https://doi.org/10.5194/egusphere-2024-1300
Preprint. Discussion started: 18 June 2024

A participatory approach to determine the use of road cut slope design guidelines in Nepal to lessen landslides

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Abstract. Road cut slope failures are a type of landslide process and are extensive across the road network of Nepal. In response to the pressing need for improved road cut slope design guidelines to help prevent these failures, this study employs a participatory approach to assess the efficacy of the current guidelines in Nepal and identify critical areas for enhancement. We organized a one-day workshop with 34 participants, conducted six semi-structured interviews and five unstructured interviews, facilitated two one-hour focus groups, and distributed 19 questionnaires. Participants in this research included local, provincial, and central government engineers, consultants, and academics. We conducted a thematic analysis of the qualitative data. Our findings reveal significant inconsistency in guideline adherence, attributed to their lack of user-friendliness, inconsistent recommendations, and inadequate training for engineers. We found that engineers at provincial and local levels often resort to empirical methods when designing cut slopes due to constraints such as land acquisition difficulties. Moreover, the absence of comprehensive geotechnical investigation further exacerbates the unreliability of slope designs. To address these challenges, we propose the development of new, contextually appropriate guidelines that prioritize simplicity, accessibility, and practicality for field application. We suggest that a program of training is conducted with all Nepali road engineers with the publication of new guidelines. Through these measures, this study aims to lessen road cut slope failures in Nepal, thereby, enhancing the resilience of the road network.

1 Introduction

The construction and widening of roads requires excavation of the ground alongside the road, often resulting in a road cut slope (a slope adjacent to the road that is often steeper than the surrounding topography) (Hearn, 2011). When road cut slopes fail (a type of landslide) it can result in substantial economic, environmental, and societal loss through slope debris colliding with pedestrians, vehicles, and infrastructure, and through debris blocking the road (resulting in a delay to people accessing jobs and services, to emergency responders, and to the transport of goods) (Hearn, 2002; Petley et al., 2007). Road cut slope failures are widespread throughout the road network in Nepal (see examples of such cut slope failures in Figure 1) due to a combination natural and anthropogenic causes (McAdoo et al., 2018; Robson et al., 2024). Paudyal et al. (2023); Robson et al. (2022, 2024) suggest that the extensive cut slope failures on the Nepal road network can be partly blamed on the limitations of current guidelines used by engineers to design the cut slopes in Nepal. In this paper, we present the methods and outcomes of a

https://doi.org/10.5194/egusphere-2024-1300
Preprint. Discussion started: 18 June 2024

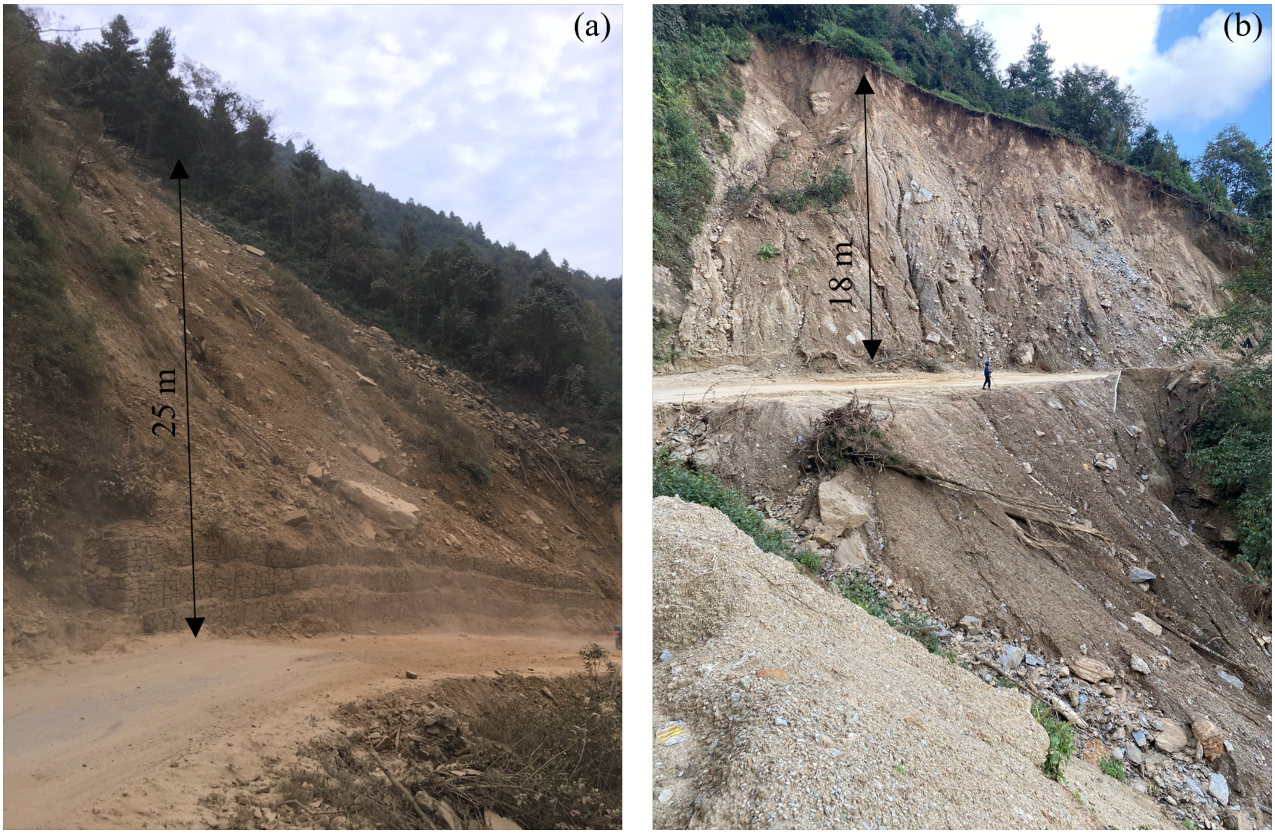

Figure 1. Photos of road cut slope failures in Nepal on: (a) the Kulekhani-Pharping feeder road in the Makwanpur District (photo taken by the corresponding author in November 2019); and (b) the Charikhot-Jiri road in the Dolakha District (photo taken by the corresponding author in November 2023).

participatory study conducted with Nepali engineers to assess how the current guidelines are used, how effective they are, and how they can be improved. The outcomes of this study are hugely important for the development of new design guidelines that are suited to the needs of Nepali road engineers, and that can be used to lessen road cut slope failures. The following paragraphs present a background on road cut slope design in higher-income countries (HICs) and low and lower-middle income counties (LIC/LMICs), followed by the context of slope stability in Nepal, the road management structure in Nepal, and an overview of the cut slope design guidelines in Nepal.

Road cut slopes must be carefully designed and excavated to prevent failure (Aydin et al., 2018; McAdoo et al., 2018; Hearn, 2002). Their design should consider the cut slope geometry (inclination and height), a drainage system, and any additional structures implemented to improve stability. The design is mainly controlled by the strength of the cut slope geomaterial (soil and rock), as well as by spatial and budget constraints (Hearn, 2011).

https://doi.org/10.5194/egusphere-2024-1300
Preprint. Discussion started: 18 June 2024

In HICs, standard practice for designing all road cut slopes involves a detailed site investigation (including in-situ and laboratory testing) to determine the geotechnical and hydrological parameters of the cut slope and surrounding land, and numerical stability analyses (usually simple Limit Equilibrium Methods, or sometimes more advanced methods such as Finite Difference, Finite Element, or Discrete Element) of the cut slope to determine the optimal design taking into account the strength of the cut slope geomaterial, as well as spatial and budget constraints. Normally all steps in this design process are conducted in accordance with national or international design standards. For example, British Standards are used in the United Kingdom and these outline that the design of road cut slope stabilization should conform to the Eurocode 7 (European codes for Geotechnical Design) (The British Standards Institution, 2023). Design guidelines (e.g. Geotechnical Engineering Office (2011)) and stability charts (e.g. Wyllie (2017); Li et al. (2008)), used to determine stable cut slope geometries inclinations based on geomaterial characteristics, are often used in the preliminary design stage.

In LIC/LMICs, the processes involved in road cut slope design and implementation are hugely variable in technical rigor, due to variability in budget. For major roads with large budgets, design generally follows a process of geotechnical investigation and numerical analysis (similar to that in HICs), directed somewhat by design guidelines. However, for road projects with a smaller budget, cut slopes will often be designed following design guidelines in government and donor agency manuals (e.g. Department of Public Works and Highways (2007); Slope Engineering Branch (2010)), without additional geotechnical investigation nor numerical analyses (Robson et al., 2022; Hearn, 2002; Robson et al., 2021). Sometimes the design of road cut slopes will be based only on a rule of thumb (based on experience designing cut slopes in the local area). Hearn and Massey (2009) conducted geotechnical assessments of case studies in Bhutan and Ethiopia and found that very limited geotechnical assessments were carried out before road construction for low-cost roads in Bhutan and Ethiopia. Robson et al. (2021) conducted a series of interviews and discussions with key stakeholders in road slope stability in Nepal and found that local roads in Nepal are often excavated using a bulldozer with no prior slope design.

Nepal is naturally susceptible to slope failure due to its mountainous topography, being tectonically active (as the Indian plate is actively subducting beneath the Tibetan Plateau), and experiencing an annual monsoon season (running from June to September during which 80% of Nepal's annual rainfall occurs) (Shakya and Niraula, 2008; Hearn and Shakya, 2017). Earthquakes are one of the main triggers of landslides (typically shallow rock avalanches) in Nepal (Owen, 2018). The other major trigger for landslides in Nepal is rainfall. 93% of landslides in Nepal occur during this four-month monsoon season (Froude and Petley, 2018). This dominance of landslides occurring during the monsoon was also highlighted by KC et al. (2024) who undertook an analysis of landslides that occurred in Nepal from 2011 to 2020. KC et al. (2024) also found a significant increasing trend in landslide occurrence in Nepal between 2011 and 2020 (landslide density was 0.85 events/1000 km^2 in 2011 and had risen to 3.34 events/1000 km^2 by 2020). The authors suggest that this trend is a consequence of the 2015 M_w 7.8 Gorkha earthquake in Nepal which caused ground cracking resulting in a reduction of the ground material strength and, thereby, contributing to landslide occurrence. This was suggested as landslide occurrence within the 14 worst-affected districts remains significantly higher than it was before the earthquake. It is also likely that changes in the intensity and timing of the monsoon season in Nepal are contributing to an increase in landslide activity. For instance, there is an increasing trend in the frequency and intensity of heavy rain events in the Himalayan foothills due to climate change (Deshpande et al., 2018).

https://doi.org/10.5194/egusphere-2024-1300
Preprint. Discussion started: 18 June 2024

These environmental and physiographic features result in Nepal having an extremely dynamic landscape, and constructing a fixed linear structure of a road on this dynamic landscape is hugely challenging. However, it has been well documented that this natural susceptibility to slope failure has been exacerbated by the rapid and haphazard construction of roads (Hearn, 2002; Shakya and Niraula, 2008; Hearn and Shakya, 2017; McAdoo et al., 2018). Robson et al. (2021) aimed to understand the issues around the coordination and protocol of implementing road slope stabilization that may lead to road cut slope failures by conducting qualitative data collection with stakeholders in road slope stabilization in Nepal. Key findings of this research were that roads were being haphazardly constructed, that there was poor communication between the key stakeholders, and that slope stabilization is not prioritized in road construction projects.

Nepal has two main road networks, a local road network (LRN) and a strategic road network (SRN). The density of the total road network has more than tripled in the last three decades due to significant national and foreign investments aiming to improve economic and social development in Nepal through road construction (Government of Nepal, 2017; Gurung, 2021). The Department of Roads (DoR), a department in the central Government of Nepal, is responsible for the management, planning, and maintenance of the SRN which comprises highways (main trunk road connecting different regions, nationally and internationally) and feeder roads (connecting district roads to the highways). Engineers working for the DoR undertake road and bridge design and maintenance (including slope stabilization). The DoR often hire external consultancies to assist in the design phase of a project and hire contractors for the construction phase of a project. Provincial and local governments are responsible for the LRN which comprises local roads (connecting settlements) and district roads (connecting local centers to district headquarters). The engineers working for the provincial and local governments undertake work on road and bridge design, construction, and maintenance of the LRN. They sometimes hire contractors for construction. The Department of Local Infrastructure (DoLI) in the central government provides technical support to some road projects. Prior to the Nepal federal government decentralization, DoLI was known as the Department of Local Infrastructure Development and Agricultural Roads (DoLIDAR) and provided technical support to local and provincial governments. International donor agencies and national development organizations also provide money and technical support for some road projects in Nepal.

The DoR has published multiple sets of standards and guidelines that include recommendations on stable cut slope inclinations (e.g.'Nepal Road Standards 2070' (Department of Roads, 2013), 'Roadside Geotechnical Problems: A practical guide to their solution' (Department of Roads, 2007), 'Guide to road slope protection works' (Department of Roads, 2003)). Figure 2 displays the tables of recommendations of cut slope inclinations within these guidelines. These are designed to be used by engineers working on road construction projects in Nepal to determine stable cut slope geometries.

Robson et al. (2022) documented that current guidelines in Nepal, as well as in other LIC/LMICs, lack technical rigor and usability. They outlined that these guidelines often do not account for important geotechnical characteristics, can lack suitable descriptions, are often generic, and are often presented in inaccessible formats. Paudyal et al. (2023) also highlighted limitations in the current Nepali guidelines, suggesting that the geomaterial classifications are too broad leading to mischaracterization of geomaterials and, consequently, the design of unsafe cut slopes. Paudyal et al. (2023); Robson et al. (2022) both call for the redesign of road cut slope guidelines for Nepal. Robson et al. (2022) presented a new methodology to develop road cut slope guidelines based on rigorous geotechnical characterization presented in an accessible format that requires only easily defined

https://doi.org/10.5194/egusphere-2024-1300
Preprint. Discussion started: 18 June 2024

Table 3.1 Recommended Standard Slope Gradient for Cut Slopes (a)

Soil classification		Cutting Height (m)	Slope Gradient (V:H)
Hard rock			1:0.3 ~ 1:0.8
Soft rock			1:0.5 ~ 1:1.2
Sand	Not dense (loose), poorly graded		1:1.5 ~
Sandy soil	Dense, or well graded	Less than 5 m	1:0.8 ~ 1:1.0
		5~10 m	1:1.0 ~ 1:1.2
	Not dense (loose)	Less than 5 m	1:1.0 ~ 1:12
		5~10 m	1:1.2 ~ 1:15
Sandy soil mixed with gravel or rock mass	Dense, well graded	Less than 10 m	1:0.8 ~ 1:1.0
		10~15 m	1:1.0 ~ 1:1.2
	Not dense (loose), or poorly graded	Less than 10 m	1:1.0 ~ 1:1.2
		10~15 m	1:1.2 ~ 1:1.5
Cohesive soil		Less than 10 m	1:0.8 ~ 1:12
Cohesive soil mixed with rock masses or cobble stones		Less than 5 m	1:1.0 ~ 1:1.2
		5~10 m	1:1.2 ~ 1:1.5

Note1: Recommended standard gradient is only indicative and detailed assessment and design of cut slopes should be carried out by an engineer. Silt is to be classified as cohesive soil.

Table 11-5 Cuttings side slopes (b)

Soil type	Side Slope(vertical:horizontal)
Ordinary Soil	1:2 to 1:1
Disintegrated rock or conglomerate	1:$^1/_2$ to 1: $^1/_4$
Soft rock, shale	1: $^1/_4$ to 1: $^1/_8$
Medium Rock	1: $^1/_{12}$ to 1: $^1/_{16}$
Hard Rock	Almost vertical

Table C3.2 Preliminary Cut Slope Gradients (V:H) for cut height < 15 m (c)

Soil classification		**Cut height (m)**		
		< 5 m	**5-10 m**	**10-15 m**
Hard rock		1:0.3 – 1:0.8		
Soft rock		1:0.5 – 1:1.2		
Sand	Loose, poorly graded	1:1.5		
Sandy soil	Dense or well graded	1:0.8 – 1:1.0	1:1.0 – 1:1.2	-
	Loose	1:1.0 – 1:1.2	1:1.2 – 1:1.5	-
Sandy soil, mixed with gravel or rock	Dense, well graded	1:0.8 – 1:1.2		1:1.0 – 1:1.2
	Loose, poorly graded	1:1.0 – 1:1.2		1:1.2 – 1:1.5
Cohesive soil		1:0.8 – 1:1.2		-
Cohesive soil, Mixed with rock or cobbles		1:1.0 – 1:1.2	1:1.2 – 1:1.5	-

Source: Guide to Slope Protection

Figure 2. Tables of recommendations of cut slope inclinations taken from the following guidelines published by the Department of Roads (DoR): (a) 'Guide to road slope protection works' (Department of Roads, 2003)); (b) 'Nepal Road Standards 2070' (Department of Roads, 2013); and (c) 'Roadside Geotechnical Problems: A practical guide to their solution' (Department of Roads, 2007).

https://doi.org/10.5194/egusphere-2024-1300
Preprint. Discussion started: 18 June 2024

parameters to be used. Although the new guidelines presented by Robson et al. (2022) make a marked improvement compared to other guidelines in terms of geotechnical rigor and usability, we suggest that if new guidelines are to be used by engineers in Nepal, it is important to have a clear understanding for the current use of road cut slope guidelines in Nepal and how new guidelines should be tailored towards the needs of engineers in Nepal.

The participatory approach study presented here was undertaken to determine the use of current road cut slope design guidelines in Nepal, their effectiveness, and how they can be improved from the perspective of Nepali road engineers. This research was designed to gain an understanding of the needs of these engineers, and what can be done to improve the resilience of the road network. This research took place in March 2023. The main component of the qualitative research was a one-day workshop with engineers working for a range of different types of agencies and organizations in Nepal. The workshop was conducted alongside semi-structured interviews, unstructured interviews, focus groups, and questionnaires. The qualitative research methods are outlined in Sect. 2, and the outcomes of the research are presented in Sect. 3 and discussed further in Sect. 4. Based on the outcomes of this research, we present recommendations for new guideline development in Sect. 5. These recommendations have been shared with the Department of Roads and the Department of Local Infrastructure at the Government of Nepal. This research has been conducted to lessen the number of road cut slope failures of the road network of Nepal, to improve its resilience.

2 Material and methods

Table 1 presents a summary of the qualitative data collection carried out as part of this research, including the type of data collection and who it was conducted with. We employed a range of qualitative data collection methods to ensure fair and representative research. Each of the qualitative data collection methods are discussed in more detail below (Sects. 2.2 to 2.4). Qualitative data analysis methods are discussed in Sect. 2.5. This study has been conducted with ethical approval from Durham University. All workshop attendees and qualitative data participants were informed about the study aims and objectives, how their data would be used, and how the data would be stored and protected. All workshop attendees and qualitative data participants signed a consent form after being given this information.

Table 1. Qualitative data collection categorized by data collection type and participant job type. Abbreviations: gov. = government.

	Semi-structured interviews	**Unstructured interviews**	**Focus groups**	**Questionnaires**	**Workshop presenters**	**Workshop attendees**
Consultant	5	3	0	0	2	6
Provincial & local gov. engineer	0	0	2	9	1	2
Central gov. engineer	1	1	0	10	2	11
Academic	0	1	0	0	2	15
Total	6	5	2	19	7	34

https://doi.org/10.5194/egusphere-2024-1300
Preprint. Discussion started: 18 June 2024

2.1 Workshop

The one-day workshop took place on 28^{th} March 2023 at the Centre for Energy Studies, Pulchowk Campus, Tribhuvan University organized by the authors of this paper. The workshop was conducted to bring together engineers and academics working on road slope stability, but working for a range of different agencies and organizations, to allow rich discussion and scrutiny of certain topics, as well as knowledge-sharing. There were 34 participants at this workshop including six engineers working for consultancies, two engineers working for the provincial government, 11 engineers working for the central government, and 15 engineers working for different academic institutions. Seven 20-minute presentations took place, each followed by 10 minutes of discussion. Two presentations were given by academics, three by engineers in the central government, and two by consultants. The presenters were in leadership roles in a range of key agencies and organizations and were able to give an overview and insight into the use of guidelines by the agencies and organizations that they represented. Presentations were mostly in English, with discussions occurring in a mixture of English and Nepali. Workshop minutes were typed in Nepali and subsequently translated into English by a student at Tribhuvan University.

2.2 Focus groups

Two focus groups (group discussions guided by Dr Bhim Kumar Dahal) took place, both with groups of local government engineers at two different local government units of Nepal (there are 753 local government units in Nepal). One focus group had 5 participants, and the other had 11 (Gill et al. (2008) recommends a maximum focus group size of 14). The focus groups were conducted to gather rich insights into the experiences of local government engineers. The groups were formed based on which engineers were available to attend. The focus groups were about an hour long and were conducted mainly in Nepali (handwritten minutes from the meeting were subsequently translated into English).

2.3 Interviews

We conducted interviews to gather an in-depth account of the participant's experiences of road slope stability in Nepal (Gill et al., 2008; Flick, 2018). Six semi-structured interviews (guided by a list of predetermined questions) were conducted in English with: two consultants at a consulting firm specializing in road construction; a government engineer; and three consultants at a consulting firm specializing in all forms of civil engineering. Semi-structured interviews were employed since their flexibility allows for the interviewee to adapt to responses by asking additional questions to pursue further details (Bryman, 2016). The questions that guided these semi-structured interviews were written by the authors of this paper to address the predetermined themes, and are provided in the Appendix B. The majority of the questions are open-ended, and where they are not, they include an open-ended follow-up question. As suggested by Gill et al. (2008), the interview questions start with questions that are easy for the participant to answer. The interviews generally lasted around 30 minutes and were recorded with permission using a Dictaphone. They all took place in the participants' offices in Kathmandu.

Five unstructured interviews (not guided by a list of predetermined questions) occurred in English: one with an academic; one with a central government engineer; and three with consultants. Unstructured interviews were employed where participants

https://doi.org/10.5194/egusphere-2024-1300
Preprint. Discussion started: 18 June 2024

seemed more at ease with free-flowing discussion. These interviews all took place in the participants' offices in Kathmandu, and minutes of interviews were handwritten.

2.4 Questionnaires

Nineteen questionnaires, a list of multiple-choice questions designed to collect information (Slattery et al., 2011), were conducted: nine with provincial and local government engineers and 10 with central government engineers. The questionnaires included 17 multiple-choice closed questions (outlined in Appendix A) and were in English. The questions were written by the authors of this paper, and designed to address the predetermined themes. The majority of questions allowed the respondent to include an answer that was not offered on the form. Some questionnaires were completed at a conference in Kathmandu (conference attendees were selected at random), whilst others were completed at provincial and local government offices. All questionnaires were completed individually and they took around five minutes to complete on average.

2.5 Data analysis

All semi-structured interviews were manually transcribed. Handwritten minutes from focus groups and unstructured interviews were typed up. The questionnaire answers were recorded in a Microsoft Excel spreadsheet. The workshop minutes were already typed up and a summary of these was sent to workshop attendees in the days following the workshop.

We conducted a thematic analysis of the qualitative data by first grouping the data into predetermined themes (deductive) and then identifying sub-themes within the main themes (inductive). Thematic analysis is a commonly used method to identify and analyze themes within qualitative data (Braun and Clarke, 2006). We followed five key steps for this process that were adapted from Nowell et al. (2017): (a) familiarising ourselves with the data; (b) grouping the data into the predetermined themes; (c) identifying initial sub-themes within the main themes; (d) reviewing these themes; and (e) writing up the findings.

The four predetermined key themes are:

1. Guideline use (outcomes presented in Sect. 4.1 with further discussion in Sect. 3.1);
2. General slope stability practice (outcomes presented in Sect. 3.2 with further discussion in Sect. 4.2);
3. Opinions on the guidelines (outcomes presented in Sect. 3.3, with further discussion, combined with suggested improvements, in Sect. 4.3);
4. Suggestions for improvements to the guidelines (outcomes presented in Sect. 3.4, with further discussion in 4.3)

The sub-themes are discussed as separate paragraphs within each of the main thematic outcome sections.

https://doi.org/10.5194/egusphere-2024-1300
Preprint. Discussion started: 18 June 2024

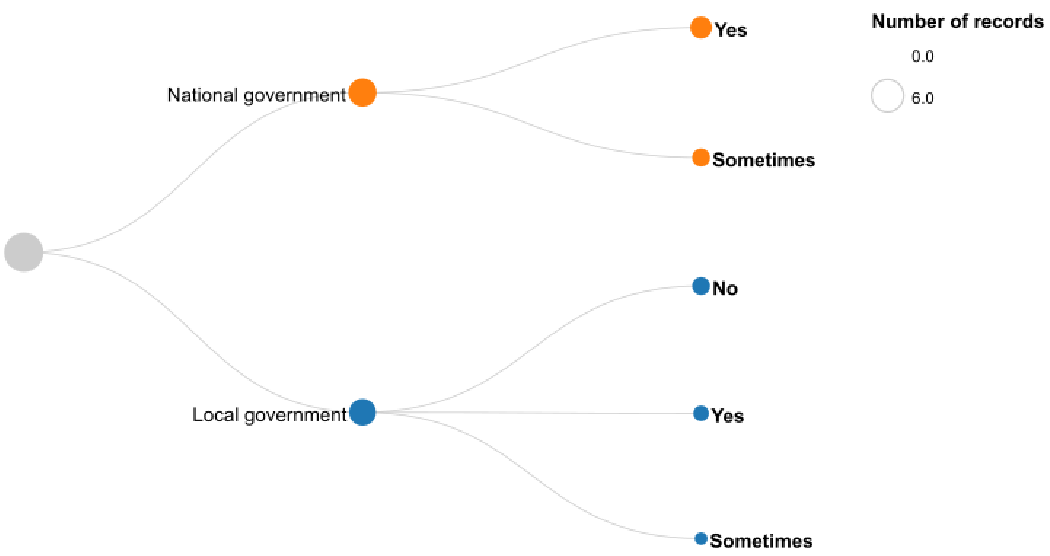

Figure 3. Dendrogram of questionnaire results for question on guidelines use. First level: What type of organization do you work for? (Question 1, Appendix A); Second level: Do you use any guidelines to design road cut slopes? (Question 6, Appendix A).

3 Qualitative research outcomes

3.1 Theme 1: Guideline use

The questionnaire included a question asking if the respondents used any guidelines or manuals to design road cut slopes (Question 6, Appendix A). All 19 questionnaire respondents answered this question. The questionnaire responses to this question are displayed as a dendrogram in Figure 3, categorized by respondents' job type. Based on the responses, it can be suggested that central government engineers mostly use guidelines for designing road cut slopes, whereas provincial and local government engineers are more inconsistent in their use of guidelines.

The questionnaire respondents that answered 'Yes' or 'Sometimes' to whether they use guidelines were asked to select which guidelines they use (Question 7, Appendix A). There were five options of guidelines to choose from including:

1. 'Nepal Road Standards 2070' (Department of Roads, 2013)
2. 'Roadside Geotechnical Problems: A practical guide to their solution' (Department of Roads, 2007)
3. 'Guide to road slope protection works' (Department of Roads, 2003)
4. 'Mountain Risk Engineering Handbook' (ICIMOD, 1991)
5. Other, please specify

https://doi.org/10.5194/egusphere-2024-1300
Preprint. Discussion started: 18 June 2024

Respondents could select multiple answers. Ten respondents only selected the 'Nepal Road Standards 2070' (Department of Roads, 2013). The other three selected more than one manual out of the prescribed answers. No respondents selected 'Other, please specify'.

The respondents that answered 'Yes' or 'Sometimes' to whether they use guidelines were asked where they use the guidelines (Question 8, Appendix A). Five respondents selected that they used the guidelines in the field, five selected that they used the guidelines at a desk, and four selected that they used the guidelines both in the field and at a desk.

The respondents that answered 'Yes' or 'Sometimes' to whether they use guidelines were asked what aspects of slope design they use guidelines or manuals for (Question 9, Appendix A). Options for answers included 'Cut slope inclination', 'Retaining walls', 'Anchoring systems', 'Drainage', and 'Other, please specify', and they could select multiple answers. 14 respondents answered this question. Out of those 14, 13 respondents selected 'Cut slope inclination', nine selected 'Retaining walls', six selected 'Anchoring systems', seven selected 'Drainage', and no respondents selected 'Other, please specify'. This implies that when engineers use guidelines, it is mainly for road cut slope inclination design.

If respondents answered 'No' or 'Sometimes' to whether they use guidelines, they were asked how they decide on the cut slope inclination (Question 10, Appendix A). The options for answers included 'Rule of thumb' (design based on experience rather than using guidelines), 'Numerical modelling', 'Stability chart', and 'Other, please specify'. Out of the six respondents that selected that they 'Sometimes' use guidelines, three selected that they use a 'Rule of thumb' approach to determine cut slope inclinations, whilst two selected 'Other, please specify' and specified that they use 'Field judgement', and one did not respond. It is thought that the 'Field judgement' approach is similar to 'Rule of thumb', in that it is based on experience without the use of guidelines. However, 'Field judgement' emphasizes the importance of using site-specific field observations. All four respondents that selected that they did not use guidelines selected that they use a 'Rule of thumb' approach to determine road cut slope inclinations.

In both focus group discussions with local government engineers, it was revealed that they use a rule of thumb approach to design cut slopes. They said that if they do use guidelines (rather than rule of thumb), they would use those published by the DoR, in particular the 'Nepal Road Standards 2070' (Department of Roads, 2013). However, they outlined that cut slope inclinations are often dictated by land acquisition problems. They have to offer financial compensation if they need to excavate into privately owned land. However, they do not have enough money to offer compensation in all projects. This results in initial safe cut slope designs being compromised, with steeper (more unstable) cut slopes that save space being implemented. This was also highlighted as a major constraint in the design of safe cut slopes in two presentations at the workshop.

In a semi-structured interview with two consultants, the consultants said that they use the 'Mountain Risk Engineering Handbook' (ICIMOD, 1991) as well as 'Nepal Road Standards 2070' (Department of Roads, 2013) for road cut slope design and geotechnical investigation. In a semi-structured interview with three consultants, they outlined that they use the Indian Standards (IS) for cut slope design. In a semi-structured interview with a central government engineer, they outlined that they use 'Nepal Road Standards 2070' (Department of Roads, 2013) to design cut slopes, however, they noted that:

"*...although we are using the guidelines, we are facing several in several stability problems again and again. So we have to revise it depending upon the practical experiences from the construction site.*"

https://doi.org/10.5194/egusphere-2024-1300
Preprint. Discussion started: 18 June 2024

Six of the presenters at the workshop suggested that the guidelines published by the DoR were not followed by Nepali road engineers, with road cut slopes being excavated to a steeper inclination than advised, and subsequently left unprotected.

Although no international consultants were interviewed, it was highlighted in a semi-structured interview with three consultants at a private firm that international experts working for international donor agencies or international consulting firms use their own company/organization's guidelines and standards, rather than those developed in Nepal. They suggested that these international guidelines and standards have a higher safety factor than the DoR guidelines as:

"*they don't want to see their designs being failed. Otherwise, they will always be questioned by those agencies to the international consultant, their reputation goes linked.*"

3.2 Theme 2: General slope stability practice

The focus group discussion with local government engineers revealed that, in general, they do not conduct any form of geotechnical investigation due to financial and time constraints. In addition, they do not conduct numerical stability analyses. During a focus group at one local government unit it was revealed that they receive more than 100 applications from residents in their municipality requesting road improvements (mainly slope-related) in one monsoon season, but they do not have the funds nor time to complete all of these, so they prioritize requests based on what has the highest demand. In a semi-structured interview with two consultants from a private firm, they suggested that geotechnical investigation is not conducted at a sufficient level of detail in Nepal, resulting in incorrect or poor geotechnical data. They thought insufficiently detailed geotechnical investigation occurs due to a lack of funding.

Groundwater has a significant influence on the stability of a slope. When questionnaire respondents were asked if they consider groundwater in their slope mitigation design, four answered 'Yes, every time', seven answered 'Yes, sometimes', six answered 'No', and two did not answer (Question 12, Appendix A). See Figure 4 for these answers categorized by respondents' job type. If the respondents' answers included 'yes' to whether they consider the groundwater table in their design, they were asked what method they use to determine the water table height (Question 13, Appendix A). If respondents answered 'No' to whether they consider groundwater in their design, they were then asked why they did not. See Figure 4 for responses. Focus groups with local government engineers revealed that they use spring lines to identify the groundwater table as they did not have sufficient funds to dig boreholes.

Two consultants in a semi-structured interview said that they regularly use Electrical Resistivity Tomography (ERT), a geophysical method to determine the subsurface resistivity distribution, to identify the water table. They highlighted that ERT is a relatively affordable method in Nepal. They then include the water table in numerical stability analyses. In another semi-structured interview with consultants at a different firm, it was revealed that they just use an estimate of the groundwater table established by locating the position of springs. Based on the qualitative data collection specific to groundwater, it seems that the handling of groundwater in the investigation and design of road cut slopes hugely varies in Nepal.

The questionnaire respondents were asked how they characterize the strength of soil and how they characterize the strength of rock (Questions 4 & 5, Appendix A). Table 2 displays the results of these questions. Two respondents selected 'Other, please

https://doi.org/10.5194/egusphere-2024-1300
Preprint. Discussion started: 18 June 2024

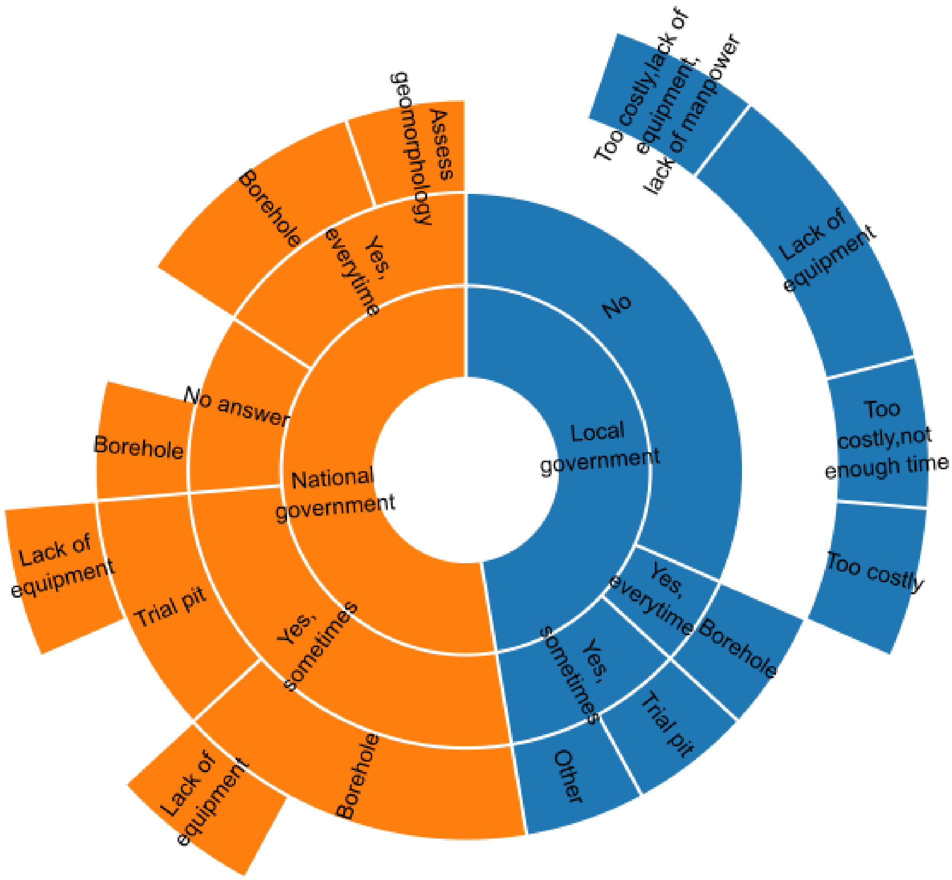

Figure 4. Questionnaire responses on questions addressing how groundwater is included in slope stability design. First level: What type of organization do you work for? (Question 1, Appendix A); Second level: Do you consider groundwater in your slope mitigation design? (Question 12, Appendix A); Third level: If yes, what method do you use to measure the water table? (Question 13, Appendix A); and Fourth level: If no, why not? (Question 14, Appendix A).

https://doi.org/10.5194/egusphere-2024-1300
Preprint. Discussion started: 18 June 2024

Table 2. Questionnaire results for question 'How do you characterize the strength of soil and rock?' (Questions 4 & 5, Appendix A).

	How do you characterize the strength of soil and rock?			
	Mohr-Coulomb	Generalized-Hoek-Brown	Rock Mass Rating	Other
Soil	15	1	0	3
Rock	6	1	10	2

specify' for both questions, but did not give extra detail on what method they used. One respondent that selected 'Other, please specify' for the characterization of soil specified that they characterized soil with visual inspection.

Local government engineers in the focus groups said that they do not use any failure criterion in the design of road cut slopes. The consultants interviewed said that they use the Mohr-Coulomb failure criterion to characterize soil, and the Generalized-Hoek-Brown failure criterion or the Rock Mass Rating system to characterize rocks.

Questionnaire respondents were asked whether the cut slope inclination design is adhered to by construction workers who are managed by contractors (Question 11, Appendix A). 16 questionnaire respondents selected 'Yes, but not very accurately', whilst two selected 'Yes, very accurately' and one selected 'No'. In a semi-structured interview with two consultants and in two presentations at the workshop, it was suggested that contractors try to cut corners to save money in projects. In a semi-structured interview, a government official stated:

"*contractors will think about the money only, they want to save money. And when going for saving money, they will do the things in an unsystematic manner so that the failure may occur*".

A key point highlighted in an unstructured interview with a consultant, an unstructured interview with an academic, and two semi-structured interviews with consultants at private firms was that the Nepali government's priority is to construct and widen roads, and that not enough time and resources are given to improving the stability of cut slopes. In a semi-structured interview, one consultant said:

"*Department of Roads or the Ministry of Physical Planning, whatever the case is, they don't give the priority for the cut slope studies and stabilization, they just care about the pavement. Okay, pavement, how wide it is. That's all. That is the problem.*"

At a focus group with local government engineers, it was highlighted that the government often provides a lump sum of money to consultants or contractors for a project, but does not specify what it should be spent on. This results in under-funding of slope stability works, with the priority in spending on the lengthening and widening of roads (excavation and construction). Furthermore, two of the presenters at the workshop, as well as consultants in interviews, suggested that the government uses road construction as a political bargaining tool. Electoral candidates promise to construct roads to win votes in elections, but often only provide sufficient money to excavate the road, and not to stabilize the road cut slopes adequately.

3.3 Theme 3: Opinions on the guidelines

The questionnaire included a multiple choice question on what the current limitations of the Nepali road cut slope design guidelines are (Question 15, Appendix A). The breakdown of questionnaire responses to this question are displayed in Table

https://doi.org/10.5194/egusphere-2024-1300
Preprint. Discussion started: 18 June 2024

What are the current limitations of road cut slope guidelines in Nepal?			
	Do not include rock/soil descriptions	Hard to use in the field	Not accurate
Single answer	2	10	1
Multiple answers	4	5	4

Table 3. Questionnaire results for question 'What are the current limitations of road cut slope guidelines in Nepal?' (Question 15, Appendix A). Thirteen questionnaire participants selected only a single answer, five participants selected multiple answers, and one did not answer.

3. Thirteen questionnaire participants selected only a single answer, five participants selected multiple answers, and one did not answer. All questionnaire participants selected from the answers that were provided, rather than specifying an alternative answer under the option 'Other, please specify'. The most common answer was that the guidelines are hard to use in a field setting.

Four of the presenters at the workshop outlined that current guidelines are not adequate for the design of safe cut slopes. All presenters at the workshop highlighted that there are inconsistencies between the design guidelines published by the DoR on slope inclinations. For example, 'Guide to road slope protection works' (Department of Roads, 2003) outline that cut slope inclinations for soft rocks should be between 40^o and 63^o, whilst 'Nepal Road Standards 2070' (Department of Roads, 2007) recommends that inclination for 'highly weathered rock' (considered as a soft rock) can be as low as 35^o. 'Guide to road slope protection works' (Department of Roads, 2003) and 'Roadside Geotechnical Problems: A practical guide to their solution' (Department of Roads, 2007) outline that the maximum cut slope inclination for any soil cut slopes should be 51^o, while 'Nepal Road Standards 2070' (Department of Roads, 2013) outlines a maximum of 45^o.

It was also discussed at the workshop that geomaterials are often incorrectly identified by practitioners in the field. This was blamed on a lack of geological knowledge of the engineers, as well as insufficient geotechnical investigation being conducted prior to the design. This was also highlighted in a semi-structured interview with three consultants at a private firm, who said:

"*...Department of Roads, do not have any geologist, they have many geotechnical engineers, but the geotechnical engineers are not always capable of identifying the potential kind of slope problems*".

However, it was emphasized in a different semi-structured interview with consultants and in two unstructured interviews with consultants that Nepali geotechnical engineers have a good understanding of the road slopes in Nepal, but a lack of resources or time leads to incorrect data and/or design. In an interview with two consultants it was said:

"*please don't think these Nepalese engineers, or these Nepalese engineering geologists or geotechnical engineers, they don't know how to work with the slope. They know very well. Because this is their own terrain.*

A lack of training on the use of the guidelines currently used in Nepal was highlighted as a key limitation by local government engineers in the focus groups. This point also featured in four of the presentations at the workshop. In the workshop, it was discussed by participants that there is a lack of advocacy in use of the guidelines by engineers working at all government departments and by governing officials.

At the workshop it was discussed that the guidelines do not address spoil disposal adequately. Spoil disposal is the disposal of soil or rock material excavated and not reused onsite. It was outlined that often excavated material is often deposited down

https://doi.org/10.5194/egusphere-2024-1300
Preprint. Discussion started: 18 June 2024

slope of the cut slope site. Depositing material in this way can cause additional instability to the entirety of the hillslope (Hearn et al., 2003).

It was also discussed at the workshop that current guidelines do not consider groundwater. Groundwater has a huge influence on the stability of a slope. This is especially important in Nepal due to the annual monsoon season, during which 80% of Nepal's annual rainfall occurs during four months of the year (Shakya and Niraula, 2008). This heavy rainfall can drastically change the height of the groundwater table in the slope and, therefore, its stability.

In addition, it was also discussed at the workshop that current guidelines do not include standards for slope benching. Benching is a method of low-cost slope stabilization used globally where the cut slope is divided into a series of horizontal steps, with near-vertical surfaces between steps.

3.4 Theme 4: Suggested improvements

The questionnaires included a question on how the usability of the guidelines could be improved (Question 16, Appendix A). All respondents answered (see Figure 5). Seven respondents gave only one answer, while 12 gave multiple answers. No respondents selected 'Other, please specify'. The responses suggest that engineers want more training on the use of the guidelines, as well as for the guidelines to include more descriptions to characterize the geology.

Questionnaire respondents were also asked how the accuracy of the guidelines could be improved (Question 17, Appendix A). Six respondents gave just one answer, 12 gave multiple answers, and one did not answer (see Figure 6). No respondents selected 'Other, please specify'. The responses suggest that engineers think the guidelines should include options for layers of different geomaterial in the slope, as well as options for groundwater.

It was outlined in the focus group with local government engineers and at the workshop, that guidelines must include the most critical aspects of slope engineering and must be developed specifically for the geological, physiographic, and meteorological conditions of Nepal. Workshop participants discussed the need for the guidelines to be developed in a way which accounts for the geology, geomorphology, and hydrology of the areas upslope and downslope of the cut slope itself, as the characteristics and behavior of these areas can affect the stability of the cut slope. In addition, workshop participants also discussed that groundwater needs to be incorporated into new road cut slope design guidelines, given the importance of pore water pressure on slope stability. Workshop participants also discussed the need for new road cut slope guidelines specifically for road benching.

It was emphasized in interviews with consultants and, at the workshop that new guidelines need to be simple to follow and user-friendly for all engineers in Nepal. In a semi-structured interview with an engineer working for the central government, he said:

"*if the guideline is friendly to the contractors, construction engineers, then they will follow otherwise they may skip it. If it is time taking any money, more money, investment things then they will skip it.*"

Some participants at the workshop suggested that there should be multiple sets of design guidelines developed, each designed specifically to suit engineers working for different government divisions (i.e. guidelines specifically made for provincial and local government engineers and guidelines specifically made for central government engineers), to reflect their varying needs, resources and challenges.

https://doi.org/10.5194/egusphere-2024-1300
Preprint. Discussion started: 18 June 2024

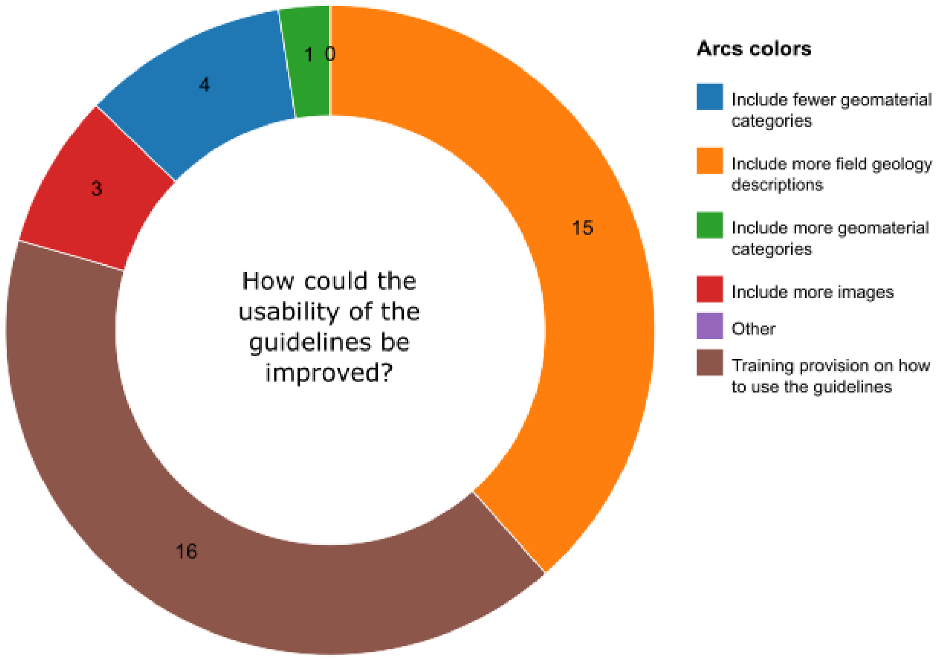

Figure 5. Questionnaire responses on the usability of the guidelines (Question 16, Appendix A) 19 questionnaire respondents answered with one or more answers.

The local government engineers in the focus groups and consultants in a semi-structured interview suggested that more training on slope stability needs to be provided to the construction workers operating on road projects. They said that new guidelines were needed, but that they need to be easy to understand and use. They noted that a training program should be rolled out along with the publication of new guidelines. They also thought that guidelines should include details on vegetation and run-off.

The consultants interviewed and workshop participants agreed that a program of training should be rolled out with the publication of new guidelines and that this should involve all engineers involved in road construction in Nepal, including contractors and construction workers. In addition, the consultants interviewed and workshop participants emphasized that there needs to be improved advocacy for the use of the guidelines by engineers, as well as by governing officials working for central government departments. It was also suggested that guidelines should specify the need for quality assurance checks to be carried out by geotechnical experts.

At the workshop, participants discussed the need to address the problem of land acquisition in new design guidelines. Provincial and local governments often cannot afford to compensate land-owners where cut slopes need to be excavated into their land for stability, resulting in steeper (more unstable) cut slopes being made. It was suggested that private land-owners should be made more aware of landslide risk reduction.

https://doi.org/10.5194/egusphere-2024-1300
Preprint. Discussion started: 18 June 2024

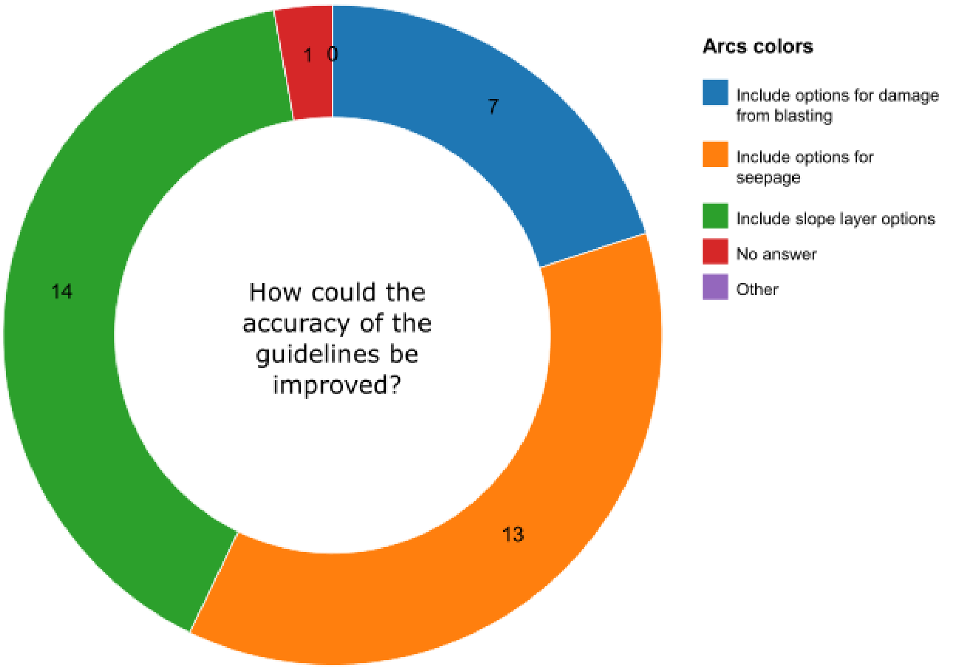

Figure 6. Questionnaire responses on the accuracy of the guidelines (Question 17, Appendix A). 18 respondents answered with one or more answers.

Another suggestion discussed by workshop participants and in four of the presentations was for the new guidelines to clearly address spoil disposal. It was suggested that a diagram should be included to show that excavated material should not be thrown down slope, but instead be deposited on stable ground or used in other construction projects. It was discussed that contractors should receive a clear plan for spoil disposal ahead of works.

4 Discussion

The qualitative research presented here aims to establish the current use of road cut slope inclination geometry guidelines in Nepal to inform the development of new guidelines tailored towards the needs of engineers in Nepal. Research participants included key stakeholders in road cut slope design in Nepal: local, provincial, and central government engineers, consultants, and academics.

4.1 Theme 1: Guideline use

A key finding in this qualitative data collection was that cut slope design guidelines are more likely to be used by central government engineers and consultants than by provincial and local government engineers (from questionnaire responses and interviews with consultants). 'Nepal Road Standards 2070' by Department of Roads (2013) was found to be the most widely used. Questionnaire responses found that the guidelines are mainly used to help the design of cut slope inclinations. Provincial and local government engineers often use a rule of thumb approach to design road cut slopes (based on questionnaire responses, as well as discussions at the focus groups).

Importantly, it was found (through the focus groups with local government engineers) that the design and implementation of road cut slopes by provincial and local government engineers is heavily constrained by problems with land acquisition. Road cut slopes end up being steeper than an initial stable (less steep) design due to not having the funds to acquire and excavate into private property. This is specifically a problem for provincial and local governments, as the DoR have a larger budget for land acquisition and compensation. A suggestion to improve this issue is for resources to be made available to provincial and local governments so that they can acquire the land necessary to excavate shallower cut slopes. 'Overseas Road Note 16' by Hearn and Lawrence (1997) state that compensation for land acquired is usually equated to the expected yield of the land during the design life of the scheme. However, Hearn et al. (2003) discuss the complexities of land acquisition noting that even if landowners are compensated, they could continue to use the land above the slope, which could result in destabilization (e.g. crop irrigation). Hearn et al. (2003) also highlight the need for the road authority to *"take an active role in the management of land inside and outside the right of way through discussions with farmers, landowners and the local authorities"* (Section 4.3.2.8). The DoR need to consider all the aforementioned points to define and clarify a protocol for land acquisition, specifically for the provincial and local government engineers.

In the workshop, it was discussed that cut slopes are often steeper than recommended by the current guidelines. This was also a key finding of Robson et al. (2024) in evaluating the inclination of road cut slopes in Nepal against the advised cut slope inclinations in DoR guidelines. This may be due to contractors trying to cut corners in projects to save money as highlighted in focus groups and interviews (Section 3.2). It could also be due to incorrect identification of geomaterials by engineers, which suggests that they have not received sufficient training on how to use the guidelines (this key point was commonly highlighted in the workshop).

Incorrect identification of geomaterials may also be due to guidelines being difficult to use in the field setting, which was indicated by the questionnaire results and discussed at the workshop (see Section 3.3). This is an important finding since our data collection also reveals that engineers use the guidelines both as part of the desk and field study (see Section 3.1). The existing guidelines do not specify whether they are intended to be used in a field or desk setting, however, 'Roadside Geotechnical Problems: A practical guide to their solution' by Department of Roads (2007) provides field assessment forms, indicating that it was developed to be used in the field. We suggest that the guidelines provided by the DoR are hard to use in a field setting as they present tables in different formats, the geomaterial descriptions are not always clear and key information about what cut slopes they are applicable to is missing. As highlighted by Robson et al. (2022), the original source of Table C3.6 (p. 12) in 'Roadside Geotechnical Problems: A practical guide to their solution' (Department of Roads, 2007) is Hearn (2011) and 'Roadside Geotechnical Problems: A practical guide to their solution' (Department of Roads, 2007) misses out the key information that this table of recommendations is only for cut slopes up to 10 m in height to achieve a FoS of 1. Incorrect identification of geomaterials could also suggest that engineers have not received sufficient training on how to use the guidelines, or that the guidelines are difficult to use in the field setting, which was indicated by the questionnaire results.

https://doi.org/10.5194/egusphere-2024-1300
Preprint. Discussion started: 18 June 2024

4.2 Theme 2: General slope stability practice

In the qualitative data collection focusing on general slope stability practice it was found that geotechnical investigation is not common practice on provincial and local roads, and where it is conducted on other roads in Nepal, it is often not conducted at sufficient level of detail, resulting in inaccurate data. A lack of funding for geotechnical investigation, and for road slope stabilization in general, may be due to under-funding by governments as they prioritize opening roads, rather than stabilizing road cut slopes along these roads (as found in the data collection and discussed in Section 3.2). Based on this finding, guidelines for the design of cut slopes up to a certain height should be designed with input parameters that do not need be identified through in-depth geotechnical investigation. Beyond a certain cut slope height, the guidelines should state that thorough geotechnical investigation is required.

Groundwater is not always considered in road cut slope design in Nepal, particularly not by provincial and local government engineers due to a lack of equipment and budget. Where groundwater testing is carried out, engineers use boreholes or ERT.

Where failure criteria are used to characterize the strength of the cut slope geomaterial, we find that the Mohr-Coulomb failure criterion is mostly used to characterize soil, whilst the Rock Mass Rating system is mostly used to characterize rock behavior. Therefore, new guidelines should be based on these criteria as to make them user-friendly for engineers in Nepal. New guidelines should also be accessible and easy to use in a field setting, including clear advice on how to characterize the geomaterial and groundwater.

This study also highlighted how the Government of Nepal have potentially mismanaged road construction at times, resulting in road slope failures. It was highlighted in our qualitative data collection that the government prioritize rapidly expanding road lengths (and widths) over constructing well-designed roads with safe road cut slopes. This was also a key finding of Robson et al. (2021). Furthermore, it was suggested that politicians use roads as a political bargaining tool. This is also highlighted by Gurung (2021) in challenging infrastructural orthodoxies in the context of Himalayan roads, specifically in the Karnali Province of Nepal. We suggest that further investigation should be carried out on the political influences of road construction in Nepal and the impact that they have. We have two suggestions for main lines of investigation into this topic: (1) research conducted to understand how road construction varies over time within an election cycle, so that the impacts following an election can be anticipated; and (2) how the link between political concerns, road construction, and road failure varies across different parts of the country. As a starting point, we need to better understand the distribution of roads, road construction, and road cut slope failures in space and time.

4.3 Theme 3 & 4: Opinions on the guidelines and suggestions for improvements to the guidelines

In the qualitative data collection it was outlined that guidelines should be developed with careful engineering consideration, whilst also being user-friendly to engineers with varying background. It was suggested that current guidelines do not adequately account for groundwater conditions and that new guidelines should do a better job of this. As in-situ testing of the groundwater is not common practice, if new guidelines are to include the effect of groundwater, this needs to be done in a way that does

https://doi.org/10.5194/egusphere-2024-1300
Preprint. Discussion started: 18 June 2024

not require practitioners to conduct costly groundwater testing. It was also suggested that the guidelines should account for the characteristics of the area upslope and downslope of the cut slope itself.

Engineers highlighted the need for new guidelines to include standards for benching. Globally, standards for bench heights in rock vary between 7 and 10 m in height. However, bench width standards are more variable depending on country specifics (Hearn, 2011). Benching standards specific to Nepal should outline bench widths recommendations for cut slopes of typical geomaterial types in Nepal.

In addition, engineers at the workshop called for clearer advice in terms of spoil disposal. They suggested that a diagram for spoil disposal could be added to the guidelines. 'Landslide risk assessment in the rural sector: guidelines on best practice' by Hearn et al. (2003) specify that considerations to spoil disposal must be done during the feasibility stage of a construction project, with potential spoil areas identified and costing (quantities estimated) carried out. Protocol for spoil disposal needs to be clarified by the central government.

The central Government of Nepal also needs to establish a protocol to ensure that contractors do not cut corners in road construction works, and that the work is carried out as per the agreed design. This can be dealt with by conducting quality assurance checks. Therefore, protocol for quality assurance checks needs to be clarified by the DoR and highlighted in new guidelines, as well as during a training program. 'Guidelines for Legislated Landslide Assessments for Proposed Residential Developments in British Columbia' by APEGBC (2010) discuss the quality assurance byelaws in Canada for the direct supervision of landslide assessments, as well as internal and external peer review of the landslide assessment. They state that direct supervision can *'typically take the form of specific instructions on what to observe, check, confirm, test, record and report back to the Qualified Professional'* (p. 30). They discuss that the internal review should be carried out by another qualified professional in the same firm, and the external review is carried out by some who is independent. Another approach to encourage contractors not to cut corners is to provide them with training to improve their understanding of the importance of following a safe cut slope design.

It was suggested that if new guidelines are published there should be a program of training rolled out on their use, to engineers working for all agency and organization types across Nepal, as well as to contractors and construction workers. An example of a successful road slope stabilization training scheme was part of the South East Asia Community Access Project (SEACAP 21) (Scott Wilson, 2009; Hearn et al., 2021). This project was conducted by the UK Department for International Development (DfID), now replaced by the Foreign, Commonwealth & Development Office (FCDO). It was a three-year project in Laos, commencing in 2006 aiming to improve road slope management practices (Hearn et al., 2021). They selected specific problematic cut slope sites in Laos to implement low-cost engineering mitgation methods. The training included a short presentation and a seminar on the work undertaken by SEACAP 21 with postgraduate students from the National University of Laos (NUoL). They also conducted an assessment of courses offered at NUoL and provided recommendations for additional course content, as well as thesis topics. SEACAP 21 also provided field training to students and lecturers from NUoL, as well as to staff from the Department of Public Works and Transport. As part of the field training, participants visited the SEACAP 21 field sites where 'experts' explained their approach to the site assessment. A training course for road maintenance engineers in Laos took place in 2019, revisiting and evaluating the success of the SEACAP 21 sites. If training is going to be rolled out with the

https://doi.org/10.5194/egusphere-2024-1300
Preprint. Discussion started: 18 June 2024

publication of new guidelines in Nepal, it should be integrated into the university curriculum for the geotechnical engineering master's program (currently only offered at the Institute of Engineering on Pulchowk Campus at Tribhuvan University), as well as through conducting field training with practicing engineers.

A key limitation of the existing guidelines highlighted during the data collection is the inconsistencies in the recommended cut slope inclinations between existing DoR guidelines. This is problematic as engineers are using different guidelines, as highlighted in the questionnaire (see Section 3.1). If new guidelines are to be published, the DoR needs to advocate for the use of the new guidelines only. It was also suggested that generally advocacy in the use of road cut slope design guidelines needs to improve from engineers themselves, as well as from governing officials. This could be encouraged during training, by emphasizing and explaining the economic and social benefit of using the new guidelines.

Engineers at the workshop suggested that different guidelines could be made specifically for engineers working for different agency and organization types. In doing so, they would be tailored towards the resources they have available to them and to their specific problems (i.e. protocol on land acquisition problems in guidelines for provincial and local government engineers). This should include developing guidelines that can be used by the excavators who lack geotechnical training, but are the people ultimately responsible for the cut slope geometry.

4.4 General discussion

As outlined in the introduction, Nepal's landscape is naturally hugely dynamic (tectonically, meteorologically, and topographically) and excavating into this landscape to construct a road is a tremendously difficult challenge. However, new road construction and widening projects are currently widespread across Nepal. New guidelines are required to reduce the contribution that these road construction projects have to slope instability.

Given the challenging landscape and constrained resources (particularly in the case of provincial and local engineers), the guidelines should reflect the capabilities to excavate a stable slope. In some cases, it may be near impossible to excavate a completely stable slope (with a high Factor of Safety) without implementing a stabilization measure (e.g. an anchoring system) over the entire slope, which may be unrealistic. Therefore, there needs to be some degree of acceptance, which may come in the form of a risk assessment within the guidelines. Where there is potential for higher societal and economic loss (i.e. on a road with heavy traffic or next to infrastructure), a higher factor of safety should be attained. This should be integrated into the guidelines.

Careful thought should also be given to the communication strategy used to publicize the new guidelines to engineers and the public. The reason for the development of new guidelines and the method employed in developing them should be communicated with engineers. The communication could hugely influence the take-up of new guidelines.

https://doi.org/10.5194/egusphere-2024-1300
Preprint. Discussion started: 18 June 2024

5 Conclusions

5.1 Concluding remarks

Robson et al. (2022) outlined that the cut slope design guidelines currently available in Nepal are not fit for purpose as they are not geotechnically rigorous and they are presented in inaccessible formats. Robson et al. (2022) and Paudyal et al. (2023) called for a new set of guidelines to be developed to replace those currently used. In order to develop new guidelines fit for engineers in Nepal, there needed to be a better understanding of how guidelines are currently used in Nepal, their effectiveness, and how they can best be improved.

The participatory approach study presented here aimed to address this need by conducting questionnaires, semi-structured interviews, unstructured interviews, focus groups, and a workshop with road engineers working for different agencies and organizations in Nepal. This data collection was conducted in March 2023. We found that central government engineers are more likely to use the 'Nepal Road Standards 2070' to design cut slopes, while provincial and local government engineers often resort to using a rule-of-thumb approach due to constraints including land acquisition difficulties. Inconsistency in the use of the guidelines can be blamed on their lack of user-friendliness (especially in a field context), inconsistencies between guidelines, and a lack of training on the use of the guidelines. We also found a lack of comprehensive geotechnical investigation by provincial and local government engineers which further exacerbates the unreliability of slope designs.

5.2 Recommendations

Based on the findings of the qualitative data collection, we present the following key recommendations for the development of new guidelines:

1. Guidelines should be produced using a rigorous geotechnical field and/or numerical analysis method, and be developed according to Nepal's geological, physiographic, and meteorological conditions.

2. Guidelines should be presented in a user-friendly format, and not be over complicated. They should be easy to use in a field and desk setting, with descriptions and diagrams to help aid geomaterial characterization. They should not require a detailed geotechnical investigation in order for them to be used.

3. Guidelines should incorporate the effect of infiltration and groundwater. However, they should recognize that detailed groundwater investigations are unlikely to be used.

4. Protocol for spoil disposal needs to be clarified and improved by the DoR. Guidelines (and training) should include clarified advice on spoil disposal.

5. The government need to clarify the protocol for land acquisition and compensation, specifically for the provincial and local government engineers. Guidelines (and training) should advise on this agreed protocol for land acquisition and compensation. Where land cannot be acquire, meaning a stable inclination cannot be achieved, the guidelines should state that an additional stabilization measure will need to be implemented.

https://doi.org/10.5194/egusphere-2024-1300
Preprint. Discussion started: 18 June 2024

6. Guidelines should specify the need for quality assurance checks (again the protocol for this needs to be clarified by the DoR).

7. Guidelines need to be produced for road cut benching.

8. When guidelines are published, training of the use of the guidelines should be provided to engineers specialized in road slope stability working for all types of agencies and organizations across Nepal, including contractors and construction workers. In conducting training, it is important to emphasize and encourage people to advocate for the use of the guidelines.

In addition to new guidelines, we suggest that a basic level of geotechnical investigation should be made compulsory for all road projects in Nepal. This could be limited to digging trial pits and conducting cone penetration tests to assess the structure and strength of the soil.

Robson et al. (2022) discuss a range of LIC/LMIC's road cut slope design guidelines that lack in technical rigor or usability and, therefore, require an upgrade (e.g. the Philippines: Department of Public Works and Highways (2007); Malaysia: Slope Engineering Branch (2010); and Liberia: Ministry of Public Works (2019)). We suggest that a qualitative study as presented in this paper should be conducted prior to the design of new guidelines for any of these LIC/LMIC's.

5.3 Next steps

The Centre for Disaster Studies, Institute of Engineering (IoE) at Tribhuvan University, Nepal, is collaborating with the Institute of Hazard, Risk and Resilience (IHRR) at Durham University, UK to develop guidelines in line with these recommendations for local and provincial government engineers in Nepal (funded by the EPSRC Impact Acceleration Account). This project is supported by Mott MacDonald UK and the Nepal Geotechnical Society. These guidelines are being specifically developed for local and provincial government engineers as it was recognized during this study that these engineers are most in need of guidelines that are suitable for their specific level of training and limited resources.

The guideline development plan has four key stages: (1) desk study to define geographical zones of Nepal based on physiographical, meteorological, and geological data; (2) fieldwork conducted across Nepal to evaluate the stability of cut slope scenarios in each of the geographic zones; (3) numerical stability analyses conducted on the cut slope scenarios to assess the stability of slopes and to extrapolate their physical conditions; (4) guideline development based on the output of the first three stages. By gathering data on cut slopes in different geographic zones, we will account for interactions between geomorphic, tectonic, and climate processes and topography on slope stability (Owen, 2018). The guidelines will be structured as a set of simple questions and corresponding simple field tests (with diagrams and photos) to help the engineers characterize the slope material and determine the most appropriate slope inclination. These guidelines will be made available in hard and soft copy. Where the suggested safe inclination cannot be achieved (e.g. due to land acquisition constraints), engineers will know that additional stability measures are required to prevent slope failure. The guidelines are being developed in consultation with the Department for Local Infrastructure (DoLI) to ensure they are aligned with their needs. Once the four key stages of the

https://doi.org/10.5194/egusphere-2024-1300
Preprint. Discussion started: 18 June 2024

guideline development are complete, a series of training sessions will be conducted with local and provincial government engineers.

https://doi.org/10.5194/egusphere-2024-1300
Preprint. Discussion started: 18 June 2024

Appendix A: Questionnaires

1. What type of organisation do you work for?
   - National government
   - Provincial/local government
   - Consultancy
   - Contractor
   - University
   - Other, please specify
2. What do you do in your role? (tick all that apply)
   - Field investigation
   - Design slope engineering interventions
   - Manage construction works
   - Research
   - Other, please specify
3. What is your academic background?
   - Master's degree
   - Undergraduate degree
   - School
   - Other, please specify
4. How do you characterise the strength of rock?
   - Mohr-Coulomb (M-C) failure criterion
   - Generalised-Hoek-Brown (G-H-B) failure criterion
   - Rock mass rating (RMR) system
   - Other, please specify
5. How do you characterise the strength of soil?
   - Mohr-Coulomb (M-C) failure criterion
   - Generalised-Hoek-Brown (G-H-B) failure criterion

https://doi.org/10.5194/egusphere-2024-1300
Preprint. Discussion started: 18 June 2024

- Rock mass rating (RMR) system
- Other, please specify

6. Do you use guidelines/manuals to design road cut slopes?
   - Yes (go to question 7, 8, 9)
   - No (go to question 10)
   - Sometimes (go to question 7, 8, 9, 10)
7. If **yes/sometimes**, what guidelines/manual do you use? (tick all that apply)
   - Nepal Road Standards 2070
   - Roadside Geotechnical Problems: A practical guide to their solution
   - Guide to road slope protection works
   - Mountain risk engineering handbook
   - Other, please specify
8. If **yes/sometimes**, where do you use the guidelines? (tick all that apply)
   - Field
   - Desk
   - Other, please specify
9. If **yes/sometimes**, what aspects of slope design do you use guidelines/manuals for? (tick all that apply)
   - Cut slope inclination
   - Retaining walls
   - Anchoring systems
   - Drainage
   - Other, please specify
10. If **no/sometimes**, how do you decide on the cut slope inclination?
    - Rule of thumb
    - Numerical modelling
    - Stability chart
    - Other, please specify

https://doi.org/10.5194/egusphere-2024-1300
Preprint. Discussion started: 18 June 2024

11. Is the cut slope inclination design followed by the construction workers?
    - Yes very accurately
    - Yes, but not very accurately
    - No
12. Do you consider groundwater in your slope mitigation design?
    - Yes, every time (go to question 13)
    - Yes, sometimes (go to question 13)
    - No (go to question 14)
13. If **yes**, what method do you use to measure the water table? (tick all that apply)
    - Borehole
    - Trial pit
    - Assess geomorphology of the site
    - Other, please specify
14. If **no**, why not? (tick all that apply)
    - Too costly
    - Not enough time
    - Don't have the equipment
    - Not important
    - Other, please specify
15. What are the current limitations of road slope design guidelines in Nepal? (tick all that apply)
    - Do not include descriptions about rock/soil types
    - Hard to use in the field
    - Not accurate
    - Other, please specify
16. How could the usability of the guidelines be improved? (tick all that apply)
    - More field geology descriptions
    - More training on how to use them

https://doi.org/10.5194/egusphere-2024-1300
Preprint. Discussion started: 18 June 2024

- More images
- Fewer rock categories
- More rock categories
- Other, please specify

17. How could the accuracy of the guidelines be improved? (tick all that apply)

- Include slope layer options
- Include groundwater options
- Include options for damage from blasting
- Other, please specify

https://doi.org/10.5194/egusphere-2024-1300
Preprint. Discussion started: 18 June 2024

Appendix B: Semi-structured interview questions

1. What type of organisation do you work for?
2. What is the role of your organisation in road construction/remediation projects?
3. Please describe your role in the organisation
4. Please describe your training/education for this role
5. What road slope stabilisation technique do you most frequently implement?
6. What do you think are the key reasons for slope stabilisation failure (the failure of engineering solutions) in Nepal?
7. What are the biggest challenges facing engineers in to stabilise road cut slopes in Nepal?
8. What strength criterion do you use to characterise rocks?
9. What strength criterion do you use to characterise soils?
10. Do you consider the groundwater in your slope mitigation design?
11. If **yes**, how do you measure the groundwater table height?
12. If **yes**, how do include groundwater in your design?
13. If **no**, why not?
14. Do you use a manual or guidelines to design/stabilise a road cut slope?
15. If **yes**, what aspect of road slope design is it most useful for?
16. If **yes**, which one and why this? Where do you use it?
17. If **no**, why not?
18. How do you decide on the cut slope inclination?
19. What are the problems in using current guidelines/manuals?
20. How can the usability of guidelines be improved?
21. How can the accuracy of guidelines be improved?
22. How well do construction workers follow a design for the excavation?
23. What do you think could improve the design/construction of slope stabilisation in Nepal?

https://doi.org/10.5194/egusphere-2024-1300
Preprint. Discussion started: 18 June 2024

24. Is there anything else you would like to add?

25. Do you have any contacts that you recommend I speak with or interview?

https://doi.org/10.5194/egusphere-2024-1300
Preprint. Discussion started: 18 June 2024

Author contributions. EBR and BKD formulated the overarching research aims. They also designed the methodology and conducted the data collection. DGT provided supervision for the project. EBR wrote the original draft, whilst the whole team reviewed and edited it.

Competing interests. The authors declare that they have no conflict of interest

Acknowledgements. We would like to acknowledge Prof. Bruce Malamud, Dr Hanna Ruszczyk and Professor Alex Densmore at Durham University for offering their helpful comments on this paper. Funding for this research came from Durham University's Research Impact Fund.

https://doi.org/10.5194/egusphere-2024-1300
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