GEOLOGICAL ENGINEERING FOR SOCIETAL & SUSTAINABLE DEVELOPMENT----BANGLADESH A CASE STUDY

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Abstract

Bangladesh is a South Asian Tropical Monsoonal Country and is facing many climate-related hazards and disasters every year which is a big challenge for the current sustainable development of Bangladesh. Every year casualties due to hazards and disasters are increasing and affecting the food security, livelihood, health, and economic growth of the country. In very recent years Geological Engineering is playing a vital role in managing climate-related issues, challenges, and hazards to become a developed nation by 2041. With the great initiatives of the GoB (Govt. of Bangladesh), several measures have been taken at the policy level to build a sustainable community and a resilient society for all to become the world leader by managing hazards & disasters. Some climate-related hazards, modeling results, hidden ground-related problems, and mitigation measures are presented in this paper to achieve the UN (United Nations) SDG's goals. Renewable & sustainable energy issues and initiatives to reduce the use of carbon emissions will also be discussed. Some examples of recent hazard and disasters and their mitigation measures to reduce rainfall-induced hazard risks are presented as sustainable solutions to reduce slope hazards in the camp area. Role of Geological Engineering certainly can play a vital role in the societal and sustainable development of Bangladesh. Rainwater harvesting technique has been introduced in the temporary shelters of the community dwellers along with low cost drainage system were installed as examples to reduce pore water pressure inside the slopes. These low cost solutions helping the hazard victims to reduce loss and manage water scarcity and sustainability in the investigated area. Suggestions are also recommended to improve the current geoscience and geoengineering-related curricula in the academic institutes including Schools, colleges and Universities to build a smart resilient society and smart Bangladesh to meet the new challenges of the 21st century under the current context of global climate change.

Introduction

Bangladesh is a low-lying country located in South Asia, bordered by India to the north, east, and west, and Myanmar to the south which extends from 20°34' N to 26°38' N latitude and from 88°01' E to 92°41' E. The country's flat topography, location in the Bay of Bengal, and heavy reliance on agriculture make it particularly susceptible to climate-related disasters. According to the Global Climate Risk Index 2021, Bangladesh is the seventh most vulnerable country to climate change in the world. In recent years, the country has experienced several extreme weather events, including cyclones, landslides, floods, and droughts, which have caused significant damage to infrastructure, agriculture, and livelihoods (Climate Vulnerability Index Report, 2023). The average temperature in Bangladesh has been increasing in recent years, with some regions experiencing temperatures above 40 degrees Celsius. Bangladesh experiences a monsoon season from June to September, which is critical for agriculture. However, in recent years, there have been changes in the timing and intensity of rainfall, leading to flooding in some areas and drought in others. Landslides have caused significant damage to infrastructure and have led to loss of life. Besides, sea level rise causing saline water intrusion is another climate driven alarming phenomena for southern region of Bangladesh. All these consequences of climate change significantly affecting the current GDP and threatening sustainability of this developing nation. Geoengineering solutions. Some sustainable geoengineering recommendations are discussed to reduce the hazards and to give benefits to the society & to build a sustainable resilient community.

Methods

The study is followed by Field, Lab methodology and Modeling. Field investigations were conducted in accordance with (British Standard 5930, 1981). Geophysical resistivity test has been conducted according to Wenner array method. Laboratory testing results were analysesd according to (British Standard 1377, 1990 and ASTM method (1974),K.H. Head (1982) & ASTM IS :2720 (Part-12)-1981,

Results

Hossain et al. (2023) discussed that140mm to 280mm of rainfall are sufficient to cause the slope failures in the south eastern folded part of Bangladesh. (Figure 1). Based on all findings some geoengineering sustaianable solutions are recommended to manage climate related hazards and to attain sustainable development of Bangladesh.. Many geoengineering solutions for slope protection, rain water harvesting to reduce water scarcity and water related hazards, climate

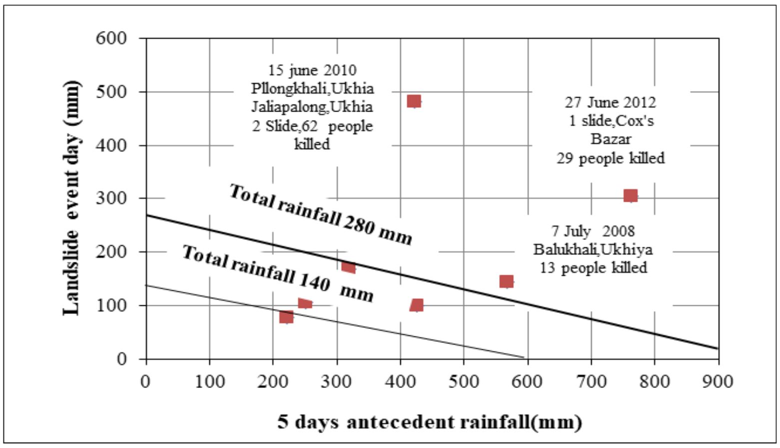

Figure 1: Rainfall Threshold Line of the South Eastern Folded Part of Bangladesh . (Hossain et al., 2023)

resilient sustainable housing, new flood level demarcation for sustainable flood resilient infrastructures development in rural and urban areas, renewable energy-based power unit installation, monitoring and EWS installation, the establishment of a National Database are the major recommended geoengineering solutions to fullfill the policy level gap for sustainable development of Bangladesh & to achieve UN SDG's Goals to be a developed nation by 2041.

Conclusion

Geological Engineering certainly can play a vital role in the societal and sustainable development of Bangladesh. Some case study results and Suggestions are also recommended to improve the current geoengineering and geoscience-related curricula in the academic institutes including schools, colleges and Universities to build a smart society and smart Bangladesh and to meet the new challenges of the 21st century under the current context of global climate change.

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THE INTEGRAL ROLE OF ENGINEERING GEOLOGISTS IN DISASTER RISK COMMUNICATION

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Introduction

Disaster Risk Communication (DRC) is the main component in shaping perceptions of disaster risk, influencing preparedness, and impacting decision-making throughout the disaster management cycle. It employs tools like GIS, drones, social media, and early warning systems, with substantial involvement from Engineering Geologists in approaches like hazard mapping and community-based disaster risk reduction.

Effectively communicating disaster risk is vital for saving lives, enhancing preparedness, adaptability, and response capacities of individuals, communities, and institutions, ultimately improving risk management. To achieve this, comprehensive applications of emerging technologies and innovations in disaster risk management by Engineering Geologists are necessary. However, a challenge in DRC arises from restricted data accessibility, often controlled by governmental institutions, leaving engineering geologists in a vulnerable position. Proper data analysis, facilitated by engineering geologists, is crucial for understanding how people live with risk. Data-driven evidence should guide decision-making processes, such as determining evacuations during extreme rainfall warnings. Both data and DRC closely intertwine, influencing individual responses to warnings. Effective best practices for DRC should follow specific rules, including setting clear goals, understanding the audience, considering other sources of information, delivering messages effectively, and using precise and consistent language. In many cases, DRC should be comprehensible, and perception with learning and reasoning associated with DRC should not be neglected afterward, as neglect may lead people to disregard DRC. Engineering geologists must explain disaster risks comprehensively, drawing on geoscience understanding, emphasizing impacts, allowing people to share experiences, being transparent about uncertainties, and avoiding scare tactics. They should also provide options for reducing risk at both individual and community levels, involve stakeholders in planning, and share insights from previous successful implementations.

The extended abstract will focus on the major roles of engineering geologists in the DRC process and provide suggestions on reducing uncertainties. Recognizing risk communication as dynamic and incorporating multi-hazard early warnings can enhance DRC effectiveness in saving lives and improving disaster management.

Multi-hazard early warning systems and DRC

In the context of South Asia, effective multi-hazard early warning systems and disaster risk communication can be achieved through enhanced disaster risk knowledge among local communities and bodies, comprehensive hazard detection, monitoring, analysis, and timely forecasting, efficient warning dissemination, and effective preparedness and response capabilities among the public. Engineering geologists should recognize that risk communication is a dynamic process, not a static outcome, and can be strengthened through multi-hazard early warnings. Effective warning messages should contain five essential elements: the warning source, hazard identification, specific areas at risk, actionable instructions, and guidance on where to seek further assistance, ensuring DRC effectiveness with minimal confusion.

In communicating disaster risks, engineering geologists must explain comprehensively, drawing on geoscience, emphasizing impacts, being transparent about uncertainties, and avoiding scare tactics. They should involve stakeholders, share successful insights, and provide options for risk reduction.

Risk Perception of people

When considering risk perception models, factors such as people's knowledge and understanding of risks, emotional and personal experiences, social amplification of risk, cultural theory, trust, values, gender, education, and ideology play crucial roles (van der Linden, 2017). Dryhurst et al. (2020) found that individuals in major developed countries like the USA, Japan, Germany, South Korea, Sweden, and Italy were less worried about COVID-19. In contrast, people from many developing countries, along with the developed countries of the UK and Spain, were highly concerned about COVID-19 infection. This finding is significant for understanding societal risk perception issues. Numerous studies show that experiential and sociocultural factors explain most of the variance in risk perception models compared to cognition and socio-demographic characteristics. Additionally, during risk communication, people from both developing and developed countries tend to trust governmental activities less and place more trust in non-governmental organizations. The situation is more chaotic in developing countries. For instance, in 2018, the residents of Melamchi Municipality in Nepal were not pleased with the river setback rules imposed by the local government (Figure 1a). However, they experienced severe flood damage in 2021 (Figure 1b). This example illustrates the risk perception of people and the losses they endured despite accurate hazard and risk assessments made by engineering geologists in 2018.

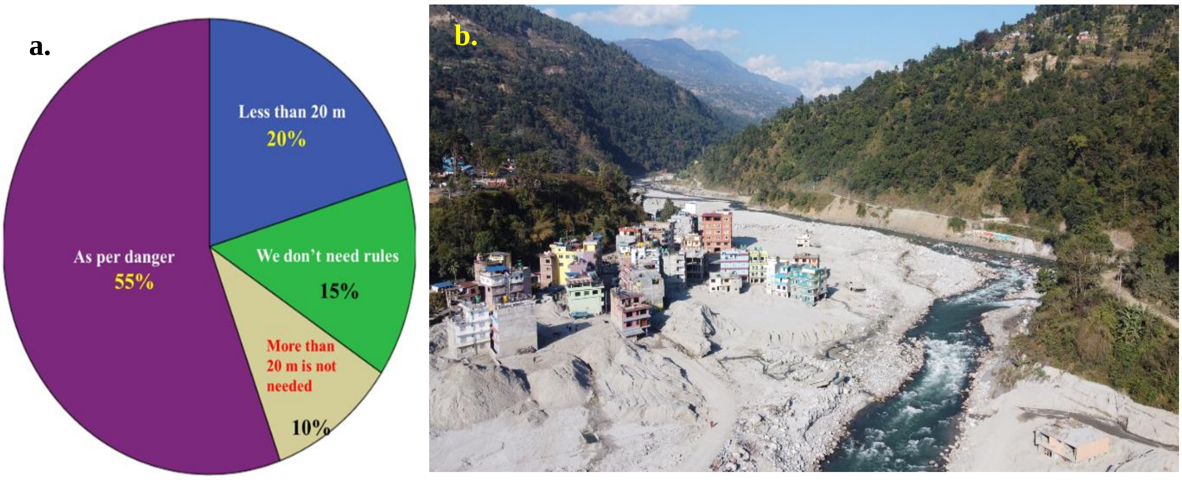

Figure 1. a. People opinion for river set back rules and b. Damaged Melamchi town after 2021 flood which was accurately estimated by engineering geologist in 2018.

Concluding remarks

In fact, the multi-hazard early warning system and disaster risk communication is possible with following activities.

- Enhanced disaster risk knowledge among local people and local bodies (municipalities).
- Detection of hazards, their monitoring, analysis, and forecasting along with communication of possible consequences on time in presence of Engineering Geologists.
- Warning dissemination and communication by effective channels and processes.
- Preparedness and response capabilities of people after warning and getting DRC messages.

Similarly, disaster risk communication (DRC) is a process, not a product, and can be effectively conducted following multi-hazard early warnings, with engineering geologists playing a pivotal role. Effective risk communication requires timely, transparent, dialogic, clear, coherent, empathetic, and proactive processes with the direct involvement of engineering geologists. Additionally, DRC necessitates analysis, planning, credibility, training, and evaluation. Achieving this involves analyzing attitudes and behaviors, understanding and respecting different perspectives, and evaluating effectiveness. There should be coherence between communication, spatial planning, and decision-making. Moreover, the DRC process must be prepared to address communication paradoxes such as reassurance, efficiency, delegation of responsibility, and ensuring the safety of the people.

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EXPLORING THE EFFECT OF TEMPERATURE ON A CASCADING HAZARD: PROJECTING THE 2021 MELAMCHI FLOOD TO A WARMER CLIMATE

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Introduction

The dependence of the shear strength of geomaterials on temperature may affect the stability of slopes and the propagation of landslides (Scaringi & Loche, 2022). Thermal sensitivity has primarily been observed in pure clays and quartz-clay artificial mixtures. However, evidence exists of significant effects in natural soils, including those from the Melamchi catchment in Nepal, for which weakening has been evaluated at elevated temperatures. Here, we discuss the implications of such evidence in a real-world case study. In 2021, a large-scale disaster occurred in the upper Melamchi catchment (169 km^2), as the outburst of a relatively small glacial lake (~2500 m^3) cascaded down the valley, carrying sediment (>10 Mm^3) with substantial entrainment. The erosion caused slope toe-cutting and numerous landslides, and eventually, the river valley downstream was filled with a thick debris layer (Asian Development Bank, 2021). In the RCP8.5 (worst case) scenario, a 4.9°C warming is expected by the end of the century, with enhanced impact in the alpine Himalayas owing to elevation-dependent warming.

Methods

We incorporated various physical processes (glacial lake outburst, landslides, flood) into a catchment-scale multihazard simulation and compared its result to that of a worst-case scenario, assuming a similar disaster would occur at the end of the century after 4.9°C warming. We developed an input dataset, which we fed to a physically based model – OpenLISEM hazard (van den Bout et al., 2018). The dataset was supplemented by a field campaign during which 71 geotechnical samples were collected and in-situ tests conducted. An engineering geological map of the area was created based on geomorphological interpretation, categorizing the region into soil classes to which geotechnical values derived from the experiments were assigned (cohesion, internal friction angle – IFA, initial moisture content, bulk density, and D50+D90 grain size parameters). Remote sensing sources provided the remaining input rasters. The global elevation product (SRTM) was filtered and interpolated to the desired resolution (20×20 m). Surface parameters were obtained from literature values of the digitally classified (supervised) Sentinel-2 image. Soil depth was modeled using a soil depth model based on the steady-state assumption of soil transport/production. The daily total rainfall from the only station available was used to establish a rainfall intensity equivalent to a 150-year return period flood value using extreme value statistics (Gumbel). Globally available precipitation data from NASA's IMERG (Integrated Multi-satellite Retrievals for GPM) were used to create a design storm with a temporal resolution of 30 min and daily totals based on measured records. Further, 15 landslides were mapped along the river corridor post-disaster during fieldwork. Each landslide was classified according to Varnes, and dimensions, including possible depth to failure, were measured. The landslide volumes were estimated based on their rotational or translational mechanism, and their runout was matched through back analysis. Laboratory-observed changes in IFA due to changes in temperature were assigned to the catchment's spatial domains according to the global clay fraction (SoilGrids250m 2.0, 2021).

Results

The heavy precipitation and the release of landslides during peak discharge facilitated a simulation replicating the Melamchi disaster in 2021. Although the simulation's accuracy based solely on the extent of flooding is not deemed critical, it showed a Kappa value of 0.65. Efforts were primarily focused on calibrating the solids based on data from reports and post-disaster fieldwork. The model underestimated the solid flow in the absence of fluid, particularly in the upper part of the catchment. Conversely, it overestimated the debris flow height along the lower catchment, especially at the headworks location of the Melamchi water diversion project. The maximum debris flow height simulated at this location was 20 m, compared to the post-disaster visual inspection estimate of ~16 m. The peak water discharge was measured at 442 m^3/s with a peak rainfall of ~50 mm/hr across the catchment. For reference, the seasonal peak monsoonal discharge is ~40 m^3/sec. Unfortunately, the exceptionally high flood in 2021 was not recorded at the Helambu station because it was swept away by the event. However, the simulation results were consistent with the measured flood height. Given the model's satisfactory fit, we proceeded to simulate the year 2100 scenario, modifying only the IFA. The simulation (**Fig. 1**) indicated an increase in debris flow height along the catchment channel by <1 m. Despite being rather small, this difference, combined with the increased flow velocity, could result in an increased impact pressure of the debris flow. Additionally, longer runout should be simulated owing to the decrease in friction coefficient, but the results remain unclear as the runout of the landslides occurred perpendicular to the river valley and impacted the opposite bank. Finally, the simulation is progressing to incorporate sediment transport during the event, which requires highly calibrated input. The anticipated changes in sediment flux are crucial, as the river is a potential source of drinking water for the people of the Kathmandu Valley.

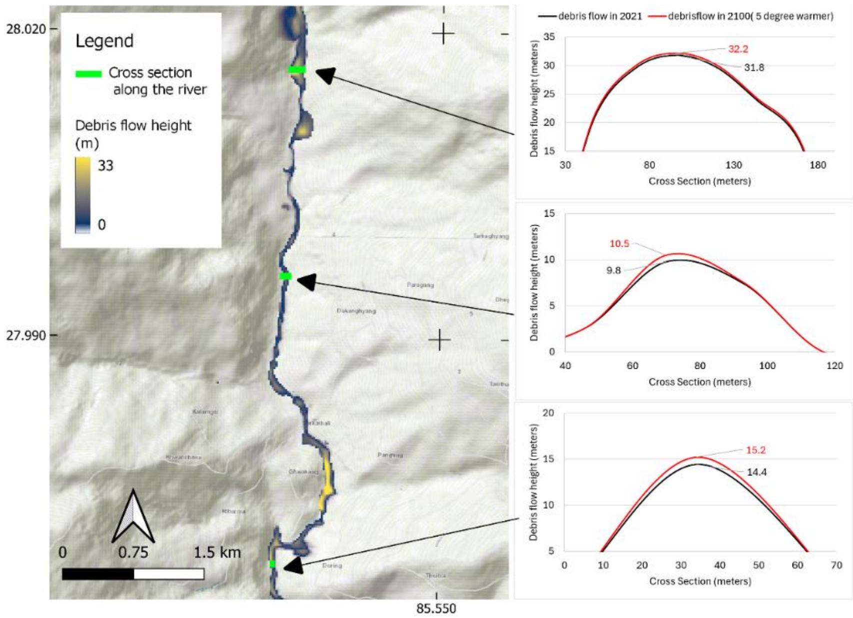

Figure 1. Simulation of the Melamchi disaster (left); back-calculated and projected debris flow heights (right).

Conclusion

We back-analyzed the 2021 Melamchi disaster by incorporating the key processes that occurred during the event. Then, we simulated the same disaster in a worst-case warming scenario (4.9°C increase in temperature) according to the experimentally measured decrease in the soil's shear strength. We evaluated an increase in debris flow height and changes in debris flow velocity, suggesting that further research is needed, particularly in developing a coupled thermo-hydro-mechanical model for catchment scale hazard analysis. Additional experiments are currently underway to clarify thermal effects in natural soils and their potential implications for natural hazard analysis.

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LABORATORY RAINFALL TEST ON PISTON FLOW PHENOMENA INVOLVING PORE AIR PRESSURE IN LANDSLIDE MASS

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Introduction

We continuously monitored the 1m-depth-ground temperature and water level of boreholes to clarify the role of groundwater flow in movement of Nishi-Ikawa landslide, a reactivated one on crystalline schist area. The monitoring results show that groundwater in the landslide mass flows in a vein-like pattern and abnormal variation of ground temperature (decreasing in summer and increasing in winter) occurs during heavy rainfall (e.g. Furuya et al., 2021). This suggests that groundwater flows within the slope cannot be explained by the commonly accepted rainfall-infiltration process. We then assumed that this process may result from the piston-flow-like extrusion of groundwater that was recharged more than a decade ago during infiltration processes in heavy rainfall (e.g. Furuya et al., 2022), and pore-air in the infiltration pass may have involved in this process. To examine these assumptions, we conducted indoor experiments, and some results are presented in this study.

Methods

Figure 1 shows a schematic diagram of the experimental apparatus. The landslide slope was modelled by connecting a rubber water hose to two cylindrical pipes with a water head difference of 100 cm between them. To reproduce a slow flow path between the two cylindrical pipes, the rubber water hose was filled with methylcellulose water solution (concentration of 15%), which has been widely used as a viscous pore fluid in centrifuge and other kind of tests (e.g. Stewart et al., 1998). The bottoms of both cylindrical tubes were filled with 10 cm of gravel and saturated with distilled water. On top of the gravel, a specimen (Silica sand: D_{50} = 0.147 mm) was tamped and filled every 10 cm up to the top of the cylindrical tube. Inside the cylindrical tubes, a buried water pressure gauge was placed at the height of 70 cm, a digital barometer was placed at a height of 50 cm from the base, and a pore pressure gauge was placed at the base of the cylindrical tube. Artificial rainfall was applied with a water spray nozzle 200 cm above the top of both cylindrical pipes. The rainfall intensity was 100 mm/h. The initial water content and the number of compaction cycles were changed, and the behaviour of the pore air pressure was monitored under each test condition.

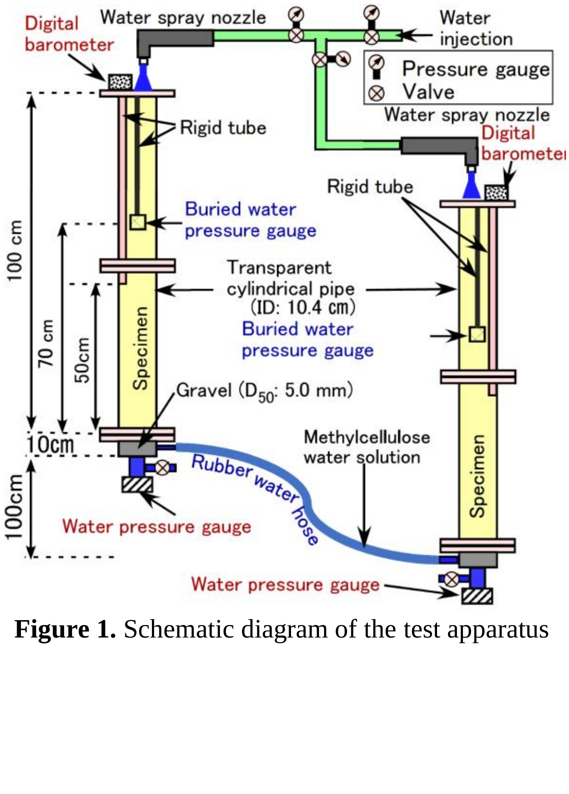

Figure 1. Schematic diagram of the test apparatus

Results

Figure 2 shows the test results. (A) shows the relationship between the water content, the start time of the generating in pore air pressure (based on the start of rainfall) (PAP), and the maximum PAP value under the condition of one tamping cycle (*e*: 1.21-1.24). (B) shows the relationship between the void ratio and the maximum PAP value under 0, 1, and 3 tamping cycles.

In Figure 2(A), the red symbols indicate the relationship between the initial water content and the time at which the PAP increased. It is seen that the higher the initial water, the earlier the starting time of the increase in PAP. The blue symbols show the relationship between the initial water content and the maximum PAP. The initial water content of the specimen was set to 5, 10, 15, and 20%. It is also noticed that the maximum value of PAP during rainfall infiltration is larger for higher initial water content. These results suggest that during rainfall infiltration, the higher the initial moisture content, the more likely the upper part of the specimen will be quikly saturated, and with the descending of wetting front, the air in the pores is less likely to escape into the atmosphere, resulting in a greater increase in the PAP. On the other hand, when the initial moisture content is smaller, it is difficult for the soil layer to be unsaturated, such that the air in the pores escapes more easily into the atmosphere with the descending of wetting front, resulting in a lower increase in the PAP. These results indicate that the moisture condition in the soil before heavy rainfall may influence the rise in pore water pressure due to pore air (pushing out groundwater).

Figure 2(B) shows that the PAP generated during rainfall increases linerly as the void ratio of the specimen decreases with a correlation coefficient of 0.97. This suggests that as the void ratio within the soil layer decreases, the soil's water retention capacity improves during rainfall infiltration (due to increased adsorption water between soil particles), leading to the entrapment of air within the specimen when the pores are filled with adsorption water (acting as a kind of seal). Conversely, when the void ratio is great, the abundance of voids within the specimen allows air to escape, and the wetting front does not descend uniformly, resulting in ineffective air entrapment during rainfall infiltration. Therefore, it is concluded taht the void ratio also plays a role in the increase of pore air pressure.

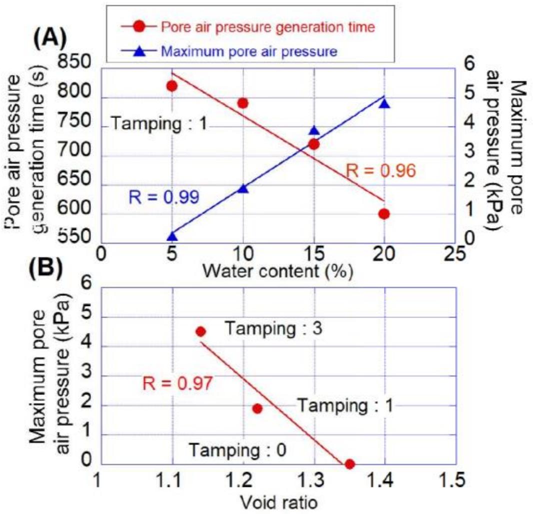

Figure 2. Test results
(A) Relationship between the water content, the start time of the generating in pore air pressure, and the maximum pore air pressure; (B) Relationship between the void ratio and the maximum pore air pressure

Conclusions

When the moisture content of the specimen is greater, air is more easily trapped within the pores during rainfall, leading to a quicker increase in PAP and a greater maximum value of PAP. The lower the void ratio of the specimen, the more adsorption water exists between soil particles, causing the wetting front to act as a sort of seal that traps air, making it easier for PAP to rise.

Acknowledgments

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RESILIENCE

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Introduction

New Zealand experienced widespread flooding and landslides (estimates of circa. 800,000 landslides (GNS 2023)) in early 2023 when cyclones Hale and Gabrielle made land in quick succession, severely impacting the north and east of the North Island. The impacts were such that a National State of Emergency was declared for the third time only, in New Zealand's history (the previous two times were the COVID pandemic and the Canterbury earthquake sequence, all within the last 15 years).

As we begin to see first-hand the impacts of severe weather events on our communities and infrastructure, we find ourselves at the cross-roads of decision making, considering risk and actions to expedite recovery, in the face of climate change. We find ourselves grappling with difficult questions and hard choices to drive resilience in an environment in which circular economy-based design is in its infancy, traditional warning and response systems are not effective across regions (early warning – to what effect?), traditional design and construction approaches are too slow, and government finances are stretched to imbalance.

The Cyclone Gabrielle Example

Unprecedented rainfall triggered a landslide that took out a 120 m long section of state highway (SH) 25A, a principal access between the west and east coasts of the Coromandel Peninsula, North Island, New Zealand. Three remedial options were considered: go around, build up from the valley floor with MSE walls, or bridge. A bridge option was selected because of the higher reliability of construction time (not lower cost) in the face of likely further rainfall and saturated deeply weathered volcanic soils. Construction began in June 2023 and the highway was re-opened about 10 months from the date that landsliding occurred, about half the time a bridge of this type would take to design and construct. This was achieved by collaboratively applying an existing bridge design (consultants and contractors working together) which allowed available materials, including repurposed steel plates for bridge beams that had been imported for another project, to be diverted for immediate use. Currently value is equated with lowest cost, but real value (increased tourism spend and GDP in the region) was achieved through faster return to service without compromising design or quality of materials (INZ 2024).

Figure 1. Upper left: landslide impacting SH25a. Upper right: bridge solution under construction (photograph from Waka Kotahi NZ Transport Agency)

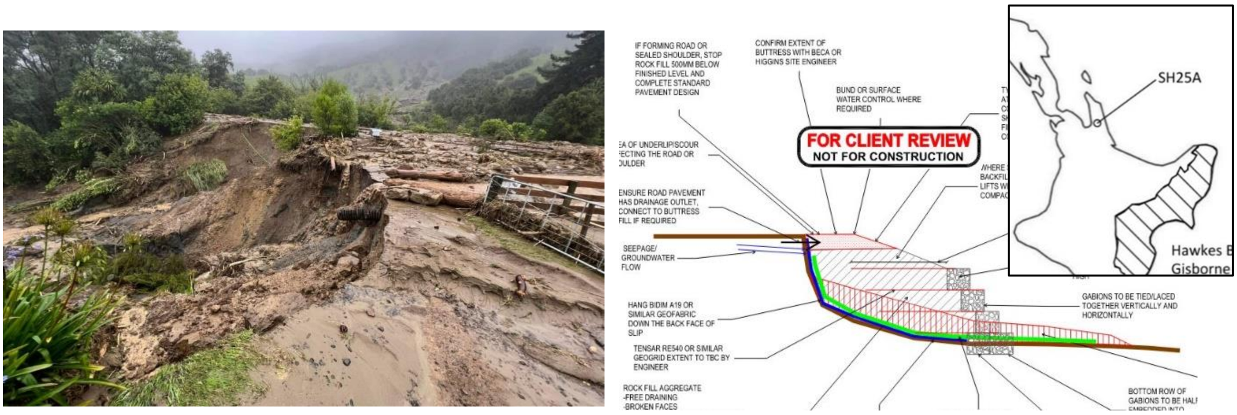

Figure 2. Example slip and standard design remediation from SH5, Hawkes Bay region (shaded on inset map).

Flooding and loss of State Highways and bridges (several sections of SH2, SH5, SH38, SH550 and SH51) was widespread across the Hawkes Bay region with links in and out of the region, power, phone and internet cut off. There were hundreds of similar underslip sites, and it rapidly became clear that there is a difference in needs between new build and emergency works or so-called "resilience" works. Applying traditional processes and standards is time consuming and costly, with repairs getting held up by options studies. Developing standard designs across a road corridor and standard design details across a region, applied by contractors with engineering geological and geotechnical support, allowed access routes to be opened up and a collaborative approach to temporary and permanent works solutions established. Pre-agreement of design life, factor of safety and departures from code were key factors in re-establishing links, noting that stretches of the highways remain vulnerable to future weather events.

Discussion

Climate resilience can be defined as "the ability to anticipate, prepare for and respond to the impacts of a changing climate, including the impacts that we can anticipate and the impacts of extreme events..." (MfE 2022). Understanding the risk of climate related instability requires understanding the hazard and its probability (e.g., AGS 2007a, GNS 2023), but climate change increases uncertainty giving us a decreasing ability to predict the impacts, which are complex. Politicians use slogans like "build back better" and "resilient infrastructure", but there is a mismatch of expectation between infrastructure owners, insurers, designers and the public around what "resilience" means. Understanding the interdependencies between infrastructure networks is key to resilience – the resilience of one infrastructure sector often depends on the resilience of others. We need to ask ourselves which highways must perform and which we can allow to fail and repair more frequently? The examples demonstrate that we need to apply scenario testing, options analysis, and adaptive planning now, before the next extreme weather event makes landfall. We need to develop standard methods of assessment and tools to provide comparable judgements around response across a network.

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FAILURE MECHANISMS OF SOFT ROCK CLIFFS DUE TO SEA WAVE MOTION: A NUMERICAL INSIGHT

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Introduction

The evolution of soft rock coastlines is mainly related to natural factors, as for example the environmental weathering processes as well as the impact of strong wave loading. Severe sea storms and intense rainfalls are seen to increase in intensity and frequency, according to the worldwide acknowledged climate change, which is recognized to be particularly intense in the last years. Wave impact stress during energetic sea storms can represent the triggering factors of coastal instability processes, giving rise to the development of rock mass failures and consequent coastal retreat (Gong et al. 2018; Lollino et al. 2021). Concerning the impact of wave action on rocky cliffs, wave impact are supposed to induce fatigue processes in soft rocks, so that, after several wave storms, with repeated loading applied to the cliff, rock starts to fail with the generation of macro-discontinuities that tend to propagate upslope to involve the whole cliff. In this perspective, some authors have also demonstrated through laboratory tests the effect of fatigue processes on soft rocks (Cerfontain & Collin 2018; Li et al. 2001). Numerical analyses have also become important tools to investigate the response of slopes and coastal cliffs under the effects of specific predisposing, preparatory and/or triggering factors (Perrotti et al. 2019; Amorosi et al. 2019). In this work, the recent evolution of a soft rocky coastal stretch on the Italian southern Adriatic sector is analysed. To investigate the most important contributing factors to coastal evolution, a numerical finite element analysis focusing on an ideal soft calcarenite rock cliff has been carried out. In particular, the role of impact loading due to strong sea motion, in accordance with the typical sea storm features in the area, is analyzed.

Methods

In order to investigate the role of wave action at the toe of soft rocky cliffs, a finite element model representing typical geometrical features of the cliffs outcropping along the south-eastern coastlines of the Apulia region has been developed. The cliff is 12 m high and is affected by a wave height of 3 m. The sea wave is simulated by means of a trapezoidal loading function, with a maximum value of 300 kPa. The behavior of the calcarenite rock is analyzed by means of an elasto-plastic constitutive model, with a Mohr-Coulomb strength envelope, with $c' = 200$ kPa and $\phi' = 30°$. A tension cut-off with a tensile strength of 160 kPa is also assumed. The boundary conditions are the standard ones, with total fixities at the bottom of the model and null displacement along the external vertical sides. A gravity loading condition is assigned at the beginning of the analysis in order to initialize the stress state of the rock mass.

Results

The numerical results indicate that strong wave impacts can induce plastic shear strains at the toe of the cliff, from which failures can propagate upwards involving the whole cliff. In particular, Figure 1 shows the concentration of plastic points at the toe of the cliff, along with the quite remarkable horizontal displacements resulting from the application of wave impact loading. A large number of analysis, adopting different assumptions in terms of material properties and wave loading impact have been also carried out to investigate the role of such features.

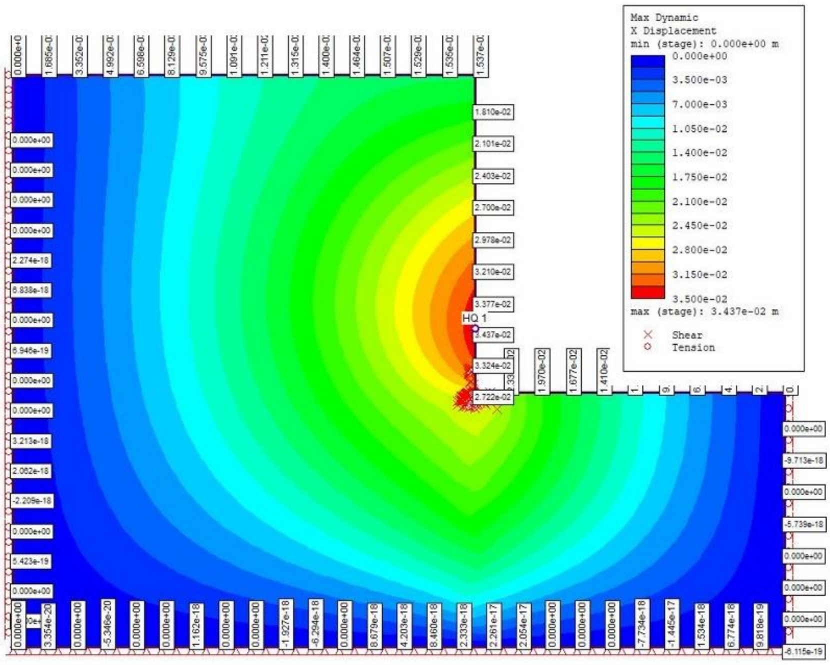

Figure 1. Horizontal displacements and plastic points calculated as an effect of wave impact.

Conclusion

The numerical analysis has highlighted the impact of wave loading as a triggering factor to induce failure in the soft rock cliffs. Although using a simple constitutive model, some interesting results have been achieved in this perspective. More sophisticated constitutive models need to be applied in order to verify the effect of rock fatigue in the generation of cliff failure, even ad lower wave impact levels.

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The importance of topographic position on landslide formation near Kutina

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Introduction

This research analyses possible preferred topographic positions of landslides in the research area. Namely, the landslide inventory (created for the safEarth and RESPONS-a Interreg IPA CBC projects) in the southwest slopes of Mt. Moslavačka gora revealed grouping of landslide locations in grapelike clusters around gullies and water courses (Pollak at al., 2022). That observation is further analysed here on the updated landslide inventory which now contains more than 1700 landslides within an area of almost 130 km^2.

The topographic position and landform analysis of the research area is done using Topographic Position Index (TPI).

Methods

This research explores typical landforms in the terrain and topographic position of landslides in the natural environment. The analysis are based on LiDAR-derived DEM (with a resolution of 0.5x0.5 m) and geological map in the scale 1:300 000 (HGI, 2009).

Firstly, DEM derivates (slope angle map, hillshade, contour map) and orthophoto was used to build very detailed landslide inventory. The same DEM was used to compute Topographic Positioning Index (TPI) for the whole research area. TPI compares the elevation of each cell in a DEM to the mean elevation of a specified neighbourhood around that cell (Weiss, 2001).

Although TPI calculations are very straightforward in ArcMap software, the analysis are done with caution. Namely, TPI values are highly scale dependant and determined by neighbourhood (window) size. Small neighbourhood (window) determine small hills and valleys, while large neighbourhoods capture larger-scale features like mountain ranges and plateaus (Jennes, 2006). Therefore, neighbourhood size should be appropriate for the morphology of the terrain, phenomenon being analysed and the purpose of the analysis.

The TPI results also depend on neighbourhood geometry. The application provides several neighbourhood types (circle, annulus, wedge, rectangle), but the authors believe that circular shape is most appropriate for our analysis. A circular neighbourhood is composed of cells whose cell centres fall within certain radius from the focal cell.

Results

Regarding general geomorphological characteristics, the flattest terrain is typical for delluvial, proluvial and of course alluvial sediments and regions.

Loose or poorly cemented deposits (M_6^2, M_7 and Pl_1) have well developed drainage network with frequent gullies and ridges in between. That enables the formation of relatively steep natural slopes in between them, which frequently sets preconditions for many slope instabilities (landslides) in the region. The contrast are loess sediments which usually don't have ridges and gullies detected.

Deep, steep and frequent gullies are found in migmatites and granites (Pz-Mz) and well-cemented sediments (M_4 and $M_{2,3}$).

In this study, TPI values are used to differentiate four topographic positions:

1. Ridge – highly positive TPI values represent locations that are higher than the surroundings, at or near top of the hill or ridge;
2. Gulley – very negative TPI values indicate positions which are lower than average of the surroundings, at or near the bottom of the valley
3. Upper slope – moderately positive TPI values
4. Lower slope - moderately negative values

Since TPI values are highly scale dependent, several neighbourhood sizes were tested (100, 250 and 500 m). Among them, a neighbourhood radius of 250 meters provides the most realistic positioning of named topographic classes in the research area.
The analysis indicates that landslide polygons are dominantly positioned on the lower slope for all tested scales (Figure 1). It can also be seen that neighbourhood circle with a radius of 250 m puts greater emphasis on the lower slope as the location for most of the landslide polygons, which corresponds to the nature of these landslides.

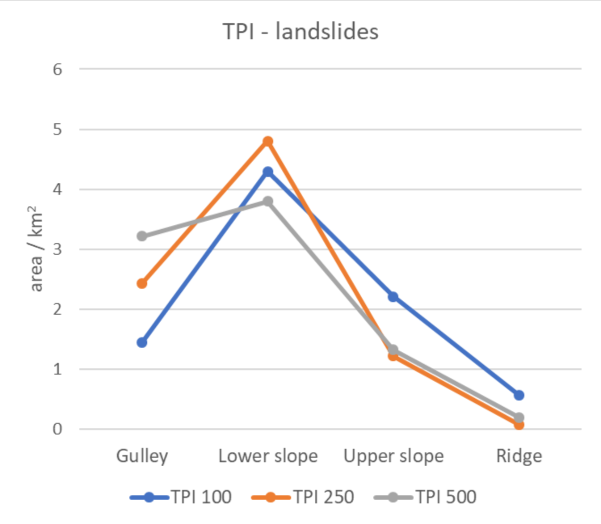

Figure 1. Topographic positions of landslides based on TPI values calculated for neighbourhood sizes of 100, 250 and 500 m.

Conclusion

The topographic analysis unambiguously proves the assumption that landslides in the research area are strongly related to the network of incised watercourses. Given that the great majority of landslides occur at lower slopes and at the edges of gullies, it is obvious that erosional activity of surface waters plays important role in landslide initiation, alongside common factors such as slope angle and pore pressure. This means that further studies should promote TPI as an important factor in detailed landslide susceptibility mapping.

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ENGINEERING GEOLOGY FOR THE SOCIETY: EXAMPLES FROM ZAGREB CITY AREA, CROATIA

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Introduction

Sustainable development relies on adequate planning for which reliable and quality data is needed. From detailed and up to date data, usable and practical thematic maps can be developed and used in geohazards assessment and urban planning. Geohazards include a variety of phenomena but in this paper the focus is on the conducted engineering geological studies in Zagreb city area (~641 km^2) by Croatian Geological Survey with emphasis on the development of geological and seismic zonation(s) (Miklin et al., 2019), detailed engineering geological maps (Miklin et al., 2007), landslide inventories (Miklin et al., 2018) and terrain stability and zonation maps (Podolszki and Terzić, 2023). These studies cover time span of more than 20 years and the aim of these studies were to improve the geohazards management and sustainable development of the Zagreb city metropolitan area.

Methods

In the Zagreb city area numerous researches and studies were conducted during the last decades, but the relevant data regarding the aspect of engineering geology and geohazards are relatively scarce. Still, there are valuable studies/data in which detailed data about engineering geological properties (Miklin et al., 2007), landslides (Miklin et al., 2018), ground type of sediments (according to Eurocode 8, Miklin et al., 2019) and geological zoning (Podolszki and Terzić, 2023) can be found. Detailed data for the part of the research area (~175 km^2, ~25% of Zagreb city area), gives insight regarding the landslide locations and type of sediments present in the ~1/4 of the Zagreb city area. Still, it must be emphasized that for the rest of the Zagreb city area (~3/4), detailed investigations are needed.

Results

Developed detailed engineering geological maps provide information about physical and mechanical properties of materials and about characteristic surface processes and phenomena for the area (geohazards, with emphasis on landslides), including the information about lithology, stratigraphy, and tectonics and as such they should be considered as standard for other areas in Croatia (Miklin et al., 2007; Miklin et al., 2018). Within seismic and geological micro zonation for the part of the Zagreb city area the geological, geotechnical, geophysical and seismic characteristics of the research area were compiled and addressed (Miklin et al., 2019). Ground type determination and description was performed and the research results were also presented on developed seismic zonation map in accordance with Eurocode 8 in scale of 1:25,000 where areas of equal soil amplification relative to the bedrock were depicted (Miklin et al., 2019). Finally, based on available geological data and small-scale maps, geozonation of Zagreb city area was conducted and a new map in scale of 1:100,000 was developed (Podolszki and Terzić, 2023). Although the developed map gives insight into geological conditions for the whole area of Zgareb city and differs four zones with six geological complexes, the developed map is a small-scale map. It can be used as guideline towards seismic risk assessment as characteristic phenomena (geohazards) for each geological complexes are defined and a ground type assessment according to Eurocode 8 is given (Podolszki and Terzić, 2023). Still, for direct use in urban planning the developed map needs to be upscaled to scale 1:25,000 (or more) with detailed (geo)data (currently non-existent or non-available for the whole research area).

Conclusion

To conduct the aforementioned studies relatively large funding was required and interdisciplinary teams of researchers throughout the years. Still, once collected detailed and quality (engineering geological) data remains as constant value as base for further updates and analysis. On the other hand, it is a never-ending process: as new data and techniques become available and/or the research area goes through changes/development – there is always room for the improvement of the developed thematic engineering geological maps (in wider sense). The best way to cope with geohazards and urbanization at Zagreb city area (or any other area) is to conduct geo-researches periodically and interdisciplinary with new technologies applied and up-to-date methodology. By adopting that approach green, safe and sustainable development can be reached.

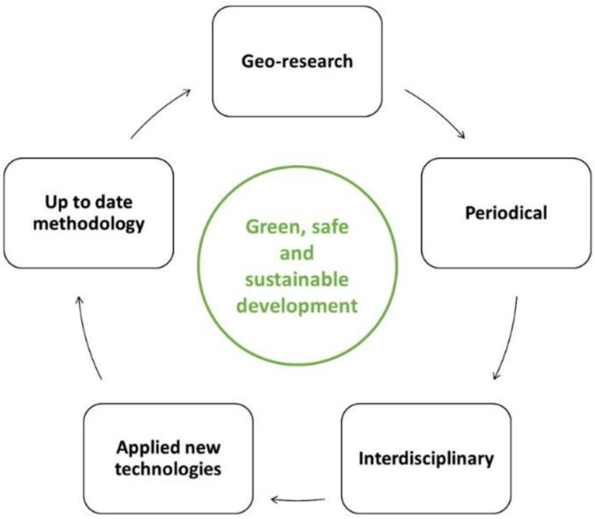

Figure 1. Never-ending process (cycle) of geo-research towards green, safe and sustainable development.

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INTEGRATION OF LOCAL RELIEF INTO SMALL-SCALE LANDSLIDE SUSCEPTIBILITY MAPPING

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Introduction

Landslide susceptibility maps (LSMs) provide insight into the spatial likelihood of landslides occurring (Fell et al., 2008). The scale of these maps depends on their intended use and the size of the investigated area. Small-scale LSMs, covering areas over 10,000 km^2 at scales smaller than 1:100,000, inform policy makers and the general public (Cascini, 2008). However, creating such maps for large areas presents challenges concerning the consistency and quality of available landslide inventories and input data from which geo-environmental conditioning factors are derived.

Geological characteristics significantly affect landslide occurrence, with slope angle often serving as the primary indicator of the stability of certain areas. Consequently, lithology and slope are commonly incorporated into small-scale LSMs. However, slope is strongly influenced by the resolution of the digital elevation model (DEM) from which it is derived. Since the derivation of small-scale LSMs implies a coarser DEM resolution, in this study, slope is substituted with local relief, which measures the difference between the highest and lowest elevations in an area (Smith, 1935), indicating the potential energy for mass movement.

Methods

The study area encompasses the entire northern and eastern continental part of Croatia, covering 29,785.5 km2. It generally belongs to the Pannonian Basin System, covered with numerous geological units. While Neogene and Quaternary deposits, varying from marls and carbonate rocks to various clastic sediments, are predominantly exposed on the surface, Pre-Neogene basement rocks are locally exposed on the slopes or cores of the mountains within the study area.

To test the applicability of local relief in landslide susceptibility assessment, two scenarios are evaluated, using geological units and slope as the conditioning factors in the first scenario (LSM1) and geological units and local relief in the second scenario (LSM2). Geological units are obtained from a 1:300,000 scale Geological Map of the Republic of Croatia (HGI-CGS, 2009), while slope and local relief are derived from a 25 m resolution DEM based on a 1:25,000 scale topographical map using Arc GIS tools (Slope and Focal statistics). To calculate local relief, the Range statistics type is used with a defined neighborhood distance of 1,200 m.

Four different sources of landslide inventories, containing a total of 1,003 landslides, are utilized. Three inventories are synthesized from historical geological maps, namely, the Engineering Geological Map of SFRY at a scale of 1:500,000 (Čubrilović et al., 1967), the Kutina sheet of the Basic geological map of the Republic of Croatia at a scale of 1:100,000 (Crnko, 2014), and a draft field geological maps at a scale of 1:25,000. This data forms the training dataset for modelling the LSMs. A landslide inventory from the publicly accessible web portal "Report a Landslide" (https://www.hgi-cgs.hr/prijava-klizista/) is used as the testing dataset to validate the LSMs' performance.

The Frequency Ratio (FR) method is employed to assess landslide susceptibility. Using 765 landslides from training dataset, FR weights are calculated, normalized, and assigned to each factor category. By summing the weights of conditioning factors, a landslide susceptibility index (LSI) is calculated. Finally, to enable the zonation of the study area according to zones of similar landslide susceptibility, LSI values are reclassified into 4 landslide susceptibility zones (LSZs): (1) low, (2) moderate, (3) high, and (4) very high. In both scenarios, the Natural Break classification is used to define LSZs, enabling consistent LSI classification and clear comparison of LSMs. LSM1 and LSM2 are adjusted for small-scale presentation and are resampled to a resolution of 150 m. The accuracy of LSMs is evaluated through relative landslide density (RLD), which is calculated as the ratio between the percentage of the number of landslides within each LSZ and the percentage of the area of a certain susceptibility zone. RLD is calculated using both the training (765) and testing (238) landslide datasets to test the model effectiveness (i.e., success rate) and the model accuracy (i.e., predictive rate), respectively.

Results

The final results of this study, the effectiveness and accuracy of the LSM1 and LSM2 models, are represented in Table 1. It can be observed that for both LSMs, the RLD increases towards the very high LSZ. Specifically, the number of landslides and RLD for LSM2 for both training and testing datasets are larger within very high LSZ compared to LSM1. Also, the number of landslides and RLD for LSM2 are smaller within the low LSZ compared to LSM1.

Table 1. Number of landslides and Relative landslide density (RLD) within each landslide susceptibility zone for derived LSM1 and LSM2 models.

LSZ	LSM1 Area (%)	LSM2 Area (%)	LSM1 (a)		LSM2 (a)		LSM1 (b)		LSM2 (b)	
			Landslide No. (%)	RLD	Landslide No. (%)	RLD	Landslide No. (%)	RLD	Landslide No. (%)	RLD
Low	60	52	5.36	0.09	0.78	0.01	15.97	0.26	7.56	0.14
Moderate	11	14	15.42	1.48	5.36	0.40	13.87	1.33	16.39	1.21
High	15	19	27.58	1.84	33.33	1.77	33.61	2.24	33.19	1.76
Very high	14	15	51.63	3.61	60.52	3.99	36.55	2.55	42.86	2.83

Notes: (a) Training landslide datset, (b) Testing landslide dataset.

Conclusion

The presented results confirm that integrating local relief into small-scale LSMs is justified. The higher RLD in the very high LSZ for LSM2 indicates a better alignment with observed landslide occurrences. Moreover, the reduced number of landslides in the low LSZ for LSM2 suggests a more accurate exclusion of stable areas from high-susceptibility zones. This highlights the effectiveness of using local relief for more accurate landslide susceptibility mapping in large areas.

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ENGINEERING GEOLOGY: A CORNERSTONE OF INFRASTRUCTURAL AND ECONOMIC ADVANCEMENT IN ALGERIA

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Introduction

Algeria, the largest country in Africa, is strategically important due to its vast territory of 2,381,741 square kilometers and diverse borders with seven nations. As the world's 10th largest country and Africa's 10th most populous country with over 46 million people, Algeria is a major player in global energy markets. In 2022, it was the 16th largest oil producer, the 10th largest natural gas producer and the 7th largest natural gas exporter worldwide (Belgacem Tahchi, 2024). The energy sector is central to Algeria's economy, with hydrocarbons accounting for 60% of budget revenue and 98% of export revenue in 2016. The country's rich hydrocarbon, natural gas and mineral resources highlight the critical role of engineering geology in resource exploration, assessment, and efficient utilization. Engineering geology's importance in Algeria's development has been increasingly recognized

Algeria geology

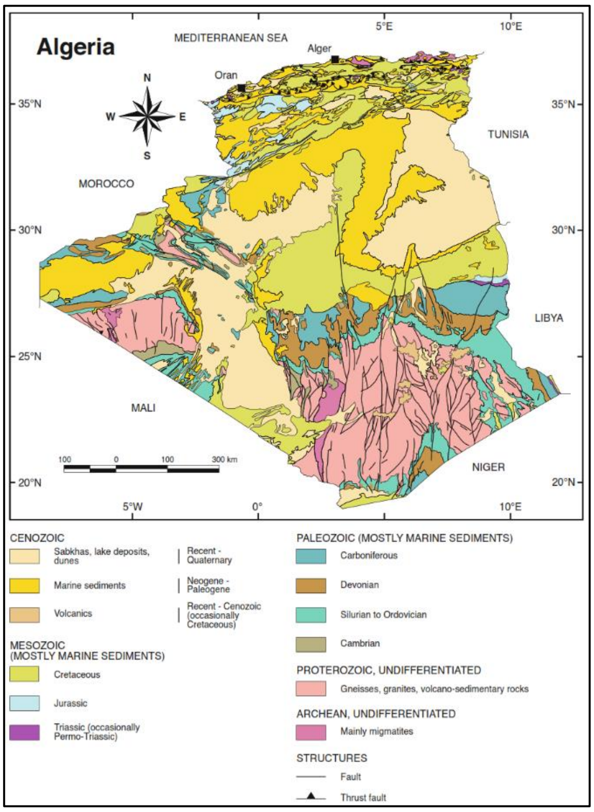

Fig. 1 Geological overview of Algeria (modified after Fabre et al, 1978)

Algeria's geology can be divided into three contrasting tectono-stratigraphic domains (Thomas Schlüter, 2006)(Fig. 1) : 1.The West African craton generally consists of a Precambrian granitized basement; 2.The eastern limit of the West African Craton borders the Tuareg shield; 3.and In the north, beginning from Tangier in Morocco through northern Algeria to Tunis in Tunisia, a folded chain extends the entire length of the Maghreb.

Economic Geology

The production of hydrocarbons is the cornerstone of Algeria's mineral sector, and contributes the majority of the country's export revenue. Although the government promotes a diverse but relatively small-scale metal production, the majority of Algeria's iron ore is comes from the Ouenza mine, whose iron content ranges from 53 to 60%. Additional iron ore mining takes place in Bou Khadra. Lead and zinc mining, which is largely artisanal, is conducted in the Oued Amizour area, while the El Abed Mine near the Algerian-Moroccan border yields between 10,000 to 15,000 metric tons of zinc concentrates annually. In addition, Algeria accounts for about 10% of global mercury production. is an important Paleozoic oil and gas region, and has significant fields such as Hassi Messaoud, with 8 billion barrels of oil, and Hassi R'Mel, with 50 trillion cubic feet of gas and 2 billion barrels of crude oil. The majority of hydrocarbon resources are concentrated in the Bechar-Timimoun, Illizi, and Ghadames Basins, and are mainly contained in structures associated with Caledonian and Hercynian tectonic movements.
Given Algeria's diverse and complex geological landscape, engineering geology plays a transformative

role beyond its essential functions. It contributes significantly to the country's infrastructural and economic progress and serves as a driving force for progress and development. The impact of discipline is particularly evident in addressing the challenges posed by Algeria's unique geological features while harnessing its natural resources for sustainable growth.

Engineering Geology in Algeria

The passage details the evolution of engineering geology in Algeria after independence in 1962. Initially focused on oil exploration, the field diversified to address national needs by creating Sonatrach S.P.A., now the largest oil and gas company in Algeria and Africa. The company operates in exploration, production, pipeline transportation, transformation, and marketing of hydrocarbons and by-products. Training specialists and adopting new technologies like 3D seismic imaging marked the 1970s-1990s. Since the 2000s, the field has embraced sustainability, environmental concerns, and the exploration of resources beyond oil and gas. Furthermore, numerous organizations now work in the engineering geology field, such as ALGEOS, LNHC, GIEC, and INGEO International. Algeria's universities have been instrumental in driving the nation's progress in engineering geology. This critical field underpins infrastructure and economic development. By establishing specialized programs, universities like institutions in Algiers, Annaba, and Oran have trained generations of skilled professionals. This reflects Algeria's goal to maximize and diversify resource use while fostering national expertise.

Infrastructure Development:

Engineering geology plays a crucial role in Algeria's infrastructure development, particularly in planning, designing, and constructing major projects such as highways, railways, and urban areas. This is achieved by ensuring structural stability and mitigating geological hazards.

Algeria boasts one of Africa's densest road networks, with 112,696 km of roads, including 29,280 km of highways and over 4,910 engineering structures (Logistic cluster, 2024). A notable 1,216 km stretch connects Annaba in the east to Tlemcen in the west. Since 2010, Algeria has implemented two five-year programs (2010-2014 and 2015-2019) aimed at economic recovery and reducing hydrocarbon dependence. These programs, with a public investment of $286 billion, focus on major rail, road, and water projects (Laridji, M.A et al, 2021).

Engineering geology is vital for achieving sustainable development objectives by:

1. Optimizing infrastructure design and implementation, considering local geological conditions to ensure longevity and hazard resistance.
2. Assessing and mitigating geological risks to safeguard populations and infrastructure.
3. Contributing to economic diversification, reducing reliance on hydrocarbons.

As a cornerstone of Algeria's development strategy, engineering geology ensures sustainable, environmentally responsible, and future-oriented economic growth.

Conclusion

Engineering geology is a cornerstone of Algeria's infrastructural and economic progress. Through comprehensive site investigations, responsible resource management and the use of innovative techniques, engineering geologists make a significant contribution to the country's development. As Algeria continues its growth trajectory, the role of engineering geology will remain essential. These qualified professionals ensure the safety and sustainability of important projects and drive the country's progress.

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