Important considerations include the soil type, moisture levels, and vegetation presence, all of which play a significant role in slope stability. Intense rainfall, swift snowmelt, and seismic events can greatly elevate pore water pressure in the soil, diminishing its effective stress and causing a loss of cohesion. This is especially critical in regions with steep terrain, where the likelihood of slope failure increases. Additionally, human activities such as deforestation, construction, and changes in land use can destabilize slopes by disrupting natural drainage systems and heightening surface runoff. The ever-changing interactions among these factors can lead to sudden landslide occurrences with minimal warning, underscoring the importance of ongoing environmental monitoring. Gaining insight into these dynamics is vital for crafting effective risk assessment and management strategies aimed at lessening the impact of landslides on local communities and infrastructure.

2.7 Structure framework

The structural framework for assessing and managing landslide risks in the Humarri Nagar region adopts a thorough approach that combines various methodologies and data sources. It starts with geological and geotechnical evaluations to comprehend the properties of soil and rock that affect slope stability, including types of soil, shear strength, and cohesion, collected through field studies and laboratory analyses. A hydrological assessment is equally important, examining rainfall trends, groundwater levels, and drainage systems to understand how water interacts with the soil, particularly during heavy rainfall. Establishing a monitoring system that gathers real-time data on rainfall, soil moisture, and slope movements is crucial, utilizing technologies such as inclinometers and remote sensing. Sophisticated modeling techniques, including finite element methods (FEM), facilitate the simulation of slope behavior under various scenarios, aiding risk evaluation. Formulating and executing mitigation strategies, such as slope stabilization methods and drainage solutions, is essential for minimizing landslide risks, guided by insights from geological and hydrological evaluations. Engaging the community and providing education are key to raising awareness about landslide risks and preventive strategies, while integrating landslide risk management into land-use planning and policy makers to ensures that development activities account for potential hazards. Collectively, these elements form a comprehensive framework that bolsters the safety and resilience of communities in landslide - prone regions like Humarri Nagar.

2.8 Regional Geology:

The Karakoram block is a geological zone that runs from Afghanistan to western Tibet and is The Karakoram block is a significant geological region stretching from Afghanistan to western Tibet, measuring between 70 to 120 kilometers in width and extending 1400 kilometers in length. It is bordered to the north by the north Pamir fault, to the east by the Karakoram fault, and to the west by the Sarobi fault and the Shyok suture to the south. The Karakoram block is divided into three distinct units, which are from north to south:

1. Northern Sedimentary Zone
2. Karakoram Axial Batholith

3. Karakoram Metamorphic Com

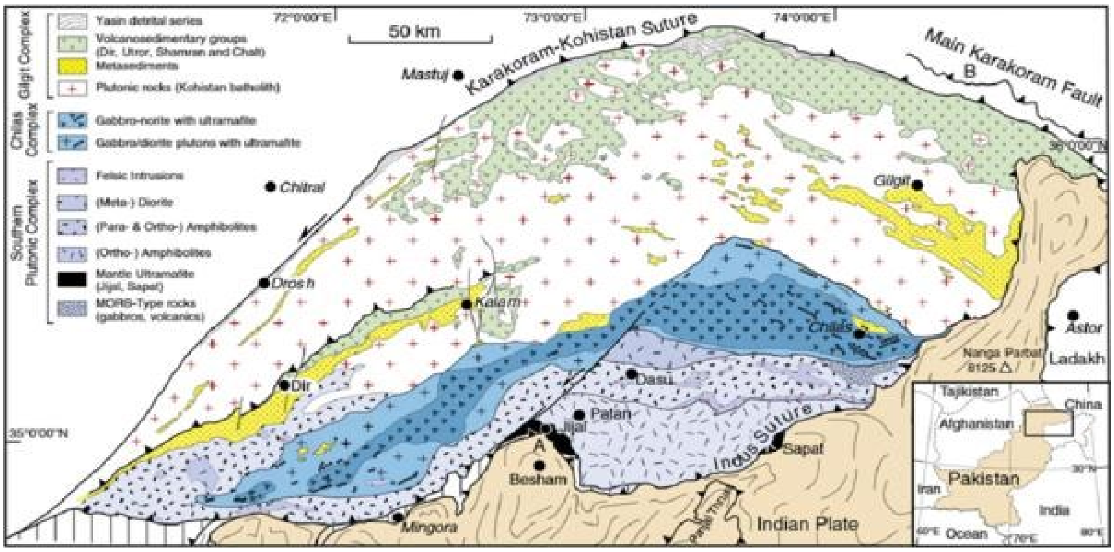


Figure 4. General geological map of the Karakoram Block (Peterson, 2019)

2.9 Northern Sedimentary Zone

The northern sedimentary zone represents the most northern section of the Karakoram block, characterized by a substantial 7-kilometer-thick sedimentary belt that overlays pre- Ordovician crystalline basement rocks. This belt extends from Shaksgam to Baroghil Pass and continues southward along the Yarkhun Valley, encompassing the upper Hunza and Chapursan valleys. The northernmost section of this zone exhibits tight folding, while the central area is structured as a monocline. Vertical faults, primarily strike-slips in nature, separate the thrust slabs. Within the upper Hunza region, three distinct tectonostratigraphic units are identified, divided by two significant faults, including an east-west reverse fault. The upper Hunza fault has thrust the southern Gujhal unit over the centrally positioned Sost unit, creating an anti-formal stack that is structurally overlain by the Misgar unit as it shifts northward across the northern fault. The North Karakoram Terrain contains sedimentary rocks from the Permian to Cretaceous periods, along with some Cretaceous intrusive. The sedimentary rocks in this northern terrain have experienced intricate and multiphase structural evolution. The strati graphic sequences in these tectonostratigraphic units are predominantly composed of i n t e r b e d d e d limestone, shale, and sandstone, dating from the Permian to Cretaceous periods. The structural framework shows various phases of folding, thrust imbrication, and late-stage wrench tectonics. Two significant deformation events are noted in the Mesozoic sedimentary rocks: the first occurred between the Lias and early Mid-Jurassic, while the second, linked to the welding of the Kohistan arc and the Karakoram microplate to Asia, took place during the Cretaceous and is associated with subduction-related magmatism in the Khunjerab-Trich Mir granitic belt. The northern Karakoram terrain documents a crustal block's evolution over 400 million years, primarily under marine conditions, with six main tectonostratigraphic cycles identified. Permian fossils from the northern sedimentary zone were uncovered by members of an Italian expedition to the Karakoram and Hindukush, who also created a geological sketch map of the upper Hunza Valley and identified six sedimentary formations, including the Misgar Slate, Kilik Formation, Gircha Formation, Passu Slate, and Gojal Dolomite. The Gircha Formation, situated between the Kilik Formation and the Gojal Dolomite, comprises a complex sequence of argillaceous, arenaceous, and calcareous beds, with argillaceous rocks making up approximately 85% of the total rock composition. The Garchi Formation, identified as Lower Permian based on fossil evidence, is believed to be part of the same formation as the Passu and Misgar Slates. The Slates are characterized by slaty shale, slate, and phyllite slate, with granite and other Intrusive rocks present. The Karakoram Axial Batholith intrudes the Passu Slates, which have faulted contact. The Gojal Dolomite is primarily composed of calcareous rocks, categorized into three types of calcareous beds. The Reshun conglomerate, considered Cretaceous, represents the youngest formations in this sequence.

- Misgar Slate,
- Kilik Fm,
- Gircha Fm,
- Passu Slate,
- Gojal Dolomite

2.10 Karakoram Metamorphic Complex

The Karakoram Metamorphic Complex (KMC) is the southernmost unit of the Karakoram block, marking the southern edge of Asia. It is geographically bordered by the Karakoram axial batholith to the north, the MKT to the south, the Reshun faults to the west, and the Karakoram faults to the east. The collision of the Kohistan arc and India with Asia, occurring between 65-50 million years ago, initiated Andean-type subduction and magmatism during the Jurassic to Lower Cretaceous periods, along with associated metamorphic processes along Asia's southern margin. Two significant episodes of metamorphism occurred east and west of this margin during and following the collision of the Kohistan-Indian plate with Asia. The southern Karakoram features metamorphic rocks that correspond to post-collisional regional Barrovian metamorphism. The KMC platform's sedimentary protolith underwent low-pressure-high-temperature (LP-HT) andalusite-grade metamorphism and crustal thickening, leading to staurolite to sillimanite grade Barrovian metamorphism due to the collision of the Kohistan-Indian arc with Asia. The southern Karakoram displays numerous meta-sedimentary and meta-magmatic units, indicating a complex, multi-stage history of magmatism and metamorphism. The timing of metamorphism, constrained by geochronological data, ranges from the late Early Cretaceous to the Miocene (105 to

16 million years ago). Regional kyanite- and sillimanite-grade metamorphism, culminating in partial melting and the formation of crustal melt leucogranites in the Early Miocene, occurred alongside the Indian and Himalayan plates, as well as the southern edge of the Asian plate. The KMC experienced five metamorphic events, including andalusite-grade contact metamorphism in the early Cretaceous, sillimanite-grade metamorphism in the Late Cretaceous, kyanite-grade metamorphism in the Oligo-Miocene, staurolite-grade metamorphism during the mid-Miocene, and sillimanite-grade metamorphism in the Mio-Pliocene.

2.11 Karakoram Axial Batholith

The Karakoram Axial Batholith is a significant Paleozoic-Mesozoic intrusive body that has intruded the meta-sedimentary formations, reflecting the magmatic history linked to the collision of Eurasia, the Kohistan-Ladakh Island arc, and the Indian plate. This batholith comprises four plutonic complexes and is a composite body made up of several plutonic units, primarily dating from the mid-Cretaceous in the western and central regions, and Miocene in the eastern region. The largest unit is the extensive mid-Cretaceous calc-alkaline Hunza plutonic complex, which exhibits remarkable reversal zoning likely resulting from depth differentiation followed by multiple phases of intrusion. The Karakoram batholith and its associated plutons contain a variety of sub-alkaline granitoids, including Warghut porphyritic granite, granites, granodiorites, diorites, tonalites, and hornblende-rich amphibolites. Pre-collision quartz diorite, granodiorite, and monzodiorite plutons were later deformed, foliated, and metamorphosed, including the Darkot Pass plutonic unit (111±6 million years ago), Ghamu Bar plutonic unit, Kesu-buniZom plutonic unit, Hunza plutonic unit (95±5 million years ago), and Batura plutonic unit (95±5 million years ago). Post-collision, undeformed monzogranite-leucogranite plutons include the Baltoro plutonic unit, Sumayar leucogranite, Hunza dykes, Chinkiang (K-AR hornblende, 36-34 million years ago), Mango Gusarpluton, and the Muztagh Tower unit, which features foliated biotite-hornblende gneiss (82-75 million years ago). The Koz Sal' alkaline complex (KSAC) exemplifies the composition of plutonic rocks found within a batholith, featuring a diverse collection of fine-grained granitoids. Additionally, the presence of leucogranite dykes and infrequent alkaline mafic dykes is noted. The Hunza plutonic unit, an intrusive body extending 15 kilometers, showcases three distinct magmatic phases: diffusive, intrusive, and leucogranitic dykes. The age of the Hunza plutonic unit (HPU) has been determined through U-Pb dating, yielding an age of approximately 95 ± 5 million years from three samples of biotite-hornblende granodiorites (Lefort et al., 1883) and 97 ± 17 million years according to Rb-Sr dating (Debon et al., 1987). Mid-Cretaceous magmatism is also recorded about 200 kilometers west of Hunza at Darkot Pass, where an isochron age of 111 ± 6 million years was established (Debon et al., 1987). Notably, compressional gradients that increase acidity are observed to the north of the batholith, while deformation is evident 10 kilometers south of HPU, leading to the recrystallization of secondary minerals like euhedral epidote and the annealing of primary minerals. The gneiss bands within the hornblende-rich pod exhibit significant shearing due to deformation. Within the deformed section of HPU, a mixing of acidic and basic gneiss, along with granodiorite and leucogranite plutons, occurs approximately 1 kilometer north of the southern contact. Two generations of leucogranite dykes intrude the HPU, with the earlier generation oriented east-west, parallel to HPU's foliation. These intrusions have been affected by folding and displacement due to subsequent geological structures. The later leucogranite intrusions are larger and form continuous sheets that intersect all other structures, predominantly within the deformed section of HPU, including its southern contact.

Pre-collision quartz diorite, granodiorite, and monzodiorite plutons subsequently deformed, foliated, and metamorphosed including: no need to list like this,

- Darkot pass plutonic unit (111±6 ma)
- Ghamu Bar plutonic uni
- Kesu-buniZom plutonic unit
- Hunza plutonic unit (95±5 ma)
- Batura plutonic unit (95±5 ma)

Post- collision un-deformed monzogranite-leucogranite plutons :

- Baltoro plutonic unit
- Sumayar leucogranite
- Hunza dykes
- Chinkiang (K-AR hornblende (36 -34 ma)
- Mango Gusar pluton
- Muztagh Tower unit foliated biotite -hornblende gneiss (82-75 ma

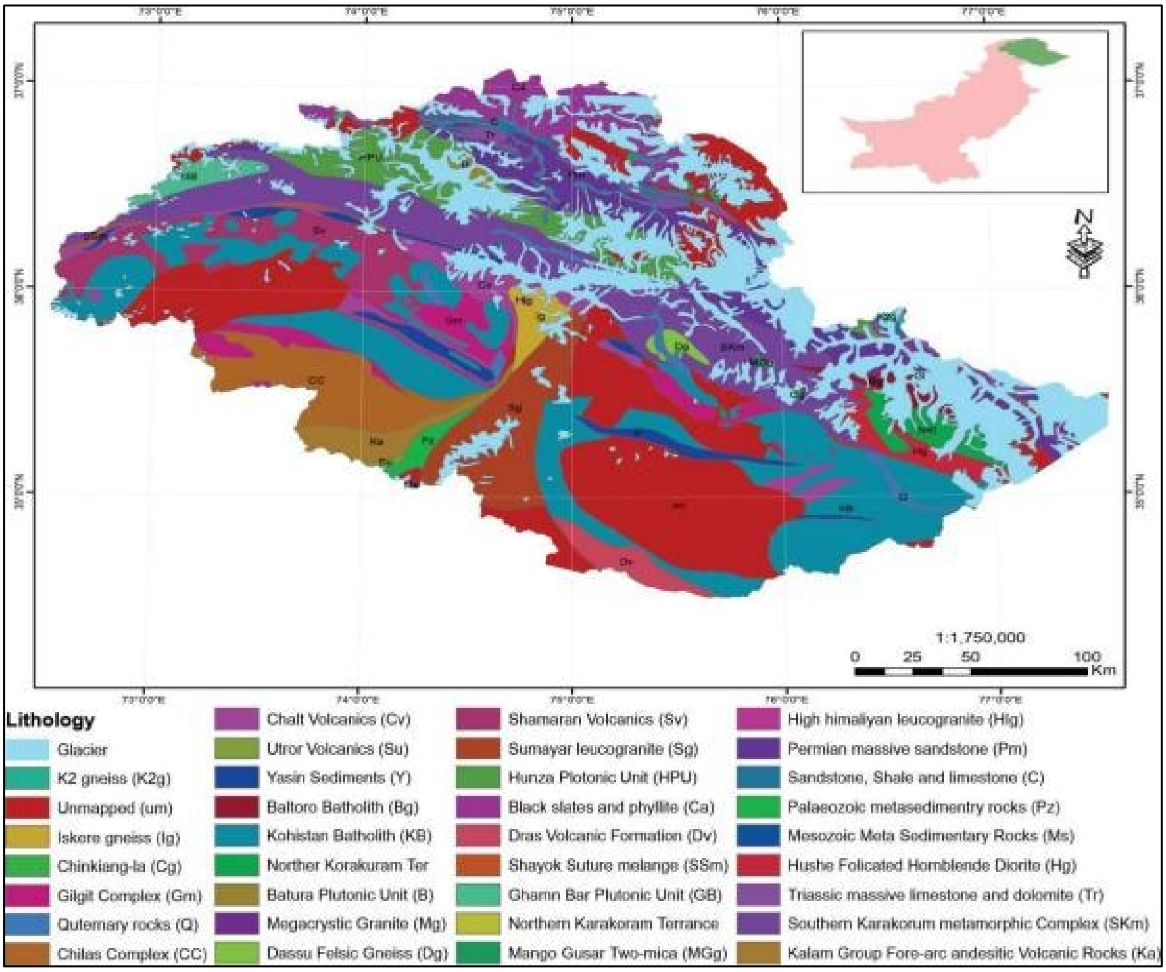


Figure 5. Geological Map of Gilgit-Baltistan

2.12 Local Work

Understanding the geological features of the Humarri area in Nagar is crucial for assessing slope stability and landslide potential. The primary geological aspects include:

2.12.1 Soil Composition: The region is predominantly made up of sandy silt, which is vital for evaluating slope stability. Key soil characteristics such as moisture content, specific gravity, and cohesion are essential in determining slope safety.

2.12.2 Geological Stratification: The area's geological framework may consist of various formations, including sedimentary deposits and loose materials. Analyzing these layers and their compositions is crucial for assessing landslide risks.

2.12.3 Hydrological Interactions: The interplay between geological formations and groundwater is significant. Factors such as pore water pressure and soil saturation levels can greatly influence the shear strength of the soil, increasing vulnerability to landslides, particularly during heavy rainfall or rapid snowmelt.

2.12.4 Seismic Activity: The geological history, including tectonic movements, can impact slope stability. Areas with a history of seismic activity may experience increased landslide risks due to the destabilizing effects of ground shaking.

2.12.5 Climatic Influences: The local climate, characterized by specific rainfall patterns and temperature variations, affects soil moisture levels, which in turn influences slope stability. Continuous monitoring of these climatic elements is essential for

2.13 Gilgit Work

2.13.1 Geological Evaluations:

Gilgit is situated in a seismically active zone with intricate geological formations. Research should concentrate on thorough geological mapping and assessments to evaluate slope stability and landslide risks.

2.13.2 Monitoring Landslides:

Establishing monitoring systems to track landslide activity in Gilgit can yield valuable data for predicting future occurrences. This may involve remote sensing technologies and ground-based monitoring methods.

2.13.3 Climate Change Impacts:

Investigating the effects of climate change on weather patterns, such as heightened rainfall and glacial melting, is vital for understanding its implications for slope stability in Gilgit.

2.13.4 Community Awareness:

Researching local community awareness and preparedness regarding landslides and geological hazards can aid in developing effective education and response strategies.

2.13.5 Mitigation Techniques:

Creating and testing various slope stabilization methods tailored to Gilgit's unique geological conditions can enhance safety and minimize landslide risks.

2.13.6 Interdisciplinary Research:

Integrating geological, hydrological, and socio-economic studies can provide a comprehensive understanding of the factors contributing to landslide risks in the region.

2.13.7 Infrastructure Assessment:

Evaluating the effects of infrastructure projects on slope stability and applying best construction practices can help mitigate landslide risks.

CHAPTER 3

LITERATURE REVIEW

The area of slope stability prediction has been always of crucial interest and there are numerous articles published on this subject for years. Potential projectiles, such as rocks, can be vast when slope stability is considered as one of the major concerns in geotechnical engineering dealing with landslides and infrastructural development. Some of the authors have done their best to enabling the understanding and prediction of the stability of slopes using those methods some of which include the limit equilibrium methods the use of artificial intelligence as well as statistical methods. Indeed, some of the very early articles that discussed the issue of slopes stability are (Irfan Haziq Razali, 02/2023), and the author introduced the so called slip circles in this type of stability analysis that are still in use today in geotechnical practice. After this, in 1967 by(Spencer, n.d.) Developed another method assuming inter-slice forces to act in parallel with each other which further expanded the analysis versatility for the stability of slopes. (Morgenstern, n.d.) Also continued to extend the stability analysis of general slip surface which provide this wider perspective that put into context the state of slopes. In the field of empirical and statistical analysis, Pradhan (Burman et al., n.d.) integrated RS and GIS techniques to specialize the Shifting the focus on to the empirical statistical analysis for landslide hazard, (Burman et al., n.d.) Utilized the RS and GIS techniques to specialize the landslide hazard and thus advocated the incorporation of the modern advancement of technology with the traditional geotechnical approach. From the analysis ofthe study, it became evident that the subject was involved with Loss in the topic of slope failure pragmatics with emphasis on ways of forecasting slope failures by analysis. Similarly, (Chakraborty

& Goswami, 2017) has also utilized the multiple linear regression (MLR) analyses to analyze a number of slope parameters with the objective of extending the approach to the development of slope stability models. The aspect of application of artificial intelligence has been on the rise in trying to predict the stability of slopes in the recent years. (Sakellariou & Ferentinou, 2005a)employed artificial neural network (ANN) to identify the following relationships between slope parameters and the model was trained against others method. In the same way, this was done in (Erzin & Cetin, 2012) where the authors conducted a study involving the use of both ANN and MLR to determine the factor of safety (FOS) of slopes under seismic forces and found that the results obtained from the ANN were more accurate. (Chae et al., 2015) when focusing on the trigger factor, decided to include saturation depth ratios into the discussion introducing a new formula. Their finding was that this method improved the characterization of the degree of vulnerability to landslides; and such a categorization was more precise compared to the conventional pre-existing hydrological models which acted in steady-state. Also in the same line of thought (Firmansyah et al., 2016) explained the influence of the soil types for the run out distance of rotational slopes, where the parameter examined was the unit weight of the soil on slopes stability. Monitoring system has also been considered in the study on assessment of slope stability. In this regard, (Kayesa, 2006) used the GEOMOS Slope Monitoring System (GSMS) in Letlhakane mine that allows the acquisition of successive data and achieve a significant development on safety in mining processes. This system demonstrates on how the technology can be applied especially in monitoring the stability of slopes in real time. In addition, (Ahangar-Asret al., 2010)utilized the evolutionary polynomial regression (EPR) for the FOS prediction, thus supporting the potential of such technique on the categorization aspect particularly on the behavior of slope in several conditions. Further in this direction (Mohamed et al., 2012a, 2012b) employed fuzzy logic as well as adaptive neuro fuzzy inference systems (ANFIS) especially for slope stability prediction and with the received results the comparison with the traditional practices was held, showing ANFIS's advantage in the sphere of accuracy. Finally, in the works of (Kumar et al., 2022)&(Prevéy & Wong, 2022)the authors state that survey geotechnical methodologies should be augmented by the computational ones regarding to the machine learning application for the slope stability prediction. Thus, their work described the dynamic of the scientific process in field of slope stability analysis with increasing use of interdisciplinary elements to enhance the prognosis of the situation

CHAPTER 4

METHODOLOGY

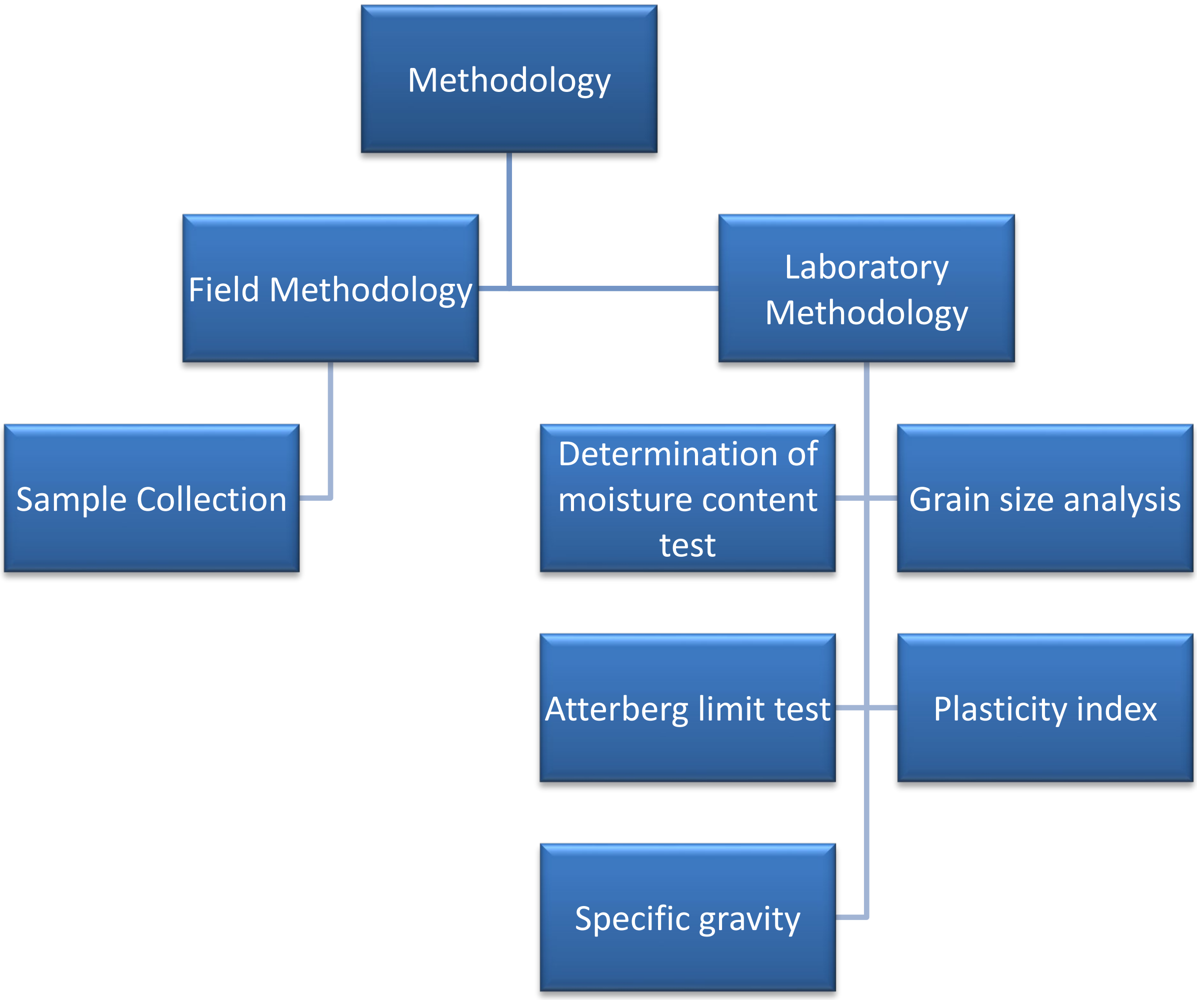


Figure 6. Graphical method

4.1 Field Methodology

The field work of this study was carried out at 36°22'28.67"N, 74°52'22.03"E coordinates in Humarri Valley Nagar, northern Pakistan. This area was selected because it is prone to unstable slopes and is affected by high altitude, tectonic activity and lithology. The main objective of the field work is to collect soil and rock samples for soil engineering analysis. Soil samples were collected from different places in the study area, especially from areas showing instability and soil risk. Use geological hammer to extract rock samples from a fresh, airless medium. A total of twelve samples were collected, including soil and rock types. These samples are carefully placed in cloth bags and transported to the next examination location. Laboratory analyses include the determination of moisture content, particle size distribution, Atterberg limit, plasticity index and shear strength, which are important for the evaluation of the geotechnical strength and slope stability of the region.

4.1.1 Moisture content

In accordance with ASTM standard D2216, soil samples were dried in an oven to determine their moisture content. After the soil sample was weighed while it was still wet, it was dried in an oven for 24 hours at 105 degrees Celsius.Once the dried soil was weighed, the moisture content was calculated using the difference between the two weights.

4.1.2 Grain size analysis

Using sieve analysis based on ASTM standard D421, the grain size analysis test was carried out in accordance with ASTM guidelines. In this work, in order to separate various particle sizes from one another, a mechanical shaker is used to shake a soil sample through a succession of sieves whose sizes decrease from top to bottom.

4.1.3 Atterberg limit test

Following ASTM D 4318 standard test procedure, cohesive soils were subjected to the Atterberg limit test. The purpose of this test was to ascertain the liquid and plastic limits of soil samples taken from the chosen slope sections. The Casagrande's equipment are used in the laboratory to determine the liquid limit. Casagrande's device was used to determine the soil samples' liquid limit for this specific investigation. For the test, soils that could pass 2425 through sieve number 40 were used, along with 120 gram soil samples. Taking for a 24h. Following that, the blended soil was poured into the Casagrande cup and struck until the sample contact was about 13 mm separated. The soil's liquid limit was determined to be the moisture content associated with 25 blows (N = 25). Using a glass plate, threads about 3 mm in diameter were rolled out to determine the soil's plastic limit. The damp soil was then placed to a moisture can, and its mass was measured. The damp soil was then dried in an oven to get the dry mass. The average moisture content was computed from these readings.

4.1.4 Plasticity index

A soil's plastic limit and its liquid limit are separated numerically, and this difference is known as the plasticity index. This figure can show you the range of moisture where the soil behaves plastically. Through the use of Equation (1), the plasticity index was determined.

Plasticity index = LL - PL

Where,

Liquid limit = LL

Plastic limit = PL

4.1.5 Specific Gravity Of Soil

The specific gravity for a given material is defined as, ―The ratio of the unit weight of a given material to unit weight of equal volume of distilled water ― In soil mechanic determination of specific gravity is used in various calculations such as hydrometer analysis and weight volume relationship. It is denoted by Gs and is a unit less quantity because it is the ratio between two similar quantities.

The values of Gs mostly falls within the range of 2.5 to 2.8 are calculated using ASTM Standard D854.

4.1.6 Uni axial compressive strength of rock (UCS).

A Schmidt Hammer laboratory test was used to determine the two rock samples' uniaxial compressive strength during the Laboratory test. The values of the Schmidt hammer rebound were determined using ASTM D2938.26 state that this formula may be used to calculate the uniaxial compressive strength of rock.0.026*Rn^2.35

4.1.7 Direct Shear Test

The triaxial test and the direct shear test are the two most used laboratory methods for determining the shear strength characteristics of soil. To determine the strength characteristics of the soil, a direct shear test was conducted in this research. A direct shear test was conducted in accordance with ASTM D3080 to evaluate the soil's shear strength properties, such as cohesion and internal friction angle.

4.2 Procedure

The earliest and most basic type of shear test setup is the direct shear test. The soil sample is put within a metal shear box, which is part of the test apparatus. The soil samples might have a round or square shape. The specimens utilized are approximately 25 mm (1 in.) high and 51 mm × 51 mm (102 m × 102 mm) wide. The box is divided in half horizontally. The top of the shear box applies the specimen's normal force. The specimens may experience typical stress of up to 1050 KN/m2. To induce failure in the soil specimen, shear force is supplied by shifting one side of the box in relation to the other.

4.2.1 Laboratory Methodology

Laboratory analysis of soil and rock samples according to geotechnical engineering methods. Moisture content was measured using ASTM D2216. Soil samples were dried in an oven at 105°C for 24 hours and the moisture content was calculated from the weight difference. The size of the sample was analyzed using ASTM D421 sieve analysis, in which the soil sample was manually shaken through a series of sieves to separate the particle into different small groups. The Atterberg limit, including the liquid limit and plastic limit, is determined according to ASTM D4318 to measure the consistency and plastic capacity of the soil, and the plasticity index, calculated as the difference between the two, is also determined. Direct testing according to ASTM D3080 is used to measure the shear strength of soil such as cohesion and internal friction. These tests provide important information about the geotechnical properties of the soil, including its stability under various moisture and loading conditions, and are important for understanding slope stability in the study area.

CHAPTER 5

RESULTS AND DISCUSSION

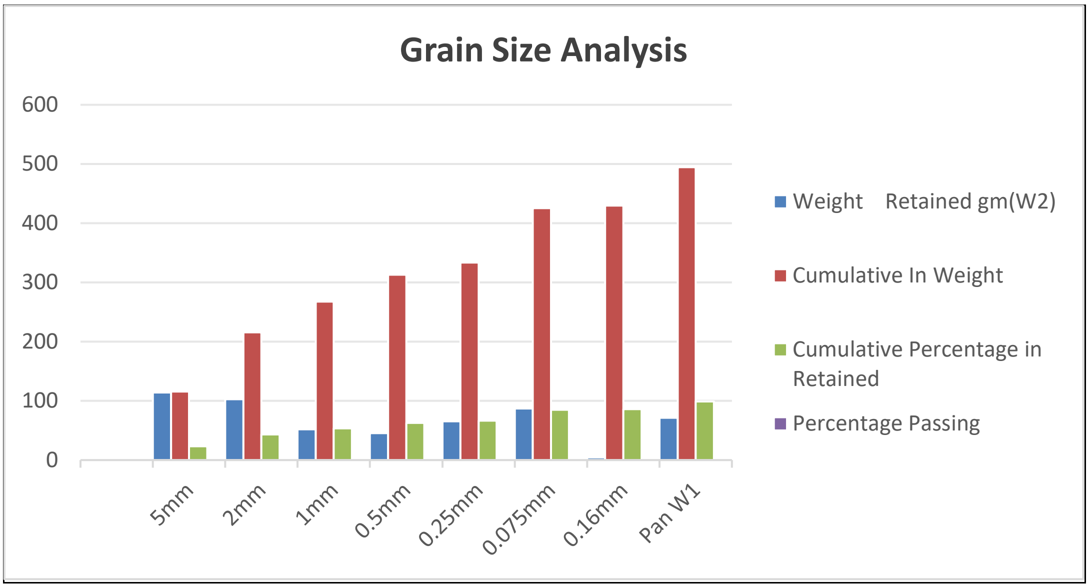


Figure 7. Result of Grain Size Analysis

Particle size distribution has an effect on soil behavior; smaller particles such as clay and clay hold more water and have a greater impact on the soil. In coarser materials, although flow is better, it still cannot be done if there is no cohesion. Poor soil quality is associated with unis table slopes.

Higher humidity (18.18% ~ 16.66%) will weaken the shear strength and decrease the risk of slope failure, especially when it rains. Lower soil pressure means better drainage and stability, highlighting the importance of water management to prevent landslides.

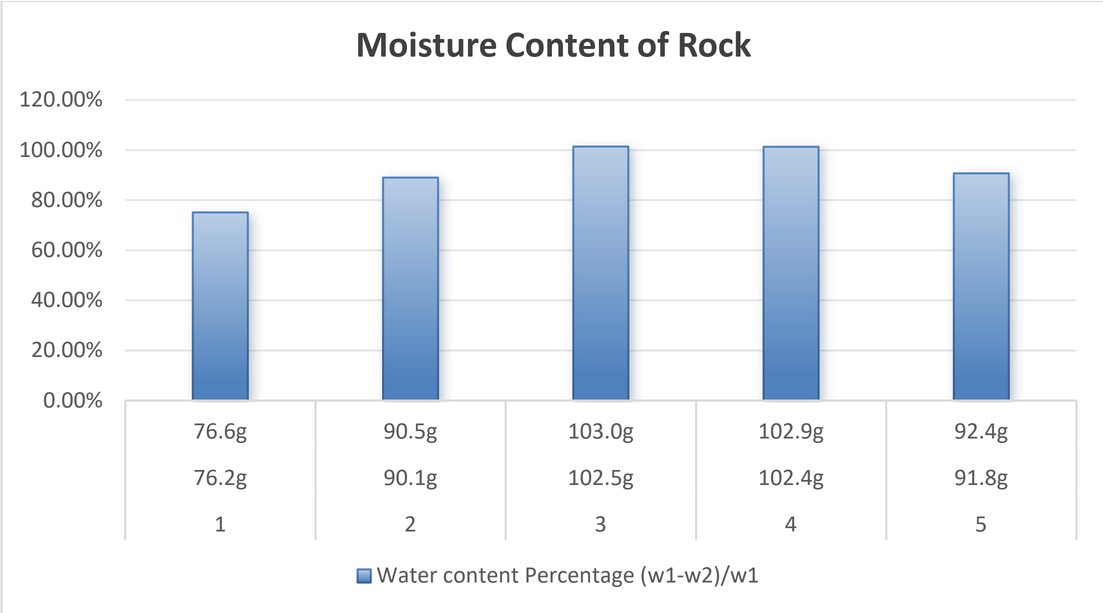


Figure 8. Results of Moisture Content test of Rock

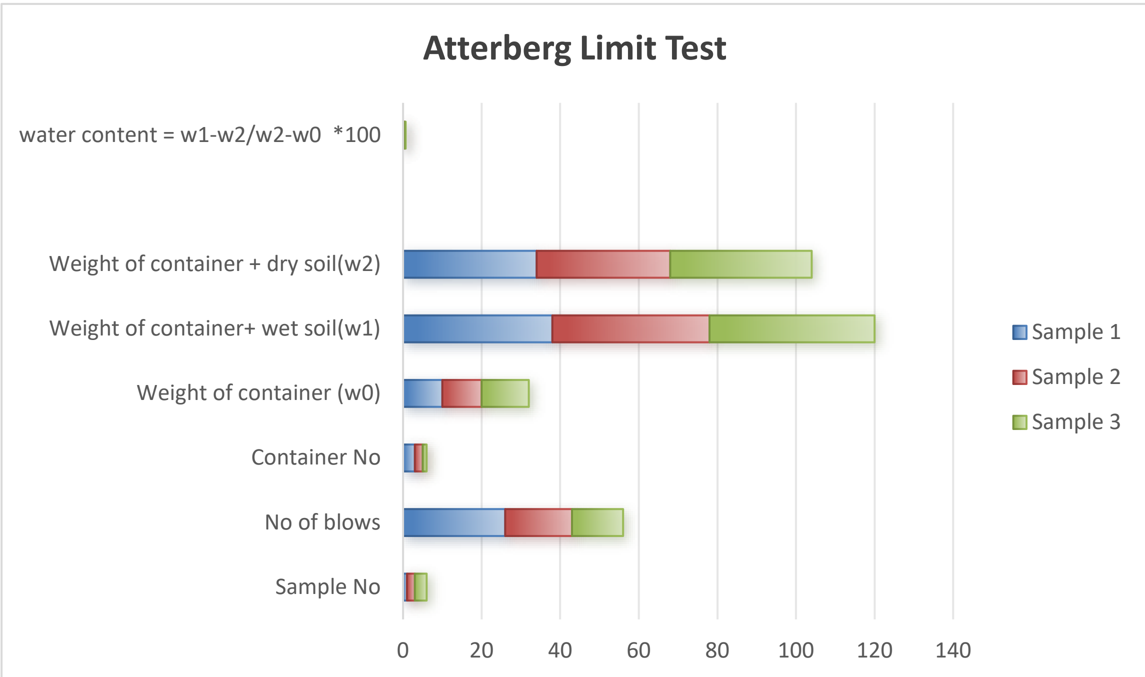
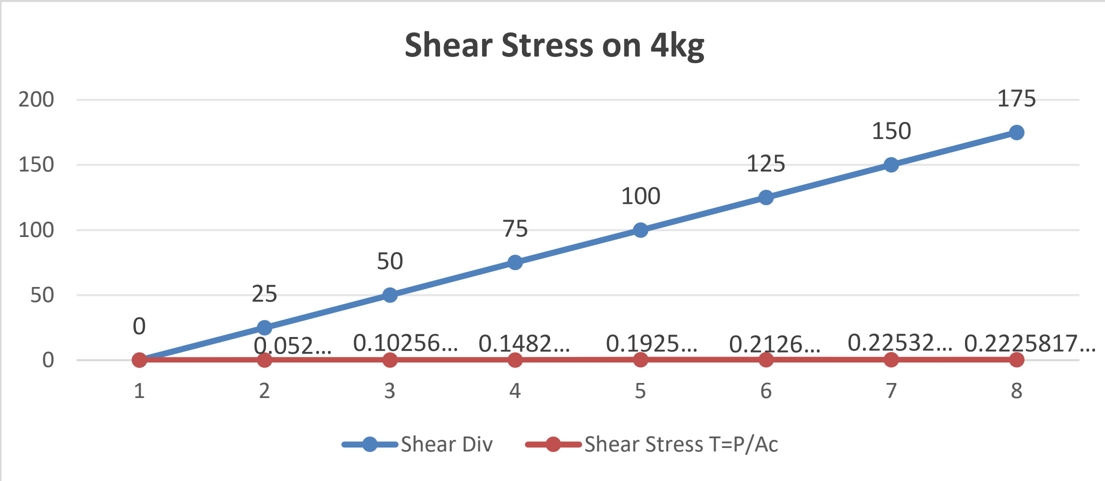
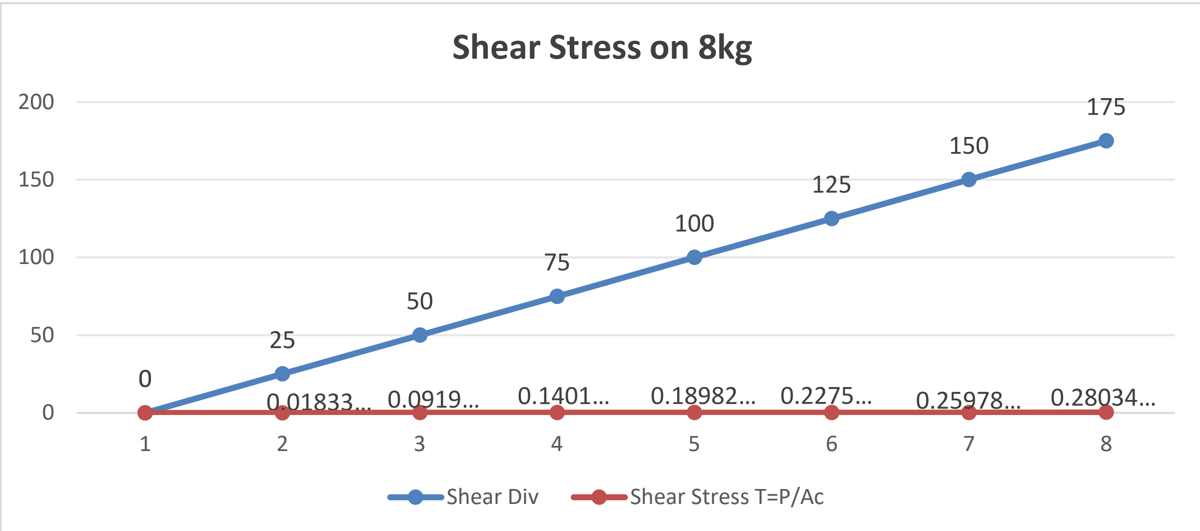


Figure 9. Atterberg limit test

The Atterberg limit indicates how the soil behaves at different moisture levels. Liquid limit and high plasticity indicate greater susceptibility to deformation that could make the slope unstable, especially in areas with variable moisture content.



Shear Stress on 4kg
200
150
100
50
0
1
2
3
4
5
6
7
8
0
25
50
75
100
125
150
175
0.052...
0.10256...
0.1482...
0.1925...
0.2126...
0.22532...
0.2225817...
Shear Div
Shear Stress T=P/Ac



Shear Stress on 8kg
200
150
100
50
0
1
2
3
4
5
6
7
8
0
25
50
75
100
125
150
175
0.01833...
0.0919...
0.1401...
0.18982...
0.2275...
0.25978...
0.28034...
Shear Div
Shear Stress T=P/Ac

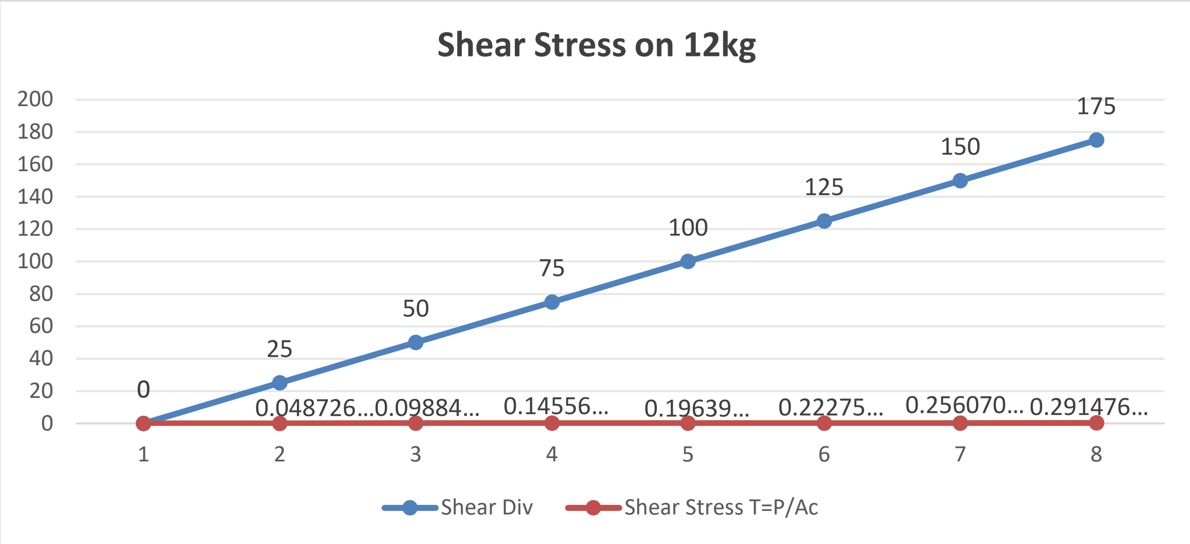


Figure 10. Result of Direct Shear Stress (4kg, 8 kg and 12kg)

- **Cohesion(c)**: Likely ranges around **5-15 kPa** for your data set.
- **Friction Angle (ϕ)**: Likely ranges around **20-35°**, based on typical slopes of failure envelopes for sandy-silt soils.

Table 1. Plasticity Index

Can No	**1 p.h**
Can weight	12g
Can weight + wet weight	26g
Can weight + Dry weight	22g

The plasticity index (PI) indicates the deformation capacity of the soil. A higher PI means that the soil will be unstable when saturated. Soils with high PI are prone to slope failure due to shrink-swell behavior, so slope stabilization is important.

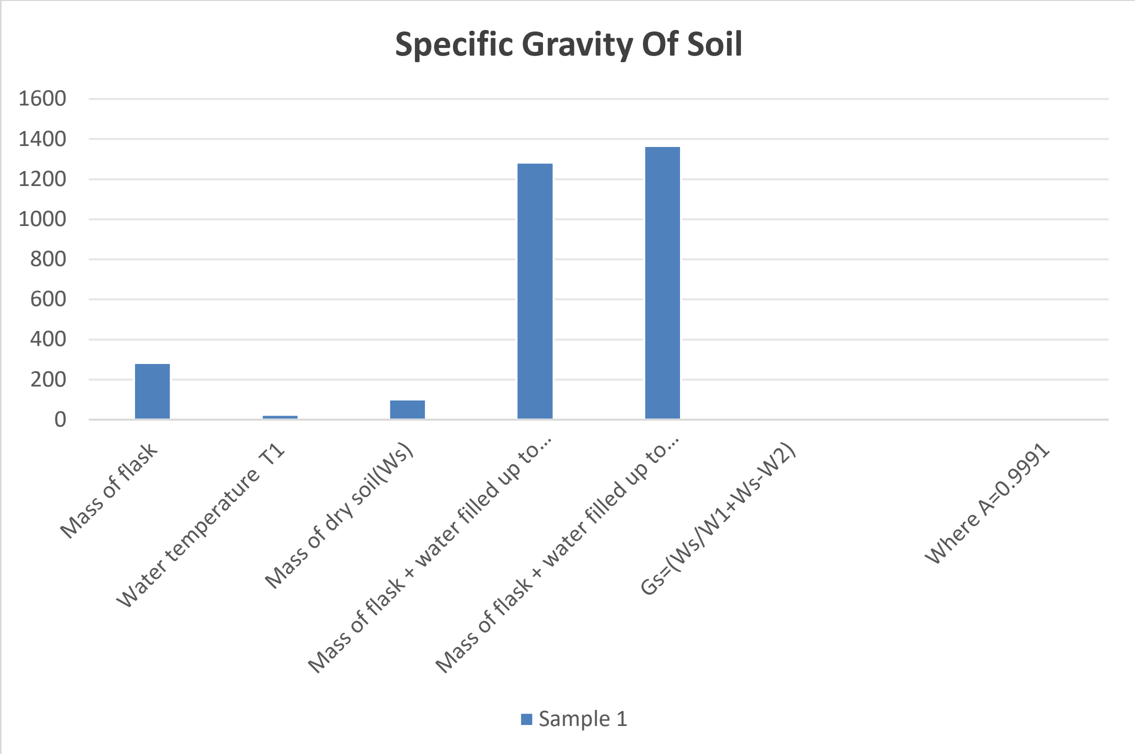


Figure 11. Specific Gravity of Soil

CHAPTER 6

CONCLUSION AND RECOMMENDATIONS

The conclusion of the thesis emphasizes the critical importance of understanding slope stability in the Humarri Nagar region, particularly due to its complex geological structure and the prevalent risk of landslides. The research highlights that various factor, including soil composition, climatic conditions, and slope geometry, significantly influence slope stability. By employing both traditional and advanced methodologies, such as Limit Equilibrium Methods and Finite Element Analysis, the study provides a comprehensive assessment of the factors affecting slope stability.

The findings underscore the necessity for effective monitoring systems and early warning mechanisms to safeguard infrastructure and residents in vulnerable areas. Additionally, the research contributes to land-use planning and enhances community awareness regarding safety protocols, ultimately aiming to create a safer living environment in Humarri Nagar. The study advocates for ongoing research and the implementation of protective measures to mitigate landslide hazards, ensuring the safety and resilience of the community against future geological events.

In summary, the thesis not only addresses the immediate concerns related to slope stability but also lays the groundwork for future studies and interventions that can enhance the understanding and management of landslide risks in the region.

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