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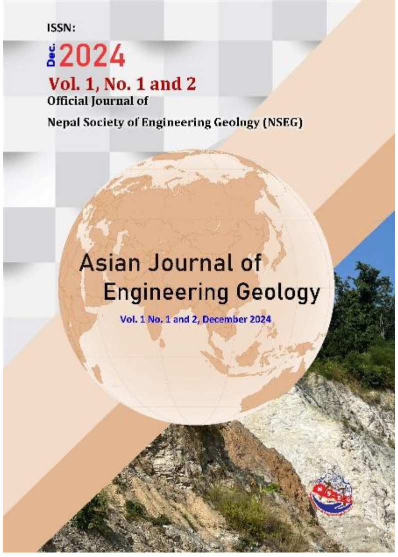

Asian Journal of Engineering Geology (AJEG)

Concept

The Asian Journal of Engineering Geology (**AJEG**), published by the Nepal Society of Engineering Geology (**NSEG**), is envisioned as a dedicated platform for advancing the understanding and application of engineering geology within the unique geological context of Asia, with a particular focus on the Himalayan region, while also welcoming contributions relevant to other parts of the world.

In recent years, research in engineering geology and related fields has seen significant progress. However, specialized publication platforms remain limited, especially in Asia, hindering the effective dissemination of research findings and knowledge sharing among engineering geologists. To address this gap, NSEG has launched the Asian Journal of Engineering Geology (AJEG), offering a professional and accessible forum for geoscientists, engineers, and environmentalists engaged in landslide studies, environmental geoscience, and engineering geological research.

AJEG aims to be a key resource for stakeholders seeking updated information on the geological challenges and engineering solutions relevant to seismically active and geologically complex regions like the Himalayas and beyond. The journal is committed to publishing original research, case studies, and technical notes that contribute to a deeper understanding of engineering geology in diverse terrains. Under the auspices of **NSEG**, **AJEG** places particular emphasis on:

- Slope stability and landslide hazard assessment
- Earthquake geology and seismic risk analysis
- Engineering geological aspects of infrastructure development
- Environmental and geotechnical investigations
- Integration of geological, geotechnical, and environmental knowledge for sustainable development

The journal actively promotes collaboration among researchers, engineers, and geologists from Asia and around the globe. By engaging regional experts and fostering interdisciplinary dialogue, **AJEG** seeks to address current and emerging challenges in engineering geology through shared knowledge and innovation.

In addition to peer-reviewed articles, **AJEG** will feature updates on conferences, research initiatives, and activities organized by the Nepal Society of Engineering Geology. This will position the journal not only as a scholarly publication but also as a hub for professional exchange and community building within the field of engineering geology in Nepal and across the region.

Aims and Scope

The Asian Journal of Engineering Geology (**AJEG**) serves as a common platform for the publication of integrated research covering all aspects of engineering geology. The journal welcomes original research articles, rapid reports on emerging engineering geology issues, case studies, and technical notes highlighting practical applications. Researchers and practitioners are encouraged to submit original, unpublished contributions. Subject areas include, but are not limited to, the following fields:

- Applied geomorphology
- Structural geology
- Applied geophysics and g
- Geochemistry
- Environmental geology
- Hydrogeology
- Land use planning
- Natural hazards
- Remote sensing techniques
- Soil and rock mechanics
- Applied geotechnical engineering
- Urban Engineering Geology
- Engineering Geology of marine and reservoir.
- Engineering geology in flash floods and tsunami
- Landslide hazard assessment and mapping
- GIS applications in engineering geology
- Landslide monitoring and landslide mitigation
- Engineering geology of the Himalayan slopes
- Rainfall-induced landslides
- Earthquake-induced landslides
- Anthropogenic controls on hazards
- Stability of dams and embankments
- Engineering geology of heritage areas, monitoring and mitigation
- Groundwater monitoring
- Seismic Hazard and Risk
- Disaster Risk Reduction and Management
- Engineering geology of Tunnels and bridges
- Foundations on slopes and plains

- Early warning of multi-hazard risk
- Landslide hazard management at community level
- Physical and numerical modeling in engineering geology
- High altitude engineering geological issues.
- Economics of natural hazards and related climate change
- Agricultural geology
- Snow avalanche
- Engineering geology and infrastructure development
- Snow cover in the Himalaya
- Environment friendly low cost infrastructure development
- Rural infrastructures and engineering geology
- Geotechnical engineering, modeling and ground improvement
- Nature-based solutions for disaster risk reduction

These topics suggest a multidisciplinary approach, encompassing various aspects of geology and engineering that have practical applications in fields such as environmental management, land planning, and geotechnical engineering.

Publication program

The Asian Journal of Engineering Geology (**AJEG**) publishes two issues each year. It is a peer-reviewed journal committed to disseminating the latest developments across various fields of engineering geology. **AJEG** is an open-access online journal, freely available to readers worldwide.

The Nepal Society of Engineering Geology promotes open access publishing to broaden the journal's global reach, enhance the visibility and impact of published research, and improve indexing across major search engines. Researchers and professionals from all relevant disciplines are invited to submit high-quality manuscripts presenting cutting-edge research or innovations in engineering geology and related areas. **AJEG** welcomes both individual and institutional submissions aligned with the journal's aims and scope.

Editorial Team

We invite researchers specializing in engineering geology to become part of the editorial board and contribute to our publication. If you are interested in joining, kindly send an email to nsegnepal@gmail.com.

Instructions to Contributors

All types of manuscripts, including original articles, rapid reports on recent engineering geology issues, case studies, and technical notes, submitted for publication will undergo peer review by at least two experts in the relevant field. The review process is double-blind, meaning the authors will not know the identity of the reviewers. In some cases, editors may also serve as reviewers.

Authors' Responsibilities

Only individuals who have made significant intellectual contributions to the content of the manuscript should be listed as authors. Authorship should be based on contributions to the conception and design of the study, active involvement in drafting or critically revising the manuscript, and participation in the final revision process.

The corresponding author is responsible for submitting the final version of the manuscript following the peer review process. Any external support, such as funding, equipment, or institutional assistance, must be clearly acknowledged in the Acknowledgment section.

In the Comments to the Editor section during submission, authors must disclose any prior or duplicate publication of the manuscript's content. All submissions to AJEG are subject to plagiarism screening, and the acceptable similarity index is limited to a maximum of 20%. Author should use given Template in the web site for preparation of manuscript.

Manuscript Preparation Overview

All submissions to the Asian Journal of Engineering Geology (AJEG) must be written in International English. Authors whose first language is not English are strongly encouraged to have their manuscripts reviewed by a native English speaker or to use a professional English editing service prior to submission. All references, including online sources, must be formatted according to the journal's referencing guidelines outlined in this document. Each submitted article must include an abstract that briefly summarizes the key content and findings of the study. The name, institutional address, and email address of the corresponding author must be clearly indicated on the title page.

Figures and tables should be embedded within the manuscript after the list of references. Original figures should be at least half the size of A4 paper in their longest dimension. Acceptable formats for figures and images are TIFF (TIF) with a resolution of 300–600 pixels per inch (ppi). Monochrome images should be saved in grayscale mode, while color images must be in RGB mode. Only single-layer images are accepted. Authors should make every effort to avoid jargon, clearly define all nonstandard abbreviations upon first use, and present the content in a clear, concise, and accessible manner.

Manuscript Preparation Guidelines for AJEG

Authors must use the official manuscript template available on the AJEG website for preparing their submissions.

Title Page

The **title page** should include the following details:

- **Title** of the article
- **Full name(s)** of all authors (first name, middle initial(s), and surname)
- **Affiliations** of the authors, including department or division, institution or organization, city, and country. Do not use abbreviations for affiliations.
- If multiple authors share the same affiliation, list all authors first, followed by the shared affiliation.
- **Email addresses** of all authors must be included.
- The **corresponding author** should be clearly identified with an asterisk (*).

Abstract and Keywords

The manuscript should begin with an **Abstract** of approximately **300 words**, clearly summarizing:

- The research problem
- The methods used
- Major findings
- Conclusions

Immediately following the abstract, list **up to five keywords or phrases** for indexing purposes as per the template provided.

Figures, Tables, and Symbols

- Special characters, mathematical symbols, and Greek letters not available on a standard keyboard must be created using the **Symbol** font.
- **Figures and tables** should be **embedded** at appropriate locations within the text **after the list of references**.
- After the manuscript is accepted, authors must also submit **figures as separate high-resolution files**.
- Figures should follow the formatting requirements outlined in the submission guidelines (e.g., TIFF format, 300–600 dpi, RGB/grayscale mode, single-layer).

Pagination, Line Numbering, and Equations

- Authors must insert both page numbers and continuous line numbers throughout the manuscript to facilitate the review process. Page numbers should appear in the footer of each page.
- Equations should be left-aligned, with reference numbers aligned to the right margin.
- For long equations, break the right side into approximately equal parts and align to the right. Place the equation number on the last line only.
- All equations must be numbered sequentially as they appear in the text.

Units

Use **SI units** throughout the manuscript. If alternative units are provided, they should appear in parentheses following the SI units.

Acknowledgments

Acknowledgments should be included before the list of References, and the title should read "Acknowledgments." Author/s should obtain a permission to acknowledge from all those mentioned in the Acknowledgements.

References

In the list of references, provide complete information of each reference material. Cite a symposium paper only from published proceedings. Do not cite an article or book only accepted for publication but not published. Do not use ibid. Please avoid excessive referencing.

Unpublished data, unpublished abstracts and personal communications should not be included in the reference list. Footnotes are not acceptable.

AJEG prefers maximum 60 references per article. The journal follows the Harvard system for citation, with author name/s and year of publication in parentheses, such as one author: (Hungr 2003) or Hungr (2003), two authors: (Doe and Morris 2009) or Doe and Morris (2009), and three authors or more: (Rahardjo et al. 2002) or Rahardjo et al. (2002).

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Review and Production Process

All manuscripts submitted to AJEG undergo peer review. Accepted materials are subject to copyediting to ensure clarity, consistency, and adherence to journal standards. Authors will receive galley proofs of their article prior to publication and are expected to respond promptly to any editorial queries. Proof corrections must be limited to typographical or printer's errors; substantial revisions or rewriting at the proof stage will not be permitted.

Page Charges

There is no page charge/s for papers submitted to the AJEG. The upper limit on length of a paper is approximately 35 manuscript pages, including tables and references. This limit may be exceeded at the discretion of the Editor-in-chief.

Online Submission

Please note that the online manuscript submission system is available through the journal's official website. This system is essential for preparing and submitting your manuscript electronically to the Asian Journal of Engineering Geology via its web-based peer-review platform.

Manuscripts should be submitted at https://ajeg.nseg.org.np . The submission portal also allows authors to track the progress of their manuscript throughout the peer-review and editorial process.

Author should use given Template in the web site for preparation of manuscript.

Lesson Learned from Hydropower Sector of Nepal and India

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Abstract: The growing global demand for electric power, particularly in Nepal and India, has accelerated the development of hydropower projects, benefiting from abundant water resources and suitable terrain. However, many projects in the Himalayas face significant challenges due to unforeseen geological conditions, leading to delays and cost overruns. Drawing on over 40 years of experience in the sector, the author highlights key engineering geological aspects crucial to the planning, investigation, and construction of hydropower projects. Topics include site selection, the choice between surface and underground structures, geological baseline reports (GBR), and geotechnical instrumentation. Through case studies, the author underscores the importance of early-stage geological investigations, proper data collection, and monitoring to avoid costly project failures. The lessons learned provide valuable insights for young engineering geologists and engineers, contributing to the successful and sustainable development of hydropower projects.

Keywords: ***Hydropower, Nepal, India, GBR, Geotechnical investigations.***

Introduction

The increasing global demand for electric power, particularly in countries like Nepal and India, has led to the rapid development of hydropower projects. These regions, blessed with abundant water resources and steep terrain, provide ideal conditions for the construction of hydropower facilities.

However, one of the key challenges faced by hydropower projects in the Himalayas and other hilly regions is the presence of unforeseen and adverse geological conditions. These conditions can result in significant delays, cost overruns, and even failure if not properly addressed. Drawing on over 40 years of experience in the hydropower sector, the author shares insights into the engineering geological challenges associated with the planning, investigation, design, and construction of hydropower projects. By addressing these challenges early in the planning process, developers can avoid costly mistakes and ensure the successful completion of their projects.

Geological Considerations in Hydropower Projects

The first step in any hydropower project is site selection. The decision to select a particular site must be based on careful consideration of the geological conditions. In many cases, poor site selection has resulted in significant project delays, cost overruns, and contractual disputes. For example, one of the common pitfalls during the site selection process is the failure to identify serious geological problems that could make the site unsuitable for hydropower development. These issues may include the presence of weak or fractured rock formations, unstable slopes, or areas prone to landslides and seismic activity. By thoroughly investigating these factors during the early stages of site selection, developers can make informed decisions, such as abandoning a problematic site in favor of a more geologically stable alternative.

This decision-making process is crucial, as ignoring geological problems during site selection can lead to substantial financial losses, not only from the direct costs of dealing with unforeseen geological challenges but also from the loss of revenue due to construction delays and penalties associated with power purchase agreements (PPA).

One of the key decisions in hydropower project design is whether to construct surface or underground structures. Both options have their pros and cons, and the decision should be based on a thorough understanding of the geological conditions and the potential risks.

Surface and Underground Structures

Surface structures, such as powerhouses and dams, are often preferred for their accessibility and ease of construction. However, they are more vulnerable to extreme weather events, such as flash floods, cloudbursts, glacial lake outburst floods (GLOFs), and seismic activity. These events can cause significant damage to surface structures, resulting in costly repairs, lengthy power outages, and penalties under the PPA for failure to deliver power. For instance, in the event of a flash flood or GLOF, surface structures may be washed away or severely damaged, necessitating expensive reconstruction efforts. Beyond the cost of repairs, developers must also contend with lost revenue during the downtime and penalties for not meeting power delivery commitments.

On the other hand, underground structures, such as tunnels and underground powerhouses, offer greater protection against extreme weather events and seismic activity. While they are generally more expensive and technically challenging to construct, their resilience to natural disasters makes them an attractive option for long-term stability. The decision to go underground must also take into account the geological conditions. For instance, poor-quality rock, high water ingress, or the presence of fault zones may complicate underground construction. However, when properly planned and executed, underground structures can protect developers from the costly consequences of natural disasters and ensure uninterrupted power generation.

Challenges in Engineering Geological Investigations

During the drilling phase of engineering geological investigations, inexperienced geologists may encounter challenges in poor-quality rock formations, leading to low core recovery and inaccurate Rock Quality Designation (RQD) values. The RQD, which measures the percentage of solid core pieces longer than 10 cm in a borehole, is a crucial parameter for assessing the quality of the rock mass. If core recovery is low, it may be difficult to accurately assess the geological conditions, potentially leading to design errors and construction delays. It is essential for engineering geologists to use proper techniques during drilling and logging to ensure accurate data collection and to incorporate this data into the drilling report. This information is vital for the geotechnical and structural designers to make informed decisions regarding support systems, excavation methods, and overall project design. Another common issue is the failure to respect the stand-up time of an unsupported span during excavation. Ignoring this critical factor can lead to unexpected collapses, resulting in disputes between the developer and the contractor regarding repair work and the associated extra costs. It is essential for engineering geologists to closely monitor stand-up time during construction and to implement appropriate support systems, such as shotcrete, rock bolts, or steel ribs, to ensure the stability of the excavation. Failure to do so can result in project delays, increased costs, and potential safety hazards for workers.

Importance of GBR

A well-prepared Geological Baseline Report (GBR) is a crucial component of the feasibility study or detailed project report (DPR) for any hydropower project. The GBR serves as a reference document that outlines the geological conditions at the project site and provides a baseline for project planning, design, and construction. It includes data from pre-construction investigations, such as drilling, geophysical surveys, and laboratory testing of rock and soil samples. The GBR is not only essential for the technical team but also for lenders and banking institutions that provide funding for the project. Financial institutions are more likely to invest in projects that demonstrate sound geological planning and a clear understanding of the technical and commercial viability of the site. The GBR should include geological mapping of the site, results of borehole drilling and core logging, rock mass classifications (RQD, GSI, etc.), identification of fault zones, shear zones, and other geological hazards, recommendations for excavation and support systems and baseline data for geotechnical instrumentation and monitoring. By incorporating all of this information into the GBR, developers can avoid costly surprises during construction and provide assurance to lenders that the project is technically feasible and financially viable.

Site investigations and monitoring

Comprehensive pre-construction investigations are essential to understand the geological conditions at the project site. This includes laboratory testing of rock and soil samples to determine their strength, permeability, and other key properties. The results of these tests are critical for designing the excavation and support systems and for determining the suitability of the site for hydropower development. In addition to laboratory testing, field investigations, such as in-situ stress testing, geotechnical instrumentation and monitoring, seismic surveys, and geophysical logging, can provide valuable information about the subsurface conditions. These investigations help engineers identify potential challenges, such as fault zones, weak rock formations, and high groundwater pressure, that could impact construction. During construction, geotechnical instrumentation is used to monitor the stability of the excavation and the surrounding rock mass. By closely monitoring these parameters, engineers can detect early signs of instability and take corrective measures to prevent failures. Regular monitoring also ensures that the project stays on schedule and within budget by avoiding costly delays caused by unexpected geological issues.

Conclusion

The successful development of hydropower projects in the Himalayan region requires a sound understanding of the engineering geological conditions and careful planning at every stage of the project. By conducting thorough site investigations, preparing detailed Geological Baseline Reports, and selecting the appropriate construction methods, developers can avoid costly mistakes and ensure the timely completion of their projects.

The lessons learned from past projects provide valuable guidance for young engineering geologists and civil engineers entering the hydropower sector. By applying these insights, they can contribute to the successful development of hydropower projects that meet the growing demand for clean, sustainable energy.

Engineering Geology of Recent Hydro-climatic Disasters in Nepal

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Abstract: Continuous rainfall starting on September 27, 2024, triggered widespread flooding, inundation, and numerous landslides across Nepal, severely affecting various regions. With 77 out of 222 rainfall monitoring stations reporting over 200 mm of rainfall, several rivers, including the Sapta Koshi, reached dangerous levels, resulting in significant damage. Kathmandu Valley experienced record-breaking rainfall, leading to the flooding of over 1,200 homes and widespread power outages. The disaster also devastated rural districts, with landslides and flash floods severely impacting areas like Dhading, Sindhupalchowk, Koshi Province, and Bagmati Province. Infrastructure, including bridges and highways, was heavily damaged, with 23 highways affected and losses exceeding 2 billion. The disaster caused substantial economic impacts, particularly for rural communities reliant on agriculture. The combination of weak geological formations, poorly planned roads, and inadequate slope stabilization measures contributed to widespread landslides, while rivers like the Bagmati and Trishuli experienced severe erosion. The situation highlights the urgent need for improved disaster risk reduction strategies, including better infrastructure design, urban planning, and early warning systems to mitigate future impacts in flood- and landslide-prone areas of Nepal.

Keywords: ***Heavy Rainfall, Nepal, Landslide, Flood, Infrastructure damage.***

Introduction

Continuous rainfall starting on September 27, 2024, led to widespread flooding, inundation, and numerous landslides of varying scales across the country. According to the Department of Hydrology and Meteorology (DHM), out of 222 rainfall monitoring stations operating nationwide, 77 stations reported heavy rainfall, with amounts exceeding 200 mm on Saturday. Among the hydrological gauging stations installed in various rivers, 23 recorded water levels above the danger mark, while an additional 14 stations reported levels exceeding the warning threshold.

In the Sapta Koshi River, the water flow reached its highest level in 56 years, with a discharge of 643,040 cusecs. Kathmandu Valley also experienced record-breaking rainfall on Friday and Saturday, with DHM identifying Saturday's downpour as one of the highest ever recorded in the valley (Figure 1). The DHM's Tribhuvan International Airport station in Kathmandu recorded 239.7 millimeters of rain in 24 hours, surpassing the previous record of 177 millimeters set in 2002. The entire Kathmandu valley was inundated on 27 and 28 September, submerging numerous houses. The disaster has resulted in loss of life, destruction of homes, and significant damage to infrastructure. In this paper, the number of deaths, damage to properties and infrastructure, and an overall situational analysis of the disaster is reported.

Affected area

The floods and landslides affected multiple regions across Nepal, with Kathmandu Valley and surrounding districts like Dhading, Sindhupalchowk, and Kavrepalanchok being hit particularly hard. Torrential rains caused rivers such as the Bagmati, Bishnumati, and Hanumante to overflow, flooding nearby settlements in Kathmandu and Lalitpur. Areas like Godavari, Imadol, and Lubhu faced severe disruptions, with thousands displaced as homes were submerged and widespread power outages occurred. In Dhading district, places like Jhyaple Khola suffered significant destruction, with landslides burying vehicles and homes.

Koshi and Bagmati provinces, along with other central regions, also reported numerous landslides and flash floods. The districts of Kathmandu, Lalitpur, and Bhaktapur experienced severe impacts, with nearly 77 fatalities in the valley alone. Over 1,200 homes were flooded, while blocked roads disrupted transportation. Bhaktapur was particularly affected by inundation from the Hanumante and Bagmati rivers, leading to significant power outages across the valley. Sindhupalchok district also witnessed deadly landslides that buried residents while they slept, underscoring the widespread nature of the disaster. Despite ongoing rescue efforts, further rainfall forecasts raise concerns about additional damage. Major highways, including the Araniko and BP highways, were blocked, cutting off several regions from essential aid and delaying rescue operations. Continuous rainfall also damaged critical infrastructure, including transmission lines, resulting in long-term power outages.

In Eastern Nepal, Koshi Province suffered from landslides and floods that devastated districts such as Dhankuta, Jhapa, Ilam, and Morang. Over 500 homes were submerged, and landslides obstructed several major highways, hampering rescue efforts. Panchthar and Dhankuta were among the worst-hit areas, where landslides claimed numerous lives, including children. In Pakhribas Municipality of Dhankuta, entire families were buried under debris. Morang and Jhapa districts also faced significant river flooding, displacing hundreds of residents.

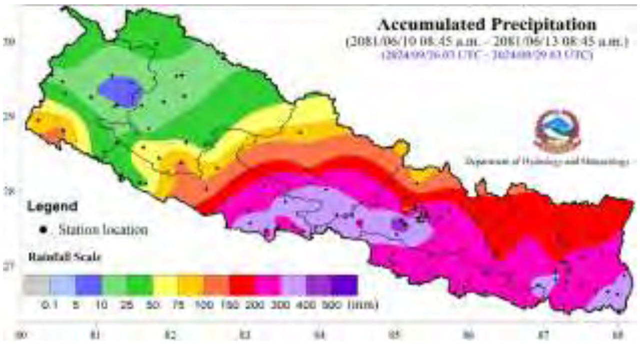

Figure 1, Accumulated Precipitation on September 27-29, 2024 (DHM 2024)

A total of 23 highways across Nepal have been affected, with estimated losses surpassing 2 billion due to roadblocks and damaged bridges. The Bhote Koshi River swept away three concrete bridges—Larcha, Liping, and Ghatte Khola—along the Araniko Highway, which serves as a key route between Nepal and China. Landslides have also blocked several sections of the highway, while water levels in multiple rivers, including the Narayani, Kankai, Kamala, Bagmati, Eastern and Western Rapti, and Babai Chepang, have risen to dangerous levels. In Koshi Province, four bridges were destroyed, including the one over Hewa Khola on the Mechi Highway in Panchthar, and the permanent bridge over Rati Khola connecting Ilam Sandakpur. Additionally, flooding washed away the bridge linking Ramechhap and Sindhuli districts in the Khurkot area.

Economic Impact

The disaster is expected to have a significant economic impact. The destruction of homes, infrastructure, and agricultural land will result in considerable financial losses for both individuals and the government. The cost of rebuilding damaged infrastructure, such as roads and bridges, will be immense. Additionally, disruptions to transportation and agriculture could lead to long-term economic challenges, especially for rural communities that depend heavily on farming as their main source of income (Figure 2).

Engineering geological causes of disaster

The affected regions are dominated by weak, fractured, and weathered rock formations, particularly schists, phyllites, and slates from the Lesser Himalayan Zone. These types of rocks are highly susceptible to failure during intense rainfall, leading to both shallow and deep-seated landslides. The heavy downpour, concentrated over a short period, caused rivers to swell, intensifying erosion along riverbanks and contributing to debris flows. Large quantities of loose sediment were also carried by the rivers, exacerbating downstream flooding. In several areas, inadequate natural drainage systems resulted in waterlogging and slope saturation, further increasing the occurrence of landslides.

Figure 2, Total Economic Loss (NDRRMA 2024)

Poorly planned and designed rural roads in mountainous regions, lacking proper slope stabilization measures, triggered many landslides. Excavations for new road corridors destabilized slopes, leading to additional failures. Settlements built on unstable hillslopes and floodplains increased vulnerability, with construction practices that failed to account for geological conditions or slope mitigation measures, intensifying the landslide risk during the heavy rainfall.

Rivers such as the Trishuli, Roshi, Sunkoshi, Bagmati, and their tributaries experienced severe bank erosion, damaging nearby infrastructure including bridges, roads, and settlements. Saturated debris accumulated during the rainfall was flushed down steep slopes, creating destructive debris flows that covered and damaged large areas with boulders and debris, making them more hazardous than typical landslides. Protective structures such as check dams, retaining walls, and slope stabilization measures were either insufficient or entirely lacking along rural roads and newly excavated areas, worsening the impact of the disaster.

These engineering geological challenges emphasize the urgent need for improved disaster risk reduction strategies, focusing on better infrastructure design, urban planning, and early warning systems in areas prone to floods and landslides in Nepal.

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Rock and Debris Fall Detection Using Total Gray Level Method

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Abstract: This study investigates the application of the total gray level method for identifying rock and debris falls through video analysis, offering a viable alternative to resource-heavy machine learning techniques. The method focuses on variations in total grayscale intensity within a specified Region of Interest (ROI) and establishes a detection threshold informed by environmental noise levels. Initial tests showed that this approach effectively detected ongoing rock and debris falls while requiring minimal computational resources. The findings indicated that while a threshold set at twice the noise level was too sensitive, increasing it to five times the noise level considerably enhanced accuracy.

Keywords: ***Debris fall detection, Early warning, Image analysis, Rockfall detection, Total gray level.***

Introduction

Rock and Debris fall are a common natural disaster that can cause significant damage to property, infrastructure, and human life. Monitoring of this event involves the continuous and systematic observation of landslide activity, including its movement, deformation, and other associated phenomena. Along with ground-based sensors and satellite monitoring, use of image analysis from video recordings is one of the important methods for monitoring landslides and slope land disasters (Liu, Kuo, & Wei, 2021) and (Noël et al., 2022). These monitoring data can help identify potential risks, assess the magnitude of rock and debris fall hazards, and inform decision-making processes for disaster management. With accurate and reliable monitoring, early warning systems can be established to notify communities and authorities in advance of potential landslide events, reducing the risk of loss of life and damage to infrastructure.

In today's world of machine learning which consumes high computational resources (Pham & Kim, 2022), simple image analysis methods which doesn't consume as much computational power can be a very important tool for detecting landslides (Liu et al., 2021). Using total gray level method, which calculates and compares the change in total gray level intensity of an image for detection, can be one of the effective methods.

Methodology

To analyze the movement of rock or debris particles in the video recording, a tracking block (Region of interest, ROI) is selected to limit the analyzing area. The total gray level $G_f(t_N)$ and the slope of gray level $S(t_N) = G_f{}'(t_N)$ in the ROI was calculated as an indicator.

For the detection of the event, noise is defined as the moving average of the gray level, while the slope of the noise represents the moving average of this gray level slope for a duration of an order larger than detection time threshold to smooth out the statistically insignificant peak events. The detection criteria hinge on two primary conditions:

First, the change in gray level must exceed a threshold

$$\text{Gray Level Change} > \alpha \times \text{Noise of Gray Level for } \Delta t_d$$

Second, the slope of the gray level change must also surpass a defined threshold

$$\text{Slope} > \beta \times \text{Slope of Noise, Positive for } \Delta t_d$$

Where, α and β are sensitivity factors which is greater than an order of magnitude larger than average noise and are based on the physical characteristics of the site and failure mechanisms including speed, size and type of potential failure. Δt_d is the time threshold for detection which is based on the smallest resolvable particle. To ensure accurate detection of landslide events, the parameters α, β and Δt_d should be determined in advance based on the specific conditions of the monitoring environment.

Results

This method was evaluated through both an experimental setup (Figure 1) and a real-world scenario (**Error! Reference source not found.**) using monitoring video footage of a landslide in Xindian, Taiwan. Preliminary tests of the Total Gray Level Method demonstrated success in detecting ongoing rock and debris falls with a stationary camera, even at low frame rates. The application of double threshold criteria allowed for the detection of fast-moving rock particles while effectively ignoring slower-moving particles that posed minimal risk to roads, resulting in a reduction of false positives compared to a single threshold approach. The detection time for this method was 0.03 seconds earlier in the experimental setup and 3.7 seconds earlier in the real-world scenario than visual detection.

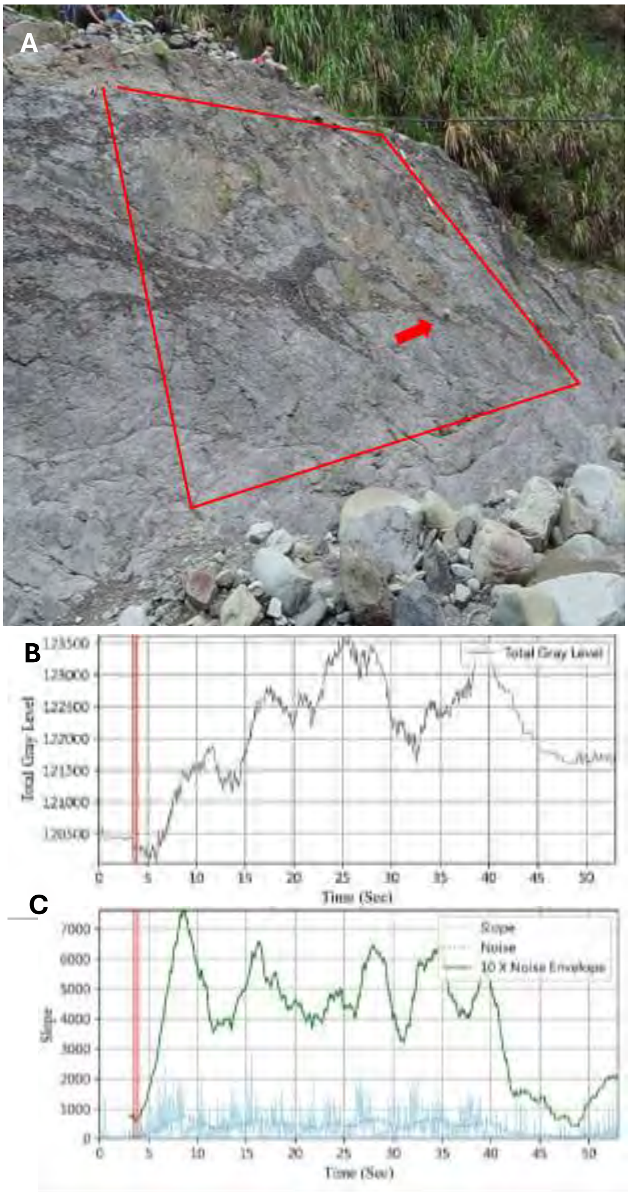

*Figure 1: Experimental setup for total gray scale method. **A**: experimental slope with ROI marked with red boundary and red arrow showing the detected rock from the program. **B**: the change of gray level for the selected ROI and **C**: is the change of slope for the selected ROI, blue markings show the change in slope, with blue line showing the noise level, the green line is the detection envelope. The red region in B and C shows the detection time.*

Conclusion

Use of traditional image analysis techniques such as total gray level method can be a low-cost and effective approach for detecting landslides. Using total gray level method can successfully detect ongoing landslides, even in low light conditions and low frame rate. Future work should focus on developing an algorithm to also determine the end of events, enabling the characterization of multiple events and their durations.

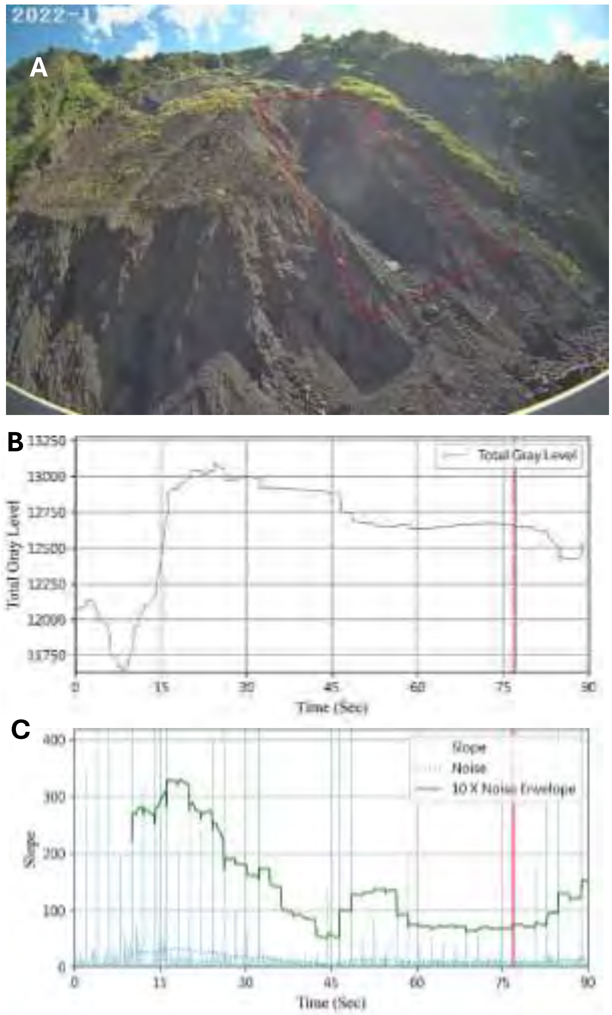

*Figure 2: Real-world monitoring at Xindian, Taiwan for total gray scale method. **A**: slope with ROI marked with red boundary. **B**: the change of gray level for the selected ROI and **C**: is the change of slope for the selected ROI, blue markings show the change in slope, with blue line showing the noise level, the green line is the detection envelope. The red region in B and C shows the detection time.*

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Comparative Analysis of Rainfall Thresholds for Landslide Initiation Using Terrestrial Rain Gauges and Satellite Data in Nepal: Challenges and Opportunities

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Abstract: Landslides triggered by intense monsoon rainfall pose a significant hazard in Nepal, leading to substantial loss of life and property. The implementation of Landslide Early Warning Systems (LEWS) based on rainfall thresholds can help mitigate these impacts. These thresholds, which specify the minimum rainfall required to trigger landslides, are essential for effective disaster risk reduction. This study investigates the uncertainties surrounding rainfall threshold definitions for landslide forecasting in Nepal, primarily due to the limited number of Automatic Weather Stations (AWS). It emphasizes the shortcomings of gauge measurements, including their sparse distribution, lack of high temporal resolution, high costs, and delayed reporting. The study also highlights the growing accuracy and potential of satellite rainfall products, which provide higher spatial and temporal resolution, comprehensive coverage, and no missing data. However, it addresses the challenges of developing LEWS using satellite data and recommends enhancing the network of rain gauges and improving landslide documentation systems. Additionally, the comparison of rainfall thresholds indicates that those derived from AWS are slightly higher than those from satellite data, suggesting that terrestrial rain gauges may indicate a greater rainfall requirement for landslide initiation.

Key words: ***Landslides, Landslide early warning system, Rainfall thresholds, Automatic weather station, Satellite rainfall product.***

Introduction

Landslides in Nepal have led to substantial loss of life and property, with 4,125 fatal incidents and 3,837 deaths recorded between 1970 and 2021, averaging 71 deaths annually (Pradhan, 2020). To mitigate these losses, implementing Landslide Early Warning Systems (LEWS) based on rainfall thresholds is crucial. These thresholds indicate the minimum rainfall required to trigger landslides and are essential for effective disaster risk reduction (Reichenbach et al., 1998; Guzzetti et al., 2008; Dahal and Hasegawa, 2008).

However, the reliability of landslide forecasting relies heavily on the quality of rainfall data. Traditional rain gauge measurements present challenges, including high costs, sparse distribution, and insufficient temporal resolution, particularly in developing regions lacking rain gauges. To address these limitations, satellite rainfall data has gained traction due to its global availability, improved spatial and temporal resolution, and enhanced accuracy. Satellite products such as CMORPH, TRMM's TMPA, and GPM's IMERG show promise for enhancing LEWS (Zhao et al., 2022). This study compares thresholds derived from Automatic Rainfall Stations (AWS) and the IMERG dataset using the CTRL-T algorithm (Melillo et al., 2018), highlighting the potential of satellite data for landslide forecasting.

Methodology

The 607 landslide catalogue prepared from the multifaceted approach was used for the analysis. Among them the landslide classified as certain are with the time of the landslide event was used for the analysis. The rainfall data the “IMERG, GPM: Global Precipitation Measurement (GPM) v6” (the spatial resolution of 0.1° ×0.1° and half hour) was used as a satellite rainfall data and the Automatic Weather Station (AWS) operated by Department of Hydrology and Meteorology was used as a terrestrial rainfall product for the determination of rainfall thresholds.

The CTRL-T algorithm was used for the determination of rainfall thresholds. It automates the reconstruction of rainfall events to determine landslide-triggering conditions. It calculates rainfall thresholds at various Non-Exceedance Probabilities (NEPs) using continuous rainfall and landslide data. The algorithm selects representative rain gauges, identifies multiple failure-causing conditions, and assigns probabilities to determine probabilistic thresholds with associated uncertainties. It employs statistical bootstrapping and the frequentist methodology, generating 5000 synthetic series using the power law equation for threshold establishment.

Result

The deployment of the CTRL-T algorithm to determine the most likely rainfall conditions for landslide initiation encountered several limitations. The Automatic Weather Stations (AWS) operated by the Department of Hydrology and Meteorology (DHM) are sparse and have been functioning only since 2019, resulting in a coarse spatial resolution. To improve data representativeness, 22 additional rain gauges were installed in the study area, and a 15 km buffering distance was implemented to fill data gaps. However, due to missing data and interruptions in the dataset, only 31 out of 235 landslide events were included in the analysis. This limited dataset may not adequately represent the conditions necessary for defining accurate rainfall thresholds.

Table1, Comparison between different non-exceedance probabilities (NEP) obtained from IMERG and AWS

NEP	Threshold Equation	
	IMERG (Satellite)	AWS (Rain Gauge)
1%	$T_{1,}$ E= 2.7 ± 1.2 $D^{0.46 \pm 0.1}$	$T_{1,}$ E= 8.0 ± 6.1 $D^{0.33 \pm 0.1}$
5%	$T_{5,}$ E= 4.0± 1.6 $D^{0.46 \pm 0.1}$	$T_{5,}$ E= 11.6± 8.2 $D^{0.33 \pm 0.1}$
10%	$T_{10,}$ E= 4.8 ± 1.9 $D^{0.46 \pm 0.1}$	$T_{10,}$ E= 14.2 ± 9.6 $D^{0.33 \pm 0.1}$
20%	$T_{20,}$ E= 6.2 ± 2.3 $D^{0.46 \pm 0.1}$	$T_{20,}$ E= 18.2 ± 11.6 $D^{0.33 \pm 0.1}$
35%	$T_{35,}$ E= 7.9 ± 2.9 $D^{0.46 \pm 0.1}$	$T_{35,}$ E= 23.6 ± 14.2 $D^{0.33 \pm 0.1}$
50%	$T_{50,}$ E= 9.8 ± 3.5 $D^{0.46 \pm 0.1}$	$T_{50,}$ E= 29.5 ± 16.9 $D^{0.33 \pm 0.1}$

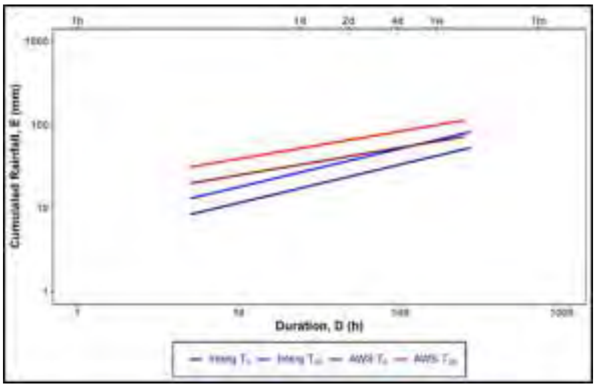

Figure 1, Comparison between different non-exceedance probabilities (NEP) obtained from IMERG and AWS

To facilitate a relative comparison between the thresholds derived from terrestrial rain gauges and the IMERG rainfall dataset (Table 1 and Figure 1), all data from the rain gauges were substituted with the IMERG dataset. This ensured that both datasets had an equal number of missing and available data points, allowing for a consistent evaluation. The analysis of the 31 landslides and their corresponding rainfall durations revealed that the thresholds from terrestrial rain gauges were slightly higher than those obtained from the IMERG dataset. This indicates that a greater amount of rainfall is necessary for landslide initiation when considering terrestrial rain gauges. Conversely, the thresholds derived from IMERG appeared steeper, suggesting that a higher precipitation amount is required over time compared to the terrestrial rain gauge data. Furthermore, the uncertainties associated with the rain gauge data were greater than those of the IMERG data, likely due to the limited number of rainfall events leading to a wider dispersion in the data set.

Discussion and Conclusion

Due to the sparse distribution of terrestrial rain gauges, lack of high temporal resolution, high costs, missing data, and the recent operations of AWS rain gauges, fewer landslides were included in the analysis, resulting in a higher degree of uncertainty. The uncertainties related to the γ parameter at a 5% non-exceedance probability (i.e., Δγ/γ) is 30.3%, and the uncertainties related to the α parameter (i.e., Δα/α) is 70.6%. These high uncertainties are attributed to the very low number of landslides used to define the rainfall thresholds, which can be reduced by increasing the number of landslides. Satellite rainfall data offers significant advantages for determining rainfall thresholds, thanks to its global accessibility, high spatial and temporal resolution, and continuous data availability, which enhances accuracy. By utilizing satellite data, researchers can expand the dataset of rainfall events from 31 to 235, reducing uncertainty associated with thresholds and addressing the limitations of Automatic Weather Station (AWS) rain gauges. This study underscores the benefits of satellite rainfall products in calculating thresholds while also highlighting their limitations. It reveals the high uncertainty in defining rainfall thresholds based on insufficient landslide data, which can hinder effective early warning systems. Although an increase in rain gauges could improve threshold determination, the current thresholds derived from AWS stations in Nepal are not promising. The study emphasizes the need for more AWS installations in Nepal's hilly terrain to enhance monitoring and prediction capabilities and recommends improving both the number and performance of these stations.

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Rockfall Analysis for the Construction of Flexible Rockfall Barrier System at Upper Tamakoshi Hydroelectric Project

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Abstract: Rockfalls pose a significant hazard in Nepal due to its steep terrain, fragile geology, and frequent seismic activity, with risks further heightened during the monsoon season. The Upper Tamakoshi Hydroelectric Project (UTKHEP), Nepal's largest hydroelectric project, has faced persistent rockfall issues at its take-off yard since the early construction phase. This study investigates the design and implementation of a rockfall protection barrier to safeguard the project's infrastructure. A comprehensive field survey, including drone imaging and rock boulder analysis, was conducted to assess potential rockfall sources and deposition zones. The CRSP computation method was employed for rockfall simulation using GeoRock-2D software, with parameters such as boulder size, slope material, and surface characteristics. Simulation results identified optimal locations for barrier placement based on maximum energy and bounce height of falling rocks. The study highlights the importance of rockfall mitigation for infrastructure protection in Nepal's mountainous regions.

Keywords: ***Rockfall, CRSP, GeoRock-2D, Rockfall barrier.***

Introduction

Rockfall in Nepal are a significant hazard due to the country's steep, mountainous terrain, fragile geology, and frequent seismic activity. The risk of rockfalls is heightened during the monsoon season, when heavy rains saturate the soil and weaken slopes, causing rocks to detach and fall onto roads, settlements, and agricultural land. Earthquakes, like the 2015 Gorkha earthquake, also play a critical role in triggering rockfalls by loosening rock formations and destabilizing slopes. These events can lead to loss of life, damage to infrastructure, and disruptions to transportation in rural and urban areas, making rockfall management a key concern for disaster risk reduction in Nepal.

Rockfall protection barriers serve as a secondary form of defense in possible deposition zones of rock fall, such as collapsed cliffs. Upper Tamakoshi Hydroelectric Project (UTKHEP) 456 MW is the largest hydroelectric project so far in Nepal which is under completion. The take-off yard of this national priority project at Gongar has been facing rock-fall issues since its early phase of construction. In this context, Upper Tamakoshi Hydroelectric Project decided to protect the structures from future rockfall hazards using special mitigating measures. An analysis was carried out for the construction of the rockfall barrier at the take-off yard.

Methodology

A joint survey was carried out in the rockfall area and old temporary fences were inspected to check the impact observed. Drone survey was also carried out to capture the terrain information, rockfall source and deposition zone during field investigation. To assist in numerical simulation, rockfall sources were identified. Figure 1 shows the drone image and tentative area of rock fall sources. In addition to this, rock boulder survey was also carried out to identify rock sizes that can fall during a rockfall event. Figure 2 shows the different types of rock boulders found in the area and the measurement carried out, which helped us identify boulders of disc shape.

Figure 1, Drone image showing the rockfall deposition and source area including vulnerable area

CRSP computation method is used for the rockfall simulation. The input parameter used for the rockfall simulation depends on the surface characteristics of the slope. The restitution coefficient represents the surface characteristics of the slope material. Both normal and tangential restitution coefficient ranges from 0.29 to 0.9. The restitution coefficient of the material is taken from different scientific studies (Pfeiffer et al. 1989, Giani 1992). The boulder size is determined from the block analysis of the discontinuities.

Figure 2, Rock boulders measurement carried out on the slope and deposition area.

Result

Simulation of rockfall event was carried out based on field observations, measurements and notes using GeoRock-2D. The profile selected for the simulation is shown in Figure 3. Boulders are assumed as cylindrical shapes. Following are the simulation input parameters:

- Rock type: Biotite banded gneiss
- Materials used in slope: degraded rock, rock detritus, paved surface debris with vegetation and terrain/grass.

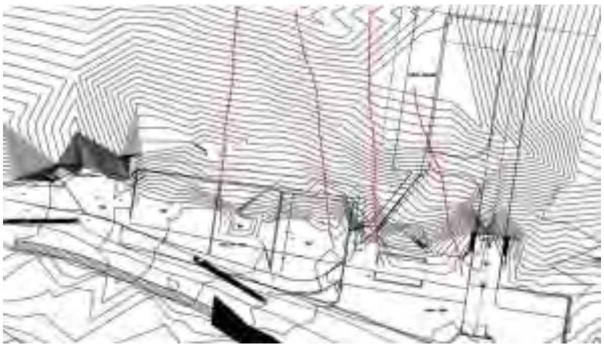

Figure 1: Selected simulation profile.

- Cylinder diameter: 0.6 m
- Cylinder height: 0.62 m
- Specific weight: 9000 kg/m^3
- Elasticity modulus: 11000 kPa

For all selected profiles, numerous trajectories were selected, and simulation was performed to determine maximum energy and bouncing height and best location to meet both criteria is selected for the position of rock fall barrier. Figure 4 shows the simulation scenarios with and without post on slope.

Conclusion

In conclusion, rockfalls pose a significant hazard in Nepal, exacerbated by the country's steep terrain, fragile geology, and seismic activity, particularly during the monsoon season. The Upper Tamakoshi Hydroelectric Project, Nepal's largest hydroelectric initiative, faces ongoing rockfall challenges, necessitating the implementation of protective measures.

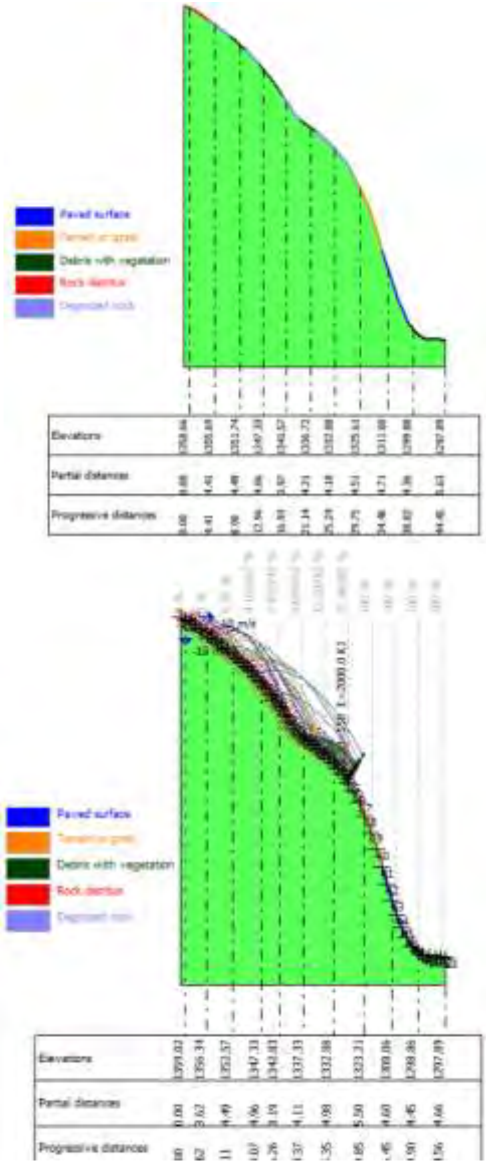

Figure 2: Simulation results on profile.

This study utilized a combination of joint surveys, drone technology, and numerical simulations to analyze potential rockfall sources and design an effective rockfall barrier at the take-off yard. The findings highlight the importance of understanding slope characteristics and boulder dynamics to enhance rockfall management strategies. The proposed barrier aims to mitigate risks, ensuring the safety and continuity of infrastructure and reducing disaster impacts in vulnerable areas.

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Paleo landslide reactivation and threat to the people in the Nepal Himalaya

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Abstract: Landslides are significant natural hazards influenced by factors such as rainfall, earthquakes, and human activities, posing severe risks to communities, particularly in the Nepal Himalaya. This study focuses on the reactivation of ancient landslides in Sindhupalchwok, Nuwakot, and Rasuwa Districts, where 114 distinct landslide deposits were reactivated during the monsoon season between 2019 and 2023. Field surveys identified and analyzed the geological and socio-economic factors contributing to this phenomenon. Laboratory tests on disturbed soil samples revealed low cohesion values (3 to 10.5 kPa) and a plasticity index of 3 to 7, indicating the soil's vulnerability to deformation under saturated conditions. Additionally, increased rainfall (ranging from 2300 mm to 3200 mm) and seismic activity, particularly the 2015 Gorkha earthquake, have exacerbated instability. The study highlights the threat to 287 houses and 792 individuals residing on these landslide deposits, underscoring the urgent need for effective risk mitigation strategies to enhance community resilience against future landslide events.

Keywords: ***Landslide reactivation, settlement threat, Nepal Himalaya, soil investigation.***

Introduction

Landslides are natural hazards that occur when soil, rock, or debris flows downhill under the influence of gravity (Varnes 1978). Various factors contribute to their occurrence, including rainfall, earthquakes, and human activities such as deforestation and construction. The monsoon season in Nepal typically brings heavy rains, leading to saturated soil conditions that can destabilize slopes (Dahal 2012).

The reactivation of old landslides has increasingly become a pressing issue in the Nepal Himalaya, particularly in regions like Sindhupalchwok, Nuwakot, and Rasuwa Districts. Many communities have long inhabited areas atop historical landslide debris, unknowingly exposing themselves to the persistent threat of reactivation. This study investigates the deformation mechanisms of reactivated landslides and the consequent risks faced by residents in these districts, particularly between 2019 and 2023.

During this period, an alarming number of one hundred and fourteen distinct ancient landslide deposits were reactivated during the monsoon season. The increasing frequency and intensity of monsoon rains, combined with geological and human factors, have led to a heightened risk of landslides. This research not only emphasizes the geological parameters influencing these reactivations but also underscores the socio-economic vulnerabilities of the communities affected.

Study Area and Methodology

The study area encompasses Sindhupalchwok, Nuwakot, and Rasuwa Districts, which are characterized by a complex interplay of geological and climatic factors conducive to landslides. Both remote sensing and extensive field surveys were conducted to identify and analyze reactivated landslides. A community survey and focus group discussion were conducted to ascertain the occurrence dates of certain unreported landslides.

Data Collection

The data collection involved, field survey, soil sampling and strength test. Landslide deposits and areas affected by reactivation of landslide were identified. Disturbed soil samples from twenty major reactivated landslides were collected for laboratory analysis. Multistage direct shear tests were conducted on unsaturated soil samples to determine shear strength parameters. Casagrande plasticity chart was used to classify the soil after doing liquid limit and plastic limit test. Seismic and precipitation data from 2010 to 2023 were collected to determine an association with reactivated landslide data.

Analysis and Result

The shear strength tests revealed important characteristics of the soil samples obtained from reactivated landslides:

Cohesion Values: Ranging from 3 to 10.5 kPa, indicating low cohesion.

Internal Friction Angle: Varies between 19 and 29 degrees, further indicating instability.

Plasticity Index: Ranged from 3 to 7, suggesting that the soils are not highly plastic.

Soil Composition: The gradation study classified the soils primarily as clayey sands (SC) with low plasticity and low cohesion.

There is no significant peak in the shear stress versus horizontal displacement curve which revealed that the soils are loose in nature (Fig.1). Similarly, the shear strength of the sampled soils is below 40 kPa.

These properties suggest that the soils are prone to deformation, particularly under saturated conditions during heavy rainfall.

The average rainfall during the monsoon season from 2010 to 2023 ranged from 2300 mm to 2800 mm, with a notable increase in early monsoon rainfall observed since 2019. The total rainfall during the monsoon period experienced a significant increase, reaching up to 3200 mm in Sindhupalchwok district, while Nuwakot district saw its rainfall peak at 3050 mm in 2023. The extreme rainfall events, particularly those occurring during the pre-monsoon period after an extended dry season, have contributed significantly to surface deformation in the study area.

The 2015 Gorkha Earthquake of 7.8 magnitude, along with its aftershocks, exacerbated the situation by loosening rock formations and destabilizing slopes. The combination of seismic activity and heavy rainfall has created a precarious situation for residents living atop these ancient landslide deposits. The number of reactivated landslides rose from 2015 to 2017; however, there was a notable increase in landslide reactivation from 2020, despite the absence of significant seismic events, attributed to a rapid increase in rainfall during the monsoon period (Figure 2 and Figure 3).

The socio-economic implications of landslide reactivation are profound. The study identified that a total of 287 houses and approximately 792 individuals are currently under threat from potential paleo-landslide reactivation in the affected districts.

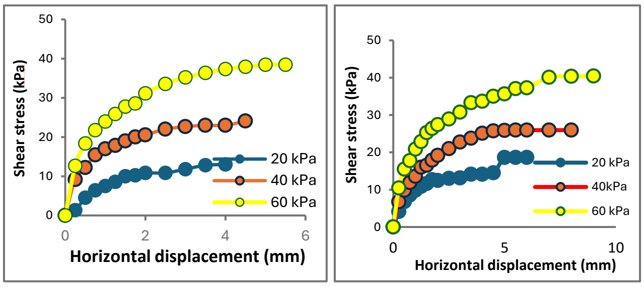

Figure 1: Shear stress versus horizontal displacement curve of two representative soil samples.

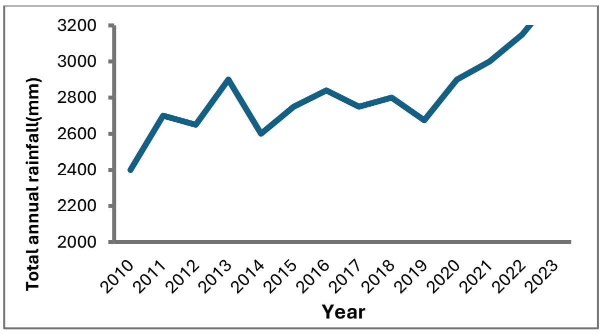

Figure 2: Year wise distribution of earthquake magnitude and reactivation events

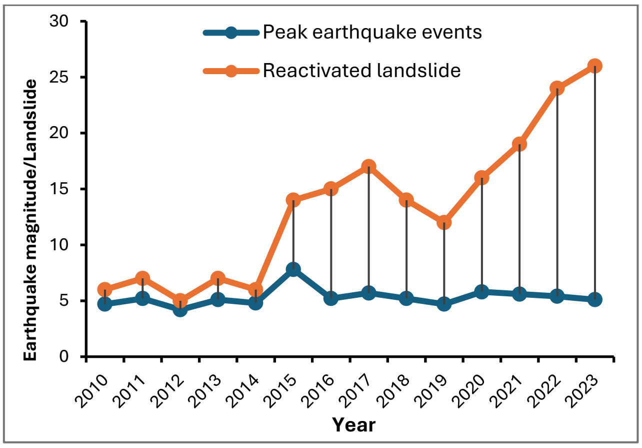

Figure 3: Average of total annual rainfall distribution in three districts

Conclusion

The reactivation of old landslides in the Sindhupalchwok, Nuwakot, and Rasuwa Districts poses a significant threat to local communities, exacerbated by increasing rainfall and seismic activity. The analysis of soil characteristics and rainfall patterns underscores the vulnerability of these areas and highlights the need for targeted interventions.

As many residents continue to live atop ancient landslide deposits, it is imperative to implement comprehensive risk mitigation strategies that include community education, monitoring systems, and effective land-use planning. Addressing these challenges will not only protect lives and property but also enhance the resilience of communities against future landslide events in this geologically complex region.

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Comparative Analysis between Crushed Aggregate from Siwalik, Lesser Himalaya and River-Bed Sources in Bagmati Region: Adopting M25 - Plain, Steel Fiber and Glass Fiber Shotcrete

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Abstract: The escalating demand for aggregates in Nepal, driven by rapid urbanization and infrastructure development, presents significant challenges as natural resources are depleting and disrupting river ecosystems. This research examines the properties of shotcrete produced from various aggregate sources, specifically Siwalik, Lesser Himalayan, and riverbed crushed aggregates and also various composition like plain, glass fiber and steel fiber shotcretes. Key performance indicators—including air content, slump (workability), compressive strength, and flexural strength—were analyzed according to established standards. Results indicated that Lesser Himalayan crushed aggregates provided superior workability, compressive strength, and flexural strength, making them the most suitable option for high-performance applications. In contrast, riverbed aggregates showed limitations that could impact structural integrity and ecosystem. Moreover, compositionally, steel fiber shows the superiority in comparison to plain and glass fiber shotcrete. This study underscores the importance of selecting high-quality aggregates to enhance the durability and sustainability of construction projects in Nepal, advocating for the adoption of crushed rock aggregates to mitigate environmental impacts while fulfilling infrastructure needs. Future research should further explore the long-term performance and environmental implications of these materials.

Keywords: ***Crushed aggregates, Shotcrete, Compressive strength, Flexural strength, Slump test, Air content.***

Introduction

The escalating demand for aggregates in Nepal, driven by rapid population growth and infrastructure development, highlights the critical role of these materials in construction applications like concrete and shotcrete. Natural quarries of sand and gravel are insufficient to meet this rising demand, leading to significant disturbances in river ecosystems. This situation necessitates the exploration of sustainable alternatives, such as crushed rock aggregates, to supplement dwindling natural resources and support infrastructure development while minimizing environmental impacts. Over-extraction of traditional aggregate sources contributes to erosion, habitat destruction, and altered river dynamics. Therefore, high-quality aggregates are essential for the durability and longevity of civil engineering projects, influencing the structural integrity of buildings, roads, slopes, bridges, and tunnels. Understanding the properties of different aggregate sources is crucial for optimizing spray-concrete/shotcrete performance and ensuring sustainable development practices in Nepal. As the country continues to urbanize, adopting crushed rock aggregates could promote environmental sustainability while meeting the growing construction demands effectively. This research aims to compare various properties of shotcrete obtained from different aggregate sources: Siwalik, Lesser Himalayan Zone, and riverbed crushed aggregates; along with different mode of composition using Plain, Steel Fiber and Glass Fiber. The study focuses on analyzing key properties such as air content, slump (workability), compressive strength, and flexural strength of the shotcrete. By evaluating these properties, the research seeks to identify the most suitable aggregate source for shotcrete applications in Nepal, promoting better performance and sustainability in construction project and practices.

Methodology

Materials used in this study were as follows:

- Aggregates: Siwalik crushed aggregates, Lesser Himalayan crushed aggregates, River-bed crushed aggregates.
- Cement: Ordinary Portland Cement (OPC)-43 Grade was used as per standard specifications.
- Water: Clean, portable water was utilized for mixing and curing.
- Additives: Chemical admixtures used as required for improving workability and performance.
- Superplasticizer: High grade PC chemicals where used source name is SBT Chemicals.

- Accelerator: Alkali Free accelerator is used source name is SBT Chemicals.
- Steel Fiber: Double hooked having and length of 0.60/30mm is used source name is Earth Fiber Pvt. Ltd.
- Glass Fiber: Glass fiber is used source name is Earth Fiber Pvt. Ltd.

Samples of shotcrete were prepared according to the guidelines provided in IS 456:2000, IS 10262-2019, SSFRB-2078, and IS 9012. The preparation involved:

- Cubic Samples for Compressive Strength: Cubes of size 10 cm x 10 cm x 10 cm were cast to evaluate compressive strength.
- Beam Samples for Flexural Strength: Beams of size 140 cm x 10 cm x 10 cm were cast for flexural strength testing (based on laboratory trial).

Testing Procedures

Workability Measurement (Slump Test): The slump cone test method was employed to assess the workability of the wet shotcrete (spray-concrete) mix. A fixed water-cement ratio was maintained according to the mix design guidelines (IS) for consistent results.

- Compressive Strength Testing: The compressive strength was evaluated at intervals of 1,3, 7, and 28 days using a compressive testing machine.
- Flexural Strength Testing: The flexural strength was tested after 28 days of curing, measuring the load at which the beam fails; using a universal testing machine.
- Air Content Measurement: The air content was measured using an appropriate method to evaluate the influence of different aggregates on the air voids in the concrete mix.

Results and Discussion

Lesser Himalayan (Quartzite, Metasandstone) crushed aggregates produced a higher slump, indicating better workability, likely due to their angular shape and gradation; as similar to the river-bed crushed aggregates, while Siwalik's aggregates exhibited moderate workability, suggesting challenges in achieving the desired flow and application of shotcrete. In addition, Steel Fiber Shotcrete shows better compressive strength in comparison to Plain and Glass Fiber Shotcrete in respective sequence. The water-cement ratio significantly influenced workability, emphasizing the importance of appropriate mix design to ensure optimal performance in shotcrete applications.

Compressive Strength

The compressive strength results indicated variations based on aggregate type:

- Siwalik Aggregates: Showed satisfactory strength development but were slightly inferior to Lesser Himalayan crushed aggregates.
- Lesser Himalayan Aggregates: Demonstrated superior compressive strength across all curing periods, highlighting their suitability for high-performance applications.
- River-Bed Crushed Aggregates: Underperformed in compressive strength tests, indicating potential limitations in structural applications.

Also, based on the composition, results indicate the variation in increasing order of compressive strength as: Glass Fiber→Plain→Steel Fiber Shotcrete.

Flexural Strength

The flexural strength results followed similar trends to compressive strength. Lesser Himalayan crushed aggregates yielded the highest flexural strength, indicating robust structural performance. Siwalik's crushed aggregates exhibited adequate flexural properties. These findings highlight the necessity of selecting appropriate aggregate sources to achieve desired flexural properties in shotcrete applications.

Air Content

The air content measurements revealed that aggregates' shape, texture, and gradation significantly influenced the air voids in shotcrete. Higher air content can lead to reduced density and strength, impacting the overall durability of the shotcrete.

Conclusion

In conclusion, the growing demand for aggregates in Nepal, driven by rapid urbanization and infrastructural development, necessitates a shift towards sustainable alternatives. The research highlights the importance of using crushed rock aggregates to mitigate environmental impacts while meeting construction needs. Lesser Himalayan (quartzite, metasandstone) crushed aggregates emerged as the most favorable option, exhibiting superior workability, compressive strength, and flexural strength, making them ideal for high-performance applications. Siwalik (sandstone) aggregates showed adequate performance, while riverbed aggregates demonstrated limitations that could compromise structural integrity. Among Plain, Glass Fiber and Steel Fiber Shotcrete, Steel Fiber and Plain Shotcrete shows the highest strength and optimum density in comparison to the Glass Fiber. Overall, this study underscores the critical role of aggregate quality in ensuring the durability and sustainability of construction projects in Nepal. Future research should explore the long-term performance of shotcrete with different aggregate blends and assess their environmental impacts, further contributing to the sustainable development of the region's infrastructure.

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Influence of Variations in Precipitation at Pore water Pressure Causing Surface Layer Failure of Naturally Undulated Slope of the Nau Kilo at Narayangadh-Mugling Road, Central Nepal

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Abstract: This work focuses on the naturally undulated slope with topographic failures, their flow direction, and the discharge of hill slope seepage, to recognize the pore water pressure variations phenomenon in connection with slope failures in the hollows. A small naturally undulated slope containing a topographic hollow, with six failures caused by rainfall events from 2001 to 2023, was chosen for this research work. The precipitation date of July 31 2003 was used for seepage and slope stability modelling in the GeoStudio environment. A threshold relationship between the topographic hollow area and maximum pore water pressure was prepared for the 24-hour maximum rainfall data and its 5, 10, 25, 50, and 100-year return period. Each return period rainfall event is normalized into a 24-hour event using daily rainfall of 6 min length with potential seepage face applied for the simulations. Furthermore, a threshold relation between the study's topographic hollow area and maximum pore water pressure indicates that a hollow of 100 sq. m area can develop maximum pore water pressure of 6.94 kPa as indicated by 24-hour maximum rainfall data.

Keywords: ***Hillslope Hydrology, Threshold for shallow failure, Pore water pressure.***

Introduction

The intense rainfall reduces the shear strength of the soil by gradually increasing pore water pressure, which leads to the instability of the slope Setyawan et al. (2021). Thus, the seepage and slope stability model is applied in naturally undulated slopes to recognize possible processes leading to slope failure and to provide proper guidance leading to the mitigation measures Acharya et al. (2016). Seepage modeling is the process of examining the flow of moisture in and out of the soil and dealing with the evolution of pore water pressure within the soil.

Methodology

The field investigation was done to gather the length/width of slope failure zones, soil thickness, and soil permeability. A dynamic cone penetration test was done to determine the thickness of the soil in the research area. For the permeability of the soil in-situ permeability test was done in the study area. Disturbed soil sampling was collected due to the impossible of

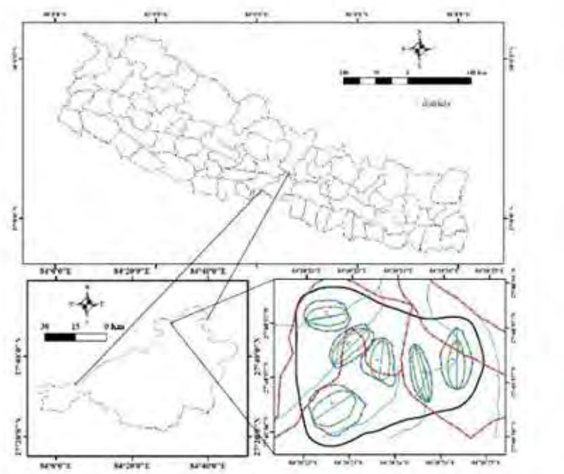

Figure 1, Location map of the study area.

undisturbed sampling in the field. An overall field survey was conducted to determine the area of the failure, soil thickness, and permeability of the soil. A series of laboratory work was performed to obtain definitive information on the soil properties.

Based on the flow direction map of the study area slopes were chosen for the modeling and evaluation of the stability of the area. The flow direction map shows the most unstable area on the flow line of the subsurface water in the naturally undulated slope. The most critical part of the slopes was chosen which represents the entire geometry of the study area. The slope was a natural slope with average slope angles ranging from 31 to 62 degrees. The required geotechnical parameters for the modeling were obtained from both field tests and laboratory tests. The slope profile was extracted with the help of Arc Map 10.8, Google Earth Pro, and DEM of the area. In the research area, six slope failures were studied. Named as A, B, C, D, E, and F as indicated in Figure 2. All slope failures were facing toward the northeast direction, recognized in the topographic map using the flow direction map. For the seepage and slope stability analysis, all six failure slopes of the naturally undulated slope were chosen for further work.

Results and Conclusion

The coupled seepage and slope stability modeling for all six failed slopes were prepared with the help of the flow direction map using the digital elevation model (DEM) of the study area. For the soil thickness, data topographic break point in the slopes was chosen. All profile sequences were discretized into the mesh of triangle elements of 0.25 m. The number of nodes was 223, 216, 164, 208, 144, and 143, whereas the number of mesh elements was 295, 297, 236, 291, 214, and 216 for slope profiles A, B, C, D, E, and F, respectively. The main input parameters used were the soil water characteristic curve (SWCC) function and the soil permeability curve (SPC) function. The slope was simulated using the maximum accumulated rainfall record in 24 hr. at Narayani at Devghat station between 2001 to 2003 A.D. The maximum 24-hour rainfall was discovered on July 31of 2003. For the slope stability analysis seepage simulated in SEEP/W is directly linked to SLOPE/W.

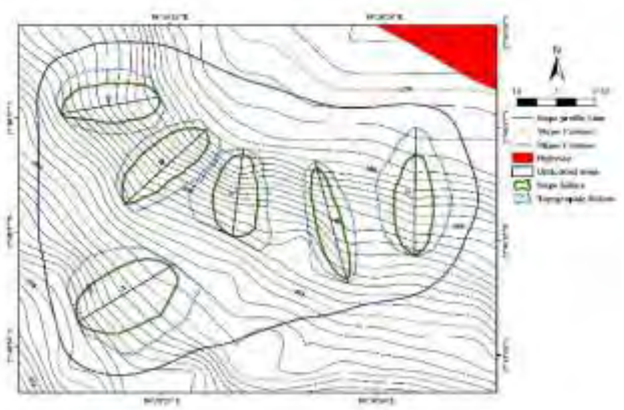

Figure 1, Naturally undulated slope with six failures.

For further simulations, different return periods of the 24-hour maximum rainfall of 31 July 2003 were considered. The hydraulic function employed in the previous simulation was used using the 5 years return period of rainfall. The Gumbell technique was used to compute the return period. The variation of pore water pressure with the topographic hollow area is shown in Figure 2 for a 5-year return period. Using the area of the topographic hollow and the maximum pore water pressure data recorded, a threshold relation between the maximum pore water pressure and the topographic hollow area was established.

The empirical relation between the maximum discharge of hillslope seepage and the topographic hollow area presented in this study for 24 h maximum rainfall data and their 5, 10, 25, 50, and 100 years return period as in Table 1. The variation in the pore water pressure is increased with increase in the rainfall long durations and low for the short period rainfall events as shown by analysis result as shown in Figure 3. Larger the naturally undulated slope, the greater the hillslope seepage as indicated by the maximum porewater pressure measured in the lower elevation part of the slope.

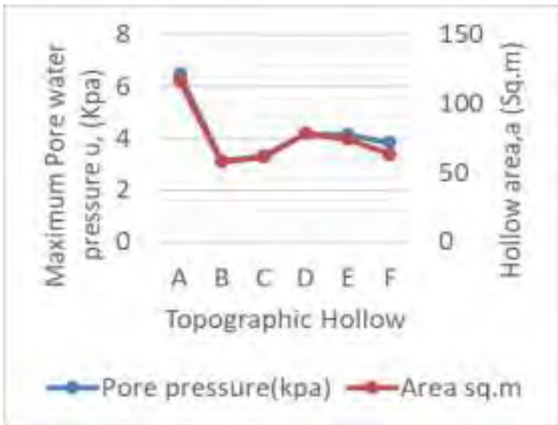

Figure 2, Variation of maximum pore water pressure with topographic hollow area for different return periods.

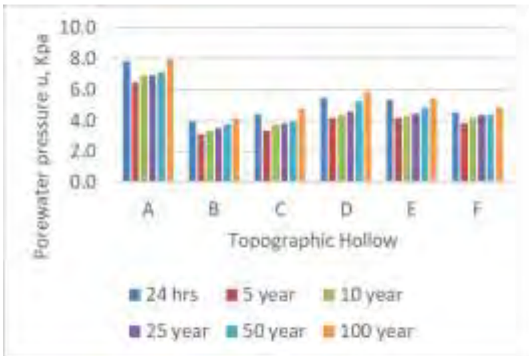

Figure 3, Pore water pressure and topographic hollow area threshold cure for slope failures for 5-year return period.

Table 1, Maximum Porewater pressure- topographic hollow area threshold equations for slope failure for different period of time. where u= Maximum Pore water pressure u, (kPa), a = Topographic hollow area, (sq.m)

Time	Threshold equation
24 hrs max	$u = 0.09*a^{0.9413}$
5-year return	$u = 0.0564*a^{0.9956}$
10-year return	$u = 0.0768*a^{0.9398}$
25-year return	$u= 0.092*a^{0.9063}$
50-year return	$u = 0.0985*a^{0.9029}$
100-year return	$u = 0.1279*a^{0.8708}$

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Road Side Slope Stabilization Using Ground Water Management at Far-Western Nepal

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Abstract: This study investigates landslide susceptibility in Nepal's Far-Western region, particularly Sudurpashchim province, where monsoon rains and rugged terrain increase landslide risks. A major landslide on the Mahakali Highway, prompted analysis using field investigations, borehole drilling, and Electrical Resistivity Tomography (ERT) to assess lithology and soil stability. Slope stability analysis shows that rainfall-induced water level rises weakened soil strength, but mitigation measures like slope benching and dewatering improved the factor of safety (FOS) from 1.20 to 2.49. Wells and horizontal drains were proposed to stabilize the area by reducing groundwater levels.

Keywords: ***Drainage wells, Horizontal drain, Geotechnical investigation, Geological investigation, Numerical analysis.***

Introduction

The Far-Western region of Nepal, particularly within Sudurpashchim province, is highly susceptible to landslides due to its rugged terrain, active geological features, and heavy monsoonal rains. As part of the geologically young Himalayan range, landslides in this area are largely triggered by natural factors, such as intense monsoon rainfall (Choi and Cheung 2013). With increasing awareness of climate change and shifting rainfall patterns, the risk of landslides in the region is expected to grow in the coming years.

A notable incident occurred around midnight on Shrawan 22, 2080, along the Mahakali Highway in Godawari Municipality-4, Kailali District. Monsoon rains triggered a significant landslide that completely blocked the highway for seven days, making it impassable for all vehicles. As a vital route connecting the highland regions to the Terai, the closure stranded hundreds of passengers and disrupted travel between the hill and Terai districts. The landslide also caused severe damage to five nearby houses, underscoring the hazards posed by rainfall-induced landslides in the region.

Methodology

This study is based on a thorough assessment of secondary data, combined with detailed field investigations, to analyze the landslide in the study area. The secondary data includes previous research, historical landslide records, and rainfall data, providing a broad context for the current study. To gain a comprehensive understanding of the site's geological and engineering conditions, performed both geological and engineering geological mapping. This mapping process helped in identifying the physical and structural characteristics of the area, such as rock types, fault lines, and slope orientations, which are critical for assessing landslide susceptibility.

In addition to geological mapping, geotechnical investigations were conducted, which included drilling two boreholes. These boreholes allowed to explore the subsurface lithology (the different layers of soil and rock) and obtain detailed information about soil properties at various depths. Key parameters such as soil composition, moisture content, and density were analyzed. Understanding the lithology is essential to determine the potential for slope failure, as certain soil and rock types are more susceptible to landslides.

To supplement the geotechnical investigation, a geophysical test known as Electrical Resistivity Tomography (ERT) was performed. As it measures the resistivity of subsurface materials to generate a profile of the area's lithology. This method helps identify variations in soil and rock properties, water content, and possible weak zones within the landslide area that may not be easily observed through borehole data alone.

Following the collection of geological, geotechnical, and geophysical data, slope stability analysis was carried out using specialized software tools like Slope/W and Seep/W (Acharya et al. 2016). The analysis was based on the data obtained from the boreholes, including soil strength, water table position, and slope geometry. The purpose of these analyses was to understand how different factors—such as soil type, water infiltration, and slope angle—affect the overall stability of the slope and the likelihood of future landslides.

By combining the results of the geotechnical investigations, ERT testing, and slope stability analysis, the study provides a comprehensive evaluation of the landslide-prone area, offering insights into its behavior under various conditions and laying the groundwork for the development of appropriate mitigation strategies.

Results

The study found that heavy rainfall caused the water level to rise from hydrostatic conditions, resulting in a decrease in soil strength (Tiwari and Ajmera 2023). Numerical analysis was conducted under various scenarios: normal conditions, rainfall conditions, and the combined effects of rainfall and dewatering using wells. The factor of safety increased from 1.20 to 1.86 in the combined condition. Additionally, with the implementation of slope benching and dewatering using wells, the factor of safety further improved to 2.40. The proposed mitigation measures were based on the geological properties and lithology, which were analyzed using a geological cross-section and verified through borehole logs, containing of sandstone and mudstone bedding as illustrated Figure 1

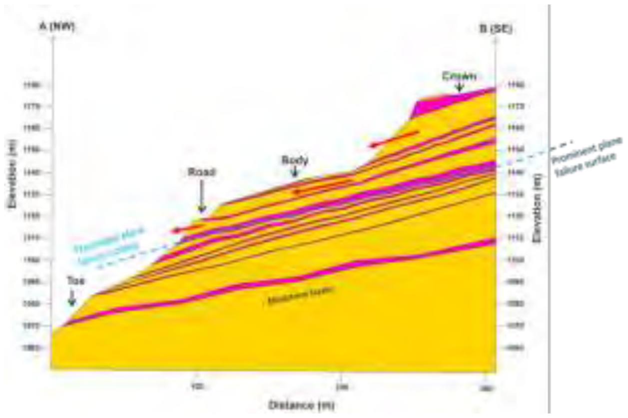

Figure 1 Geological interpretation of global plane failure scenario in the landslide area evident by lithological settings of the landslide area.

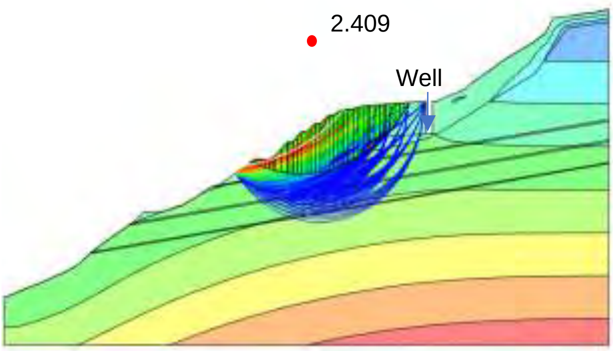

Figure 2 Obtained factored of safety after cut benching and dewatering using well. Model analysis for cut benching on valley side with rainfall and dewatering condition, FOS: 2.409.

Conclusions

The study conducted in the far-western region of Nepal, particularly in Sudurpashchim province, reveals that landslides are primarily triggered by intense monsoon rainfall and geological factors inherent to the Himalayan terrain. A significant incident occurred on Shrawan 22, 2080, along the Mahakali Highway, causing disruption and damage due to rainfall-induced landslides. The methodology involved a combination of geological, geotechnical, and geophysical investigations, including borehole drilling and Electrical Resistivity Tomography (ERT), to understand the area's subsurface properties. The slope stability analysis, using specialized software tools, highlighted that rainfall reduces soil strength and increases landslide risk.

The prevailing rock type predominantly comprises sandstone, exhibiting frequent bedding alternating between sandstone and mudstone plane. Through geological and geotechnical analyses, is deemed to have experienced failure along the mudstone plane. This failure is attributed to the impact on shear strength parameters resulting from changes in groundwater conditions and saturation in mudstone plane. According to the Electrical Resistivity Tomography (ERT) report, the ground within the landslide area is highly saturated at the time of study.

The study's results emphasize the importance of mitigation measures, such as dewatering and slope benching, which significantly improved the slope's factor of safety (FOS). The most effective strategy, combining slope benching and dewatering, increased the FOS to 2.49. These findings suggest that the landslide was largely driven by saturation of the mudstone plane, weakening the slope's stability. Dewatering wells and horizontal drains are recommended to lower the groundwater level and enhance long-term stability in the affected region.

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Numerical Modeling of Debris Flow Originating from Topographic Hollows at Koyalghari and Simaltal Area along Narayangadh-Mugling Highway

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Abstract: Assessing debris flow runout is essential for evaluating landslide hazards and developing effective land use plans. This study used the LISEM (Limburg Soil Erosion Model) to analyze debris flow runout based on geotechnical soil parameters. By integrating rainfall-induced failure and runout through physically-based modeling, the study aimed to predict landslide impact areas using forecasted precipitation. Focusing on the Koyalghari and Simaltal areas along the Narayangadh-Muglin road, the model's validation in Simaltal showed substantial agreement with historical runout patterns. For extreme rainfall events, debris flow heights between 0.92 m and 1.1 m were estimated at the highway, indicating potential damage to traffic. The findings highlight the model's reliability in predicting debris flow runout and providing valuable insights for hazard management.

Keywords: ***Physical based modelling, Cohens Kappa, Debris flow runout, LISEM model***

Introduction

The mountainous areas of Nepal are naturally unstable and particularly vulnerable to landslides for number reasons like their rugged topography, presence of soft soil cover, high intensity monsoon rainfall and frequent earthquake. Rainfall plays a crucial role in triggering debris flow from topographic hollow. In addition to the intensity and duration of rainfall, the hydrological phenomenon, soil particles, and properties influence the slope stability (Dahal and Hasegawa, 2008). The main objectives of the research are to apply a physically based model for debris flow runout estimation and validate the model using laboratory data and field observation of historical landslides.

LISEM (LImberg Soil Erosion Model) developed by Faculty of Geo-Information Science and Earth Observation (ITC) of Twente University is a physically based dynamic model that offers a more comprehensive analysis by taking into account the physical processes involved in debris flow runout. It uses a physically based approach to model the movement of water and solid material down a slope taking into account the physical processes involved in debris flow and the interaction with the topography (Bout et al., 2018).

Methodology

The study area of the research is located at Simaltal and Koyalghari in Ichhakamana Gaupalika, Chitwan district (Figure 1)

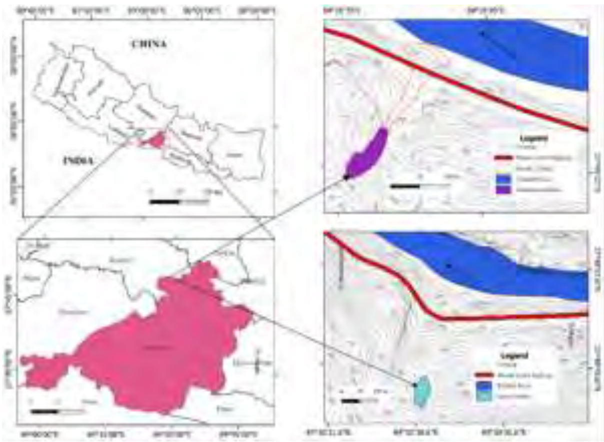

Figure 1: Location map of study area.

The flow chart of the methodology used for modeling debris flow in the LISEM model is shown in Figure 2. Using different soil parameter determined from laboratory and field test, various input maps were prepared in GIS. Finally, prepared map was imported in LISEM model and suitable rainfall data was taken for simulation.

Results

Geologically, the study area lies in the Nourpul Formation of the Lesser Himalaya Zone. The area is mostly covered up to 3m thick colluvial soil, primarily low plastic silt (ML) and low plastic clay (CL). The input map of the soil parameter was determined from the average value of geotechnical parameter obtained from field and lab test given in Table 1.

Runout modeling was performed in LISEM model for two areas i.e. first in the Simaltal area to represent debris flow occurred in 2010 using actual precipitation that triggered debris flow and then in the Koyalghari area using extreme rainfall intensity. The maximum debris height of 9.243 m was obtained in Simaltal area as shown in Figure 3. The debris flow runout covers total area of 15492.24 m^2. At highway the average maximum debris height was 1.107 m and affected about 60 m length of highway from chainage 23+630 m to 23+690 m.

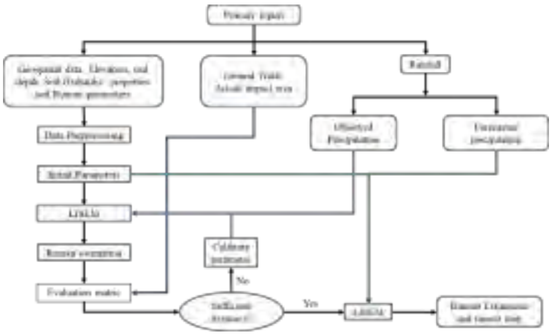

Figure 2: Flowchart of LISEM model employed for debris runout estimation.

Table 1: Summary of values of various parameter used in the study hollow and validation hollow.

Parameters	Values in validation area	Values in Study area
Cohesion (KN/m^2)	13.83	16.51
IFA (radian)	0.46	0.46
Soil density (Kg/m^3)	1757.76	1640.12
Porosity	0.323	0.385
Specific gravity	2.58	2.51
Initial rock size (m)	2.62E-04	1.19E-04

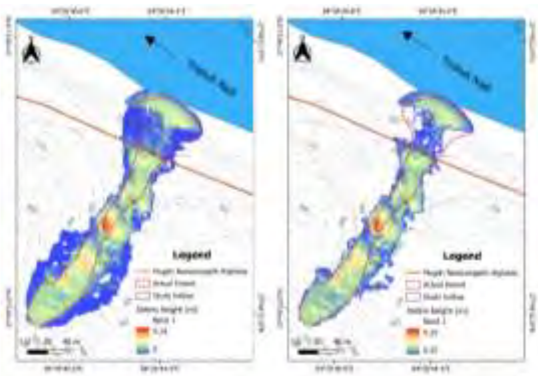

Figure 3: Debris flow runout in Simaltal area considering total debris height (left) and Threshold height that results maximum value of Cohens Kappa (right)

The accuracy of the runout modeled in Simaltal area was calculated using Cohen's Kappa. The sensitivity analysis was carried out changing debris flow height during accuracy estimation to understand how different thresholds height impact the performance of a model. The maximum value of Cohen's Kappa was 0.7453 using the threshold height of 0.45 m. Map obtained using observed precipitation in the Simaltal area that resulted in maximum Cohen's kappa value is shown in Figure 3.

Simulation was also performed in Koyalghari area along Narayangadh-Mugling road section. The study hollow was modelled for various extreme events based on 23-year rainfall data. Based on the result, the average debris height for various rainfall event at highway is shown in Table 3. The highest debris height was obtained for 3-day maximum rainfall as shown in Figure 5.

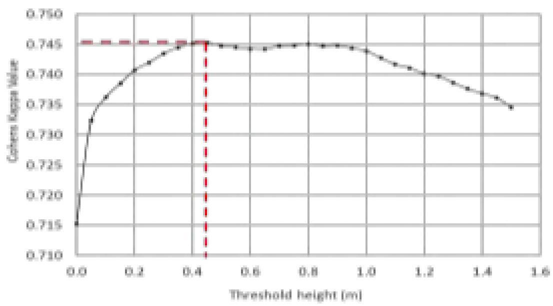

Figure 4: Cohens Kappa value for various threshold height.

Table 3: Average debris height at Highway for various rainfall period.

Maximum rainfall	Average debris height (m) at highway for various return period rainfall			
	Actual	**5 yrs**	**10 yrs**	**25 yrs**
1-day	0.9626	0.9266	0.9482	0.9689
3-day	1.1153	0.9563	0.9341	0.9333

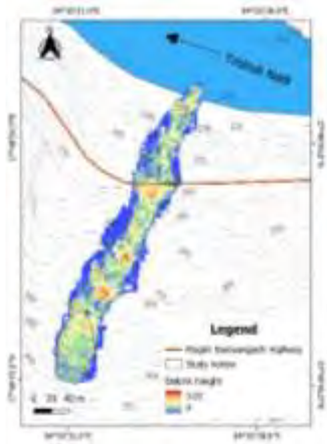

Figure 5: Debris height simulated in Koyalghari for 3-day max rainfall of 2006.

The study successfully applies the LISEM model to simulate and estimate debris flow runout in topographic hollow based on debris height at Koyalghari area. The model validation in the Simaltal area demonstrated substantial accuracy and supported the conclusion that physically-based models can reliably predict debris flow runout in similar geotechnical and topographical settings.

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Determination of Terrain-Specific Restitution Coefficients and Rockfall Hazard Assessment in Urbanized Mountainous Areas of Nepal

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Abstract: The primary aims of this study were to determine the restitution coefficient of the material and to simulate rockfall at the steep slope in Chaku Bazar. Initially, the normal and tangential restitution coefficients were calculated for 10 different rock boulders, varying in shape and composition using the Tracker Video analysis. The computed values for normal and tangential restitution coefficients were then used to simulate rockfall behavior using GeoRock 2D across four different sections, predicting rockfall trajectories and run-out distances. The normal restitution coefficient for vegetated rocky terrain was 0.34, while for solid rock it was 0.73. Likewise, the tangential restitution coefficient was 0.51 for grass-covered areas and 0.82 for rocky surfaces. After determining the restitution coefficients, the calculations revealed a maximum collision energy of 15000 kJ and a maximum bounce height of 30 meters at the bazar area.

Keywords: ***GeoRock 2D, Rockfall, Restitution coefficient***

Introduction

Rockfall is the natural downward movement of one or more detached blocks with small volumes, characterized by free fall, bouncing, rolling, and sliding (Varnes, 1978) which pose threat to the environment and resulting in loss of life and property (Bunce et al. 1997). These rock blocks can be dislodged through various processes, including natural mechanisms such as freeze-thaw cycles (McCarroll and Pawellek, 1998), seismic events (Abebe et al., 2010), or by human activities such as slope excavation or earth-moving operations (Dorren, 2003).

The impact of the rockfall depends upon the estimation of trajectories, bouncing heights and the kinetic energies of the unstable blocks. These elements are frequently derived through the application of kinematic modeling techniques created using numerical codes like CRSP or RocFall (Pfeiffer and Bowen 1989). The key input parameters influencing the estimated rockfall hazard in computer simulations are the coefficients of restitution. These parameters measure the energy loss that occurs when a block impacts the slope (Sabatakakis et al. 2015). The coefficients of restitution are divided into tangential (Rt) and normal (Rn) components relative to the slope. Two primary methods are used to determine these parameters: direct measurement through experimental tests, both in situ and in the laboratory, and back-analysis of natural or artificially triggered rockfalls (Evans and Hungr 1993). The research focus of the determination of restitution coefficient of the slope material and Rockfall Simulation at Chaku Bazar.

Materials and Methods

This study experimentally evaluates the coefficient of restitution for boulders colliding with rock slopes under different impact conditions, followed by the calculation of their kinetic energy and re-bounce height at four distinct sections of the terrain. The method applied for the study is describe as,

Newton (1686) originally defined the coefficient of restitution (R_C) as the ratio of the rebound velocity to the incident velocity of two colliding particles (or small spheres) along the normal direction. The kinematic definition of the coefficient of restitution, has been generalized and extended to three dimensional collisions by Brach (1991, 1997).

$$R_C = \frac{V_{1n} - V_{2n}}{U_{1n} - U_{2n}}$$

where, V_{1n} & V_{2n} = normal components of rebound velocities, and U_{1n} &U_{2n} = normal component of initial velocities of two colliding bodies. Both normal and tangential component of the restitution coefficient has significant role on the velocities and trajectories of the falling block.

Rockfall simulation

The rockfall simulation in this study was conducted using the CRSP method in GeoRock 2D Software, a widely used tool for rockfall problems. Key input parameters included the restitution coefficient of slope material, slope geometry, and boulder data. The restitution coefficient was derived from field tests and tracker analysis, while the slope geometry was based on contour data defining the cross-sectional profile of the slope. Boulder data, including shape and size, was determined through field measurements and Zingg classification of 100 boulders. The analysis also considered block stability using major discontinuities. The CRSP method applies a rigid body approach, analyzing rock interactions with the slope during contact phases, including slipping and reversal behavior. The terminal impulse calculated from these phases is used to determine outgoing velocities, helping identify critical rockfall events and associated risks.

Result

The in-situ field test where the rockfalls are examined by filming the nature of boulders and evaluates the normal and the tangential coefficient of restitution from different rock samples using video analysis and modelling tool, called Tracker (Figure 1). The values of normal and the tangential coefficient of restitution have been determined for 10 different rock boulders varying on shape and lithology. The tangential coefficient of restitution for the bedrock varies from 0.77 to 0.87 which is in the range of standard values in dolomitic terrain. Similarly, the average normal coefficient for bed rock is 0.73. the average normal and tangential coefficient of restitution for bedrock with vegetation is 0.25 and 0.37 respectively (Table 1).

Table 1, The determined restitution coefficient for rock fall simulations.

Description	Rn	Rt	Roughness
Bed Rock	0.73	0.82	0.5
Bedrock With Vegetation	0.34	0.51	0.5

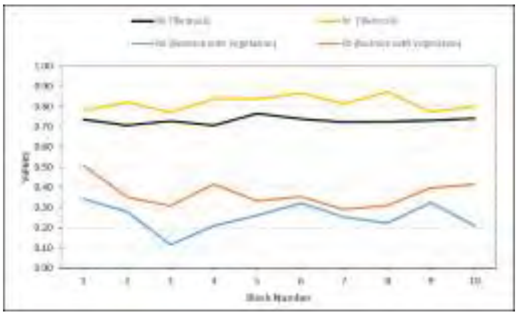

Figure 1, Determined restitution coefficient of the slope material.

The field measurement and discontinuities plot show that the size of the boulder is 2.4 m on average. The Zingg classification of the boulder data shows that the shape of the boulder is Disc Shape. The factor of safety for each block formed by the intersection of discontinuities has found 1.35 for toppling failure, 0.95 for wedge failure and 0.83 for the plane failure. The result shows that there is possibility of the rock slope failure. On varying the shape and size of the block the factor of safety has increased.

The rockfall simulation result shows that the rockfall hazard can be of maximum energy 15000 kJ to the settlement area of Chaku Bazar and Araniko Highway (Table 2). Similarly, the maximum run-out distance will be 160 m. The rebounce height will be 30 as the terrain has very steep which has more than 80°.

Table 2, Section wise rockfall simulation result.

Section	Energy (kJ)	Max. Height (m)	Run out (m)
Section 1	14000	24	140
Section 2	15000	25	160
Section 3	7000	30	160
Section 4	6900	30	160

Conclusion

In this research, rockfall hazard assessment was carried out using field tests and simulations, leading to recommendations for significant stabilization measures. Kinematic analysis indicated a high likelihood of planar failure occurring at rock slope of Chaku Bazar in which factor of safety is less than 1, with notable chances of wedge and toppling failure. The analysis implies that the rock fall is significantly dependent on restitution coefficient and this value should be site specific. The findings highlight the elevated risk, particularly at the toe of the slope, where the highway road is the primary element exposed to danger.

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