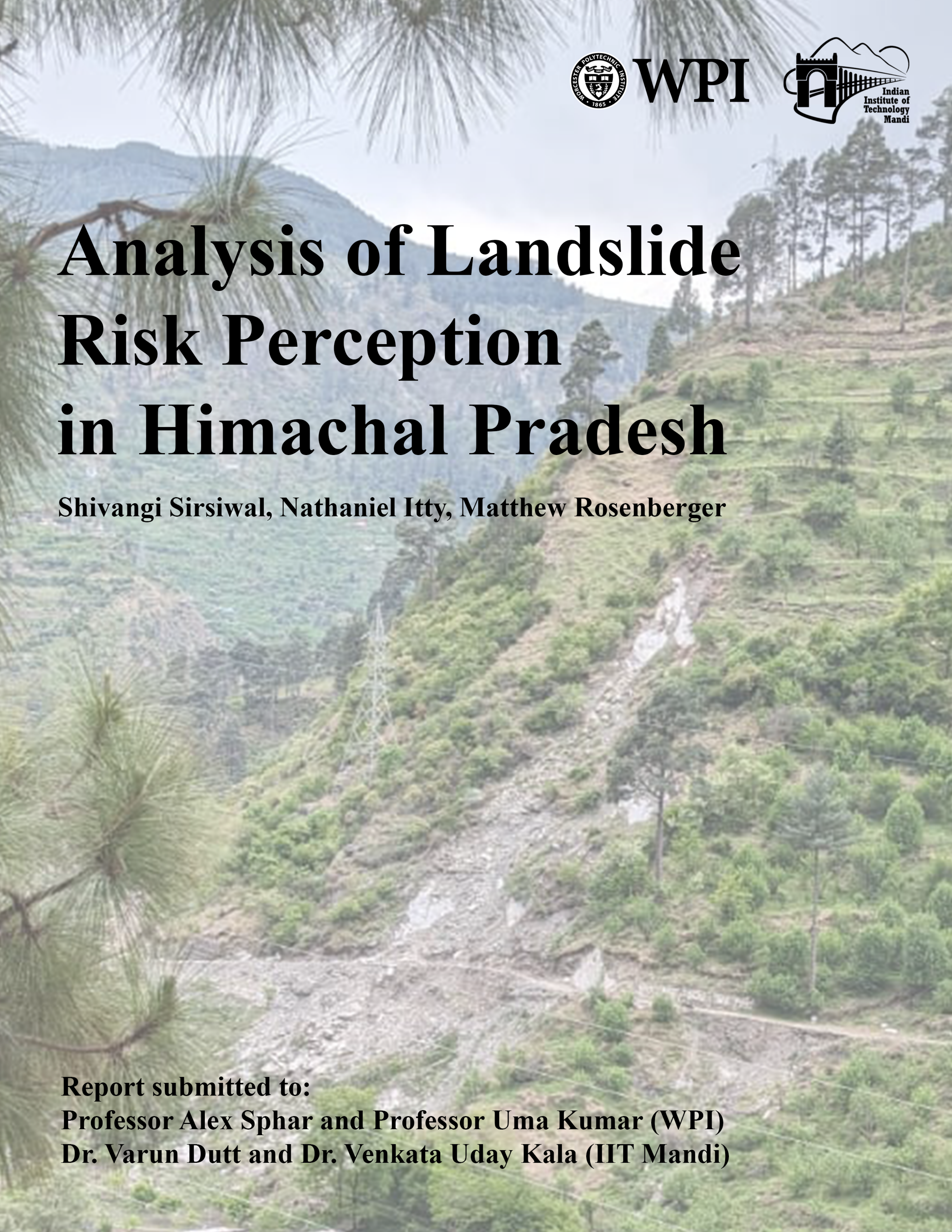

WPI

Indian Institute of Technology Mandi

Analysis of Landslide Risk Perception in Himachal Pradesh

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Report submitted to:
Professor Alex Sphar and Professor Uma Kumar (WPI)
Dr. Varun Dutt and Dr. Venkata Uday Kala (IIT Mandi)

Analysis of Landslide Risk Perception in Himachal Pradesh

An Interactive Qualifying Project
submitted to the faculty of
WORCESTER POLYTECHNIC INSTITUTE and
the INDIAN INSTITUTE OF TECHNOLOGY, MANDI
in partial fulfilment of the requirements for the
degree of Bachelor of Science

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Submitted On:
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Abstract

Himachal Pradesh, India, has seen an exponential increase in rainwater-triggered landslides over the past decade. This study explores local perspectives on landslide risk and investigates the use of virtual reality to measure risk perception from a physiological standpoint. Community interviews and surveys revealed clear gaps in existing risk mitigation programs, and virtual reality showed potential for use in future risk management. The results suggest that the current risk mitigation plan could benefit from the development of a crowd-sourced landslide alert application to assist in the effective dissemination of lifesaving landslide warnings and government aid as well as further development of the virtual reality tool for simulated early warning system testing and landslide risk education.

The team with the villagers from Shegli after the interview.

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- Our IIT teammates, for designing the Virtual Reality simulations, helping with field visits, and assisting with survey design and data collection and analysis.
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Authorship

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Executive Summary

Himachal Pradesh, India, is devastated by landslides every monsoon season. In 2023, rainfall increased exponentially, leading to 168 reported landslides that claimed 503 lives. 17,120 landslide-prone sites have been identified in Himachal Pradesh, with 110 being located in the Mandi District. Mandi was also one of the disitricts worst hit by the increased rainfall in the past monsoon season. Himachal Pradesh sits on the geologically active Himalayan thrust line, resulting in highly unstable slopes with high risk of landslides. The hills and valleys are particularly prone to landslides due to their loose composition and the presence of drainage and fault lines.

Landslides in Himachal Pradesh are primarily caused by excess rainfall, with oversaturation of the soil slowly weakening the slope's integrity. This problem is exacerbated by deforestation and urbanization, which disrupt natural drainage systems and remove natural stability. As global warming melts Himalayan Glaciers at an exponentially faster rate, introducing more water into the water systems, it is clear that the issue of rainfall-induced landslides will continue to grow.

To address the exponential increase in landslides, state organizations have focused on both disaster preparation and response measures. The Geological Survey of India has conducted landslide susceptibility mapping using a combination of historical data and analyzing causal factors. Mitigation measures in Mandi are primarily focused on retaining slope structure and drainage of excess water. Awareness programs have also been held in an attempt to train individuals with effective response measures, but these programs have remained widely inaccessible to local populations. Response to landslides is primarily aimed at search and rescue when an incident is reported, then shifts to clearing roads and restoring infrastructure in affected areas.

Understanding local perspectives is paramount for creating effective disaster response measures. Local communities possess a wealth of indigenous knowledge about their environment and the ways disasters affect their communities. Recent research on climate risk management has found that farmers' practices that were passed down for generations aligned with established scientific principles for drought prediction, suggesting the potential of leveraging local knowledge to improve disaster management. Local observations in Himachal Pradesh could provide valuable insights for landslide prediction and mitigation. By incorporating this knowledge with existing technologies, a more comprehensive understanding of landslides in Himachal can be formed.

Virtual Reality (VR) emerges as a promising tool to assist in the creation of disaster preparedness programs. By enabling users to experience simulated landslide scenarios in a safe, controlled environment, VR can be used to measure physiological reactions to landslide risk as well as behavioral responses to landslide early warning systems. Studies have also shown VR to be successful as an educational tool, and its recent application to landslide awareness has yielded positive results. This suggests VR could be a valuable tool for improving disaster preparedness programs for landslides in Himachal Pradesh.

The goal of this project was to understand landslide risk perception and awareness in Himachal Pradesh. The objectives to achieve this goal were as follows:

1. Understand local perspectives on landslides
2. Measure physiological response to landslides in a simulated environment
3. Understand government perspectives and identify gaps with local risk perceptions

This project utilized two forms of data collection: field visits and virtual reality data collection. Communities in the Kamand Valley region that were most affected by landslides during the 2023 monsoon season were identified, and interviews were conducted with local stakeholders to understand how landslides impact their families, communities, and daily lives. Each person that was interviewed also responded to a risk perception questionnaire to quantify their understanding of the risks posed by landslides and their response when one occurs.

This study also performed a preliminary analysis of Virtual Reality as a tool to understand risk perception. Three VR simulations were designed that encompass different situations where an individual could encounter a landslide: driving on a road when a landslide occurs, walking when a landslide occurs, and experiencing a landslide while in your home. Participants were put through one of these simulations to measure their internal response to landslides and responded to a questionnaire before and after the virtual reality experience.

Field visit interviews with villagers from local communities revealed a strong understanding of landslides including common causes, warning signs, and historica landslide sites. However, unpredictable increases in landslides due to worsening environmental conditions and terrain changes necessitate an increase in awareness programs and the implementation of better early warning systems. Landslides devastate the livelihoods of local communities and cut off access to resources, leaving them waiting days for roads and infrastructure to be restored. The results from the risk perception survey further support this, showing that locals are highly aware of the risks posed by landslides and take precautions during extreme weather conditions including heavy rain, cloud bursts, and lightning. However, a clear disconnect exists between local communities and government response measures. Despite being aware of the factors that cause landslides, government authorities are not aware of the scope of the problem due to a lack of reporting of incidents when they occur.

The virtual reality simulation showed strong potential for measuring participant landslide risk perception. Electroencephalogram (EEG) data indicated that participants were more alert when traveling through landslide-prone areas, while heart rate variability (HRV) showed that participants were stressed and had elevated heart rates. Analysis of participants' responses during collisions revealed panic during landslides, causing them to accelerate which increased their stress levels and elevated their heart rate. Survey results showed that the effect of the simulation was limited due to inaccuracies compared to real-life scenarios.

This project's findings indicate a clear need for the inclusion of local perspectives in decision making and the development of more effective mitigation and response systems. Government officials engaging in dialogue with local stakeholders about their experience with landslides could lead them to a more complete perspective of the issue in Himachal Pradesh. This would allow them to make better-informed policy-making and resource allocation decisions.

A potential future landslide risk mitigation effort could be a crowd-sourced landslide alert app. Users can report potential warning signs or ongoing landslides, triggering alerts for others in the area and sending real-time data to disaster management authorities. This app can be paired with a solar-powered siren system in each village, allowing for immediate evacuation alerts and bringing awareness to everyone in an affected area. Additionally, the app can function as a landslide database, improving hazard maps and informing future mitigation efforts through detailed information about incidents and their locations.

Further development of the virtual reality tool could also prove useful. While the simulation had the potential for measuring risk perception, it needs refinement to enhance realism and immersion. Current implementations lack natural warning signs of impending landslides. Additionally, the landslide dynamics and road conditions need adjustments to reflect real scenarios. The VR tool also has potential applications for raising awareness about landslide warning signs and their consequences and should be tested on local communities.

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1 Introduction

Every monsoon season, the people and communities of Himachal Pradesh, India, are devastated by landslides that take hundreds of lives and destroy countless homes and businesses. These disasters also destroy many crucial roads and highways, leaving the local population with decreased access to resources and forcing schools and businesses to close for prolonged periods. This issue has been seeing exponential growth in the past few years, with the monsoon season of 2023 being the worst the region has seen in quite a while with the state reporting 168 landslides and 503 deaths (TNN, 2023). Between July 7th and 14th 2023 alone, the state experienced average rainfall levels 436% higher than normal monsoon-season daily average (Sana et al., 2024). The landslides resulting from this period of extended rainfall claimed 223 lives and closed 1,300 roads alongside causing millions of USD worth of property damage (Sana et al., 2024).

Of the 17,120 landslide-prone sites in Himachal Pradesh, 110 are located in the Mandi district (PTI, 2023). Mandi district was also one of the worst hit by the increased rainfall in the monsoon season of 2023, with cumulative rainfall in the range of 400-700 mm of water (Sana et al., 2024).

Understanding the risk awareness and perception of the local population is a powerful way to gauge in what ways and areas the community would most benefit from support. This project set out to analyze the level of awareness of the population about landslides by two approaches to risk assessment. Surveys and interviews were conducted with local communities to provide insight into their understanding of landslide risks and past experiences. Virtual Reality (VR) simulations replicating common landslide scenarios were utilized to provide insight to the way individuals respond when a landslide occurs. By combining the qualitative data from surveys and interviews with the quantitative data from the simulations, this project forms a comprehensive understanding of landslide awareness in Himachal Pradesh, providing insights for the creation of effective risk mitigation strategies.

2 Background

Understanding indigenous knowledge and local perceptions of natural disasters in high-risk areas is crucial to mitigating the risks posed by them. Integrating local knowledge with the pre-existing scientific understanding of these phenomena can help to guide research and intervention to the proper areas and strengthen relationships between the local populations in need of assistance and the scientific community that aims to assist them. Virtual Reality (VR) stands out as a promising tool in evaluating local knowledge and risk perception, offering immersive experiences that can effectively measure a participant's response to potential threats and their response to warning and disaster response systems.

Figure 1: Landslide in Kullu, Himachal Pradesh (AP, n.d.)

2.1 Geography of Mandi

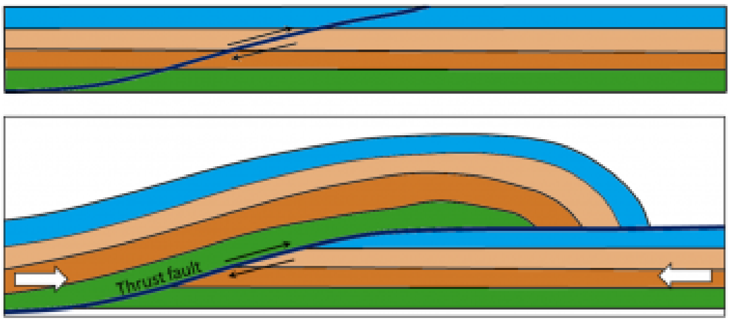

Figure 2: Diagram of the creation of a thrust fault (Earle, n.d.)

Mountain ranges are created when two continental tectonic plates collide, and "since both plates have a similar thickness and weight, neither one will sink under the other. Instead, they crumple and fold until the rocks are forced up to form a mountain range" (American Museum of Natural History, 2024). This process creates a thrust fault, as seen above in Figure 2. The Himalayan Mountain Range was created in the same way, with the Indo-Australian tectonic plate carrying India and Australia colliding with the Eurasia plate carrying Europe and the rest of Asia. The two plates continue to push into each other to this day, causing the Himalayas to grow about 2 cm in height every year (PBS, 2024).

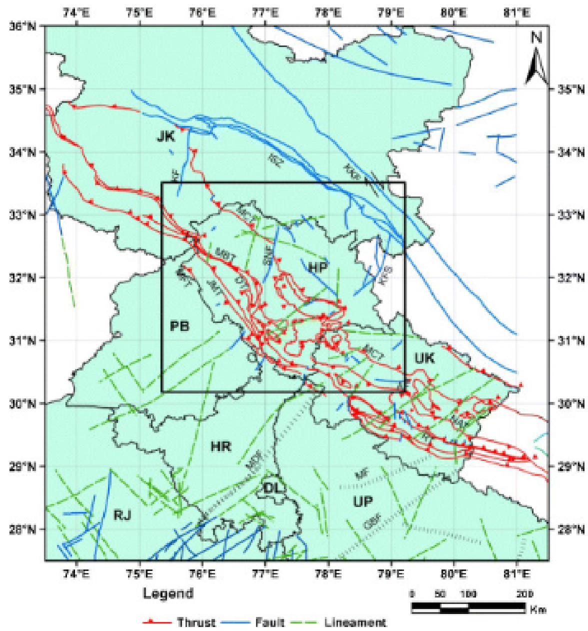

Figure 3: Fault Map of Himachal Pradesh (Patil et al., 2014)

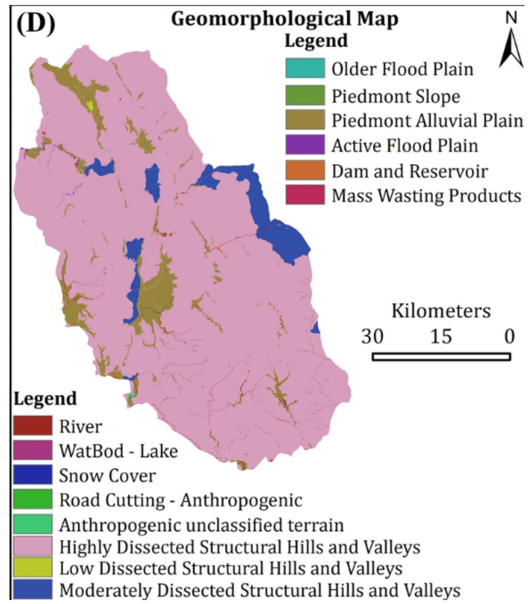

Figure 4: Geomorphological Map of Mandi (Singh et al., 2023)

Himachal Pradesh sits directly on top of the Himalayan thrust line, as seen in Figure 3. This means the state's geography and land composition is dictated not only by intense past seismic activity but also the ongoing tectonic motion. This is reflected in the geomorphological map of the state seen in Figure 4. This map shows the land composition of Himachal Pradesh to be mostly highly dissected structural hills and valleys, a land type usually the result of high tectonic activity. This land type is comprised of hill and valley structures that are not securely held together. They are often dissected by drainage and fault lines throughout the structures, creating very unstable slopes and high-risk landslide conditions. Figure 5 shows a map of the Mandi district with landslide sites from 1998 to 2017 represented by red dots. Next to this, in Figure 6, the roadways in Mandi district can be seen. Many of the slide sites are concentrated around National Highway 3, which leads into the Kullu district. This highway is one of the few that connects the Kullu and Mandi districts, and is a critical path for many merchants in the Kullu district (The Times of India, 2024). This perilous and busy path is an example of a roadway wherein EWS could play a crucial role in saving lives.

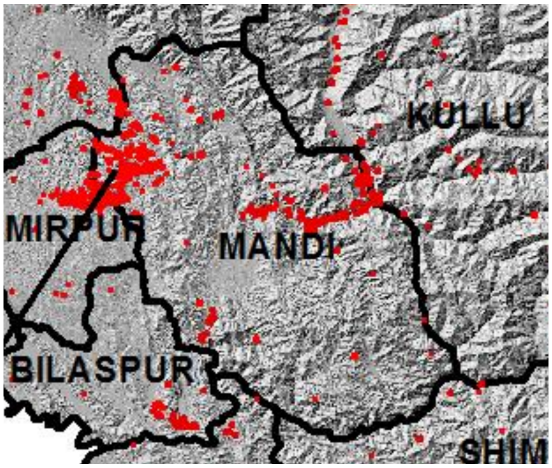

Figure 5: Satellite mapping of landslides in Mandi (Landslide Atlas of India, 2023)

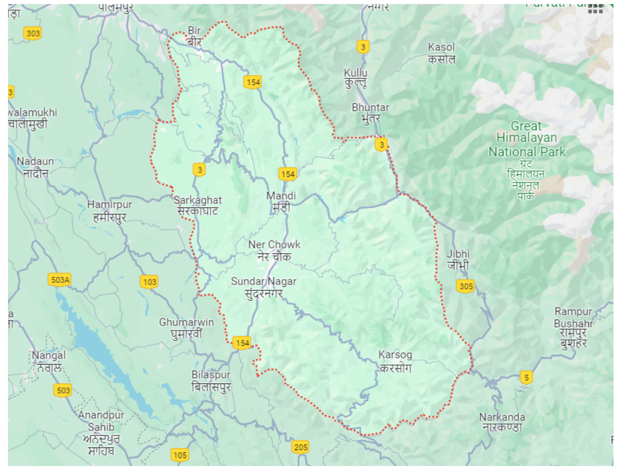

Figure 6: Map of Mandi District (Google, 2024)

2.2 Landslides

A landslide is defined as "the movement of rock, earth, or debris down a sloped section of land" (Rutledge et al., 2023). In Himachal Pradesh, this is generally caused by an excess of rainfall, especially during the monsoon season usually lasting from June to September (NOAA, n.d.). During this time, rainwater saturates the soil which, in areas where the soil is unstable, can lead to decreased soil suction and compromise the integrity of the slope (Alsubal et al., 2019).

A vast majority of landslides in Himachal Pradesh are triggered by rainwater infiltration (Sana et al., 2024). This happens when, during periods of heavy rainfall, the water seeps into the porous soil and creates cracks and drainage channels in the slope, saturating the soil. In younger mountains composed of loosely-packed soil like the Himalayas, these fissures develop and grow easily (Zhang et al., 2020).

The strength of a slope is determined largely by the slope's effective strength, which is the internal stress of the slope that holds it together (Ferré & Warrick, 2004). Effective strength is calculated by subtracting the porewater pressure within the slope from the slope's total stress (Ferré & Warrick, 2004). Total stress is the stress from the weight of the slope and anything on top of it (Shanmugam, 2012). Porewater pressure is the force applied by the groundwater in the slope, pushing the soil apart (Shanmugam, 2012).

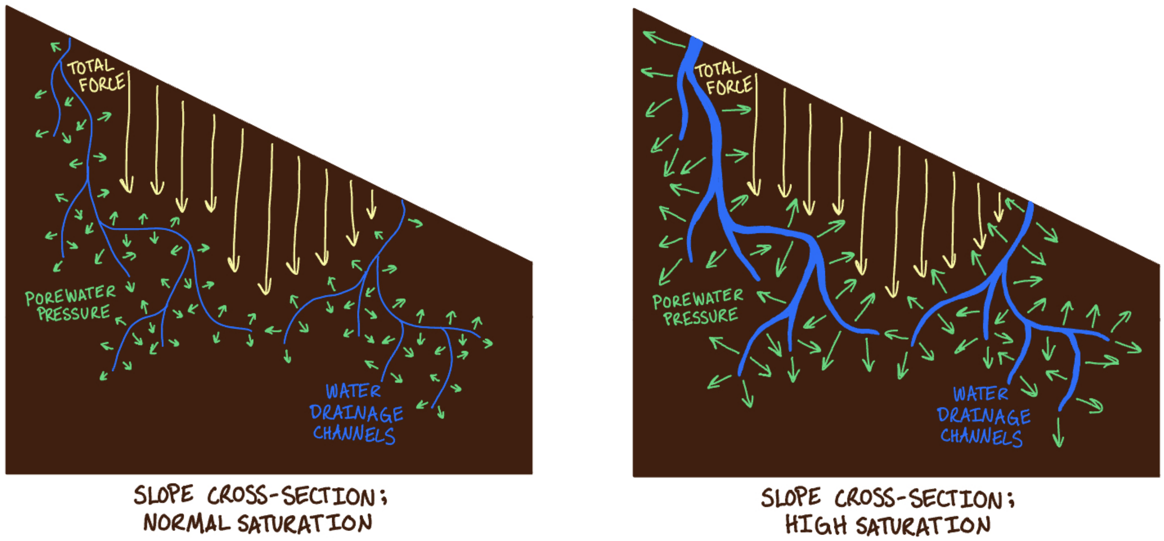

Figure 7: Impact of increased porewater pressure on soil dynamics

When the water saturation level is normal, as seen in the left of Figure 7, the porewater pressure is less than the total force and the effective strength of the slope is positive. This means the shear strength of the slope is high, indicating the slope is resistant to shear force, which is force that moves or deforms an object across a plane, which means the slope is stable (Al-Karni, 2012). Conversely, when the slope is oversaturated, as in the right of Figure 7, the porewater pressure is significantly increased as the influx of water causes the drainage channels and groundwater to press more soil out of the way. Eventually, the porewater pressure will exceed the total force and the effective strength of the slope will become negative. This means that the shear strength of the slope is very low, and the slope is vulnerable to landslides (Al-Karni, 2012).

When cutting a road, the slope that results on the side of the road is considerably steeper than it was before, impacting the shear force applied to it (Pradhan et al., 2022). When an object is on a slope, the normal and shear forces on the object must add up to its gravitational force. When the angle of the slope is increased the normal force acting on the object is decreased, increasing shear force as a result (Johnson et al., 2024). This phenomenon is depicted in Figure 8. To keep the object from falling, its shear strength must be high enough to counter this force (Johnson et al., 2024). By cutting into the road and increasing the angle of the slope, the shear

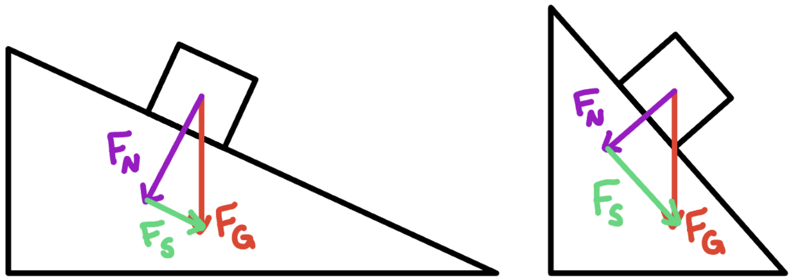

Figure 8: Gravitational, normal, and shear forces acting on an object on a less-steep (left) and more-steep (right) slope

force on the slope is increased. The cutting also leaves the soil vulnerable to further water infiltration, which can decrease the shear strength (Pradhan et al., 2022). If the shear force exceeds the shear strength of the slope, it is vulnerable to a landslide.

In heavily vegetated slopes, during rainfall some of the water first comes into contact with the vegetation, where it will either eventually evaporate or drip to the ground slowly (Hlásny et al., 2015). Some of the water will hit the ground directly and run down the side of the slope, where its path will be interrupted and diverted by plant life, causing the water to disperse and descend the slope more gradually (Hlásny et al., 2015). Some of the water will infiltrate the slope soil, where some of that new groundwater will be absorbed by plant roots (Hlásny et al., 2015). All of these factors decrease the amount of water infiltration and erosion to the slope, maintaining its integrity. Without this vegetation cover, all the water falls directly onto the exposed soil, either directly infiltrating the slope or eroding it as all the water flows down the same path unimpeded (Hlásny et al., 2015).

Vegetation root networks are also crucial to slope stability, as the roots can physically hold the soil in place (Cao et al., 2023). When these root networks are removed, they can not easily be replaced, as even with reforestation it could take years to reestablish a root network strong enough to support the slope (Depicker et al., 2021). The placement of the vegetation also needs to be carefully considered, as planting vegetation in certain locations can increase the riskiness of potential slides. For example, planting a tree at the edge of a slope next to a road could lead to a surcharge on the slope leading to collapse (Depicker et al., 2021).

Himachal is home to around 2,500 glaciers, most of which feed into major rivers and water networks (Studies, 2017). As the temperature in Himachal Pradesh has been increasing by approximately 0.02 °C per year as a result of global climate change, these glaciers are melting more rapidly every year (Himachal Pradesh Knowledge Cell on Climate Change, n.d.). This increases the volume of water in the state's ecosystem, increasing the frequency and intensity of the rains as well as overall groundwater saturation (Prakash, 2023). The rainfall patterns in the state have also seen a shift in recent years, diverting from moderate and consistent rainfall to periods of dry weather interspersed with periods of extremely heavy rainfall (The Economic Times, 2023).

The combination of man-made alterations to the mountains' ecosystem as well as the shift in global climate has created an environment very conducive to landslides in Himachal Pradesh and Mandi. The increase in volume, intensity, and frequency of rain as well as the continuous weakening and removal of the mountain's natural slope-support networks paints a clear explanation of the sudden exponential increase in landslide occurrences in the state.

2.3 Disaster Preparation and Response

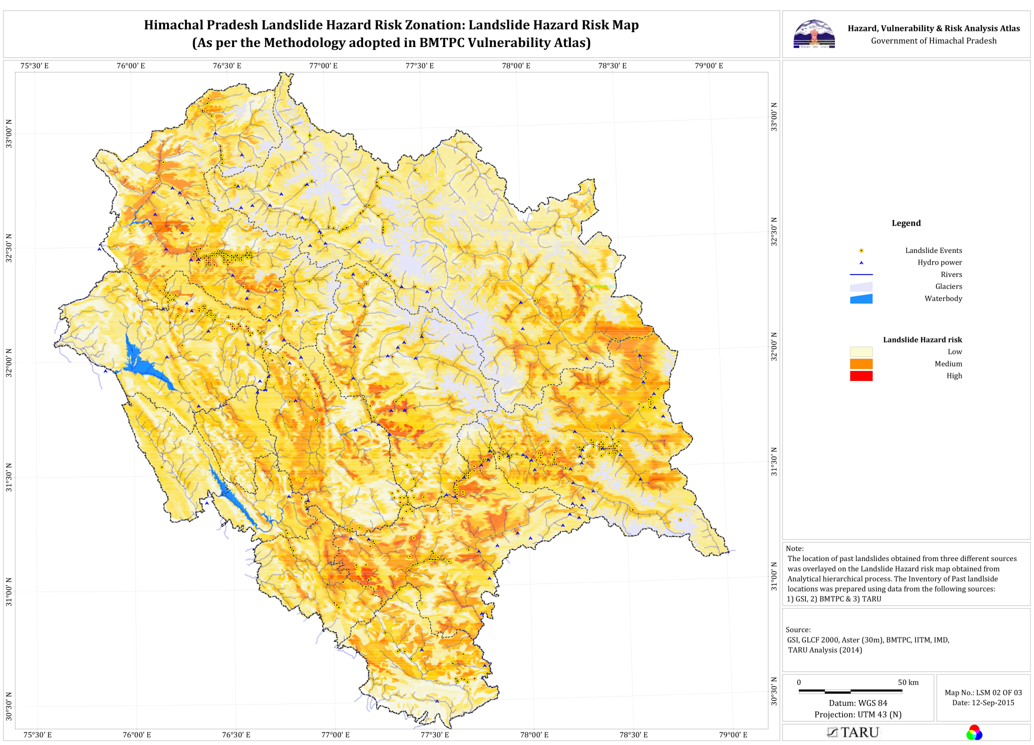

Figure 9: Himachal Pradesh landslide susceptibility map
(HPSDMA, 2017)

To combat the increase of landslides in Himachal Pradesh, state organizations have done work focusing on both disaster preparation and response measures. The Geological Survey of India (GSI) has completed landslide susceptibility mapping (Figure 9) of 42,093 sq. km of landslide prone areas in Himachal Pradesh using Geographic Information System (GIS) software to analyze data from past landslides and environmental factors such as rainfall, slope, and land cover (PIB, 2023). This serves as a foundation for disaster preparedness, allowing for other organizations to prioritize mitigation in high risk areas. Khanduri & Verma (2018) identified four classes for landslide mitigation using zonation: change in slope geometry, drainage, retaining structure, and internal slope reinforcement. Drainage is the most important of these, as high water levels cause the soil to lose its shear strength and increase its porewater pressure and slope, reducing its resisting force (Khanduri & Verma, 2018). In Mandi, the National Institute of Disaster Management (NIDM) focuses on drainage and retaining structure, handling mitigation through the construction of gabion walls, check dams, precast concrete pipes, steps and plantations (NIDM, 2017). These measures are effective at preventing slope movement, and help control drainage by slowing down the flow of water. However, these are primarily implemented at sites after a landslide has occurred, so a more comprehensive approach is needed to implement them at high-risk areas using the susceptibility mapping to prevent landslides before they occur.

India's NIDM also focuses on raising awareness, offering online training modules on disaster preparedness and response. However, these modules required prior education and an course fee, making them inaccessible to those in these rural communities that need them most. Similarly, the Geoinformatics and Building Technology Research Centre in partnership with Chitkara University in Himachal Pradesh held a three-week summer school program about landslide disaster management, but required participants to be familiar with landslides and their mechanics (SDMA, n.d.). Other landslide resources in India face similar issues, as most research and resources surrounding landslides in Himachal are available only digitally and in English. Awareness programs need to cater to local communities that are most at risk to landslides in order to be effective.

The National Disaster Management Authority (NDMA) is another Indian organization focused on risk management. The Landslide Risk Mitigation Scheme (LRMS), is an initiative under the NDMA focused specifically on landslides. The initiative includes landslide risk awareness and response courses targeted at government officials, detailed scientific research and reporting on landslides throughout India, as well as providing funding for site-specific mitigation efforts. One site-specific effort funded by the LRMS in December of 2017 was the Development & Evaluation of Low-Cost Landslide Monitoring Solutions with IIT Mandi and the Defence Terrain Research Laboratory (DTRL) (National Disaster Management Authority, n.d.). This project developed a system of “low-cost sensors and other instruments for landslide monitoring, using micro-electromechanical systems (MEMS)-based sensor technology and artificial intelligence” (NDMA, n.d). The system works by increasing focus on subsurface soil motion; chains of sensor nodes are lowered into boreholes drilled into landslide sites. These sensor nodes measure soil “accelerations and displacements via an accelerometer, soil moisture via a capacitive soil moisture sensor, and soil stress via a piezoelectric pressure sensor” (NDMA, n.d). This data is sent to a server where a machine learning algorithm evaluates it to determine the risk of a landslide. Depending on the magnitude of soil movement, the system categorizes risk as either nonexistent, low, medium, or high. If any of the three risk levels are reached, the early warning system (EWS) is activated, setting off roadside sirens and flashing lights (Figure 10) and sending SMS alerts to nearby residents and disaster management authorities. These SMS alerts include information about the level of the event as well as a link to a map pinpointing exactly where the event is predicted to occur.

Figure 10: EWS Roadside Post

Landslide response can be divided into two parts: rescue and recovery. After a landslide is reported, search and rescue of individuals trapped by landslides is carried out by the District Administration, police, and National Disaster Response Force (NDRF) (NIDM, 2017). Heavy earth-moving machinery is deployed to clear the debris and save individuals who are trapped inside. Social Emergency Response Volunteers and police help with transporting those who are injured, diverting traffic on roads, and managing crowds that rush to the site after hearing the news (NIDM, 2017). After the rescue is completed, the focus shifts to recovery. The primary objectives of the government organizations is to provide relief to those who were affected by the landslide, and restore any damages to infrastructure. A relief of Rs.10,000 each is provided to the next of the kins of deceased, and the victims and families from the villages that were declared unsafe are relocated and provided with necessary supplies (NIDM, 2017). The roads are cleared by the Public Works Department, which can take anywhere from a few hours to multiple days (Express News Service, 2023). They are also responsible for repairing any damages to water lines. The Himachal Pradesh State Electricity Board then takes action to restore damaged electrical wires and poles, transformers, and provide alternate power arrangements to places where supply lines can't be easily repaired (HT Correspondent, 2023). Finally, remedial measures are implemented by the NIDM to mitigate future landslides in the area.

2.4 Indigenous Risk Perception Evaluation for Disaster Management

In their 2023 article *Climate Risk Management with Indigenous Knowledge and Perception - Evidence from Drought Prone Regions of India*, Dr. Anindita Sarkar and Dr. Nairwita Bandyopadhyay spoke with residents of drought-prone areas in India, specifically four villages in Gujarat and three villages in Rajasthan, to analyze the use of indigenous knowledge for drought prediction. They found that in a few cases, the residents of these regions unknowingly observed practices that had scientific backing to them (Sarkar & Bandyopadhyay, 2023).

An example of such a practice is farmers in Rajasthan will observe the direction of the wind in the time following the festival of Holi to determine whether it will rain that year or not; wind blowing west indicates no rain and north indicates more rainfall (Sarkar & Bandyopadhyay, 2023). These patterns in wind direction and rainfall observed by the local population aligned with scientifically evaluated wind circulation patterns that would determine whether the winds would be bringing in moisture-rich air from the Pacific or dry air from further inland (Sarkar & Bandyopadhyay, 2023). Over many generations, the local population of that region observed this pattern and passed down this knowledge to their children. Though the pattern may not have been observed or recorded in a traditionally scientific manner, these observations are valid and have been tried and tested for generations (Sarkar & Bandyopadhyay, 2023).

In the conclusion of their paper, Dr. Anindita Sarkar and Dr. Nairwita Bandyopadhyay write “it is important to capture farmers' perceptions of water scarcity because it helps explain investment decisions, contributes to scientifically justified adaptive behaviour, and can motivate better design of projects aimed at natural resource management and livelihood adaptation. Such inquiry has direct implications for improving our approach to climate change adaptation, which is, at its core, a behavioural change” (Sarkar & Bandyopadhyay, 2023). Just as the knowledge built up by generations of farmers in these drought-prone areas can create a better understanding of why droughts happen in those regions and how best to predict and deal with them, so too could the knowledge base built by villagers in the Mandi region help to better understand landslides and how to predict and deal with them.

2.5 Virtual Reality to Measure Risk Perception

Awareness programs play a critical role in disaster preparedness and the effectiveness of response measures. Virtual Reality (VR) emerges as a promising tool to improve disaster preparedness. Virtual Reality can be defined as a computer-based system that employs software, screens, and interactive devices to generate a simulated 3D environment (Alene et al., 2023). The most apparent advantage of VR is the ability to present stimuli in three dimensions (Cipresso et al., 2015). Designers can present a range of complex conditions to the user and examine their behavior. There are three core elements of VR, the virtual environment, immersion, and interactivity (Alene et al., 2023). The virtual environment is an immersive simulated world that users can interact with and is computer-generated or constructed using images or video. Immersion is the extent to which the user feels like they are in the virtual environment (Norris et al., 2019) and improves the realism that users experience. The head-mounted display (HMD) is the primary type of VR immersive technology (Figure 11). Interactivity is the way users can engage with and manipulate the virtual world, giving users a sense of agency in the simulation and increasing the potential applications of the technology in different research environments.

Figure 11: Oculus Rift S HMD (Kaufland, 2023)

Virtual Reality has seen many recent applications in education, training, and hazard identification. In the field of education, a study from Bangladesh developed a virtual reality biology lab that overcomes the lack of equipment and infrastructure for students and allows them to get practical biology learning (Ahmed et al., 2023) and proved to be an effective substitute for hands-on laboratory experience. Research about safety training compared interactive VR training with video fire extinguisher training, finding that VR was more effective and resulted in higher knowledge acquisition and retention (Lovreglio et al., 2021). Studies have also applied VR to training workers and disaster simulation (Xu & Zheng, 2020) and have seen major success. The primary difference between VR and conventional tools is that it allows the user to experience hazardous situations without compromising their health and safety. In addition to this, it is less restrictive, repeatable, flexible, and low-cost (Norris et al., 2019). Users can experience a situation in real-time, forcing them to respond quickly and training their brain with effective response measures, making them more prepared when a situation arises. Research has shown that experience can heavily impact decision making and risk perception (Hertwig

& Wulff, 2022). Decision making is a crucial factor of disaster response (Zhou et al., 2018), and a VR simulation can be used to teach effective decision making during landslides through repetition.

Virtual Reality was recently used for raising awareness about quick clay landslides in Scandinavia, Canada, Alaska, and Russia. Alene et al. (2023) developed a VR tool for quick clay landslides that recreated a 2020 landslide event (Figure 12) from Norway utilizing a digital terrain model and hazard and risk maps (Alene et al., 2023). It allows users to engage with the causes of the landslides and witness the consequences without exposing themselves to any risk. The usability of the tool was tested with a survey, where most participants had positive attitudes toward the VR experience, suggesting that it could serve as a valuable educational and communication platform. The findings from this study support the usefulness of VR technologies for raising awareness about landslide risks and can be applied to landslides in Himachal Pradesh.

Figure 12: Quick clay landslide in the Quick-Aware virtual reality tool (Alene et al., 2023).

2.6 Conclusion

The research project on landslide risk awareness in Himachal Pradesh integrates traditional knowledge with modern technology to create a comprehensive understanding of the issue. By combining early warning systems with virtual reality simulations, the project aims to bridge the gap between traditional practices and contemporary methods of risk mitigation. Virtual reality simulations offer an innovative approach to assess risk awareness by immersing participants in realistic landslide scenarios. This method provides valuable insights into community response behaviors, facilitating the development of more effective disaster response measures.

Furthermore, understanding the local lifestyle and environment is crucial for tailoring interventions to the specific needs of each community. By delving into daily circumstances and environments, researchers can enhance the realism of simulations and foster a deeper understanding of landslide risks. A data-driven approach, leveraging insights from traditional knowledge, VR simulations, sensor data, and past events, forms the foundation for developing comprehensive risk mitigation plans. These plans aim to inform changes in disaster legislation and policy implementation, while also raising awareness among communities to encourage proactive preparedness.

In summary, this project proposes a balanced approach that integrates traditional wisdom with modern technology to address landslide risks effectively in Himachal Pradesh. Through innovative methodologies and data-driven insights, the research seeks to enhance risk awareness and facilitate the development of more resilient communities.

3 Methodology

The primary goal of this project was to understand landslide risk perception and awareness in Himachal Pradesh. This was done by conducting interviews with local populations and data collection through a virtual reality simulation. These results were used to make recommendations to improve risk management. The project goal, objectives, and approach are summarized in Figure 13.

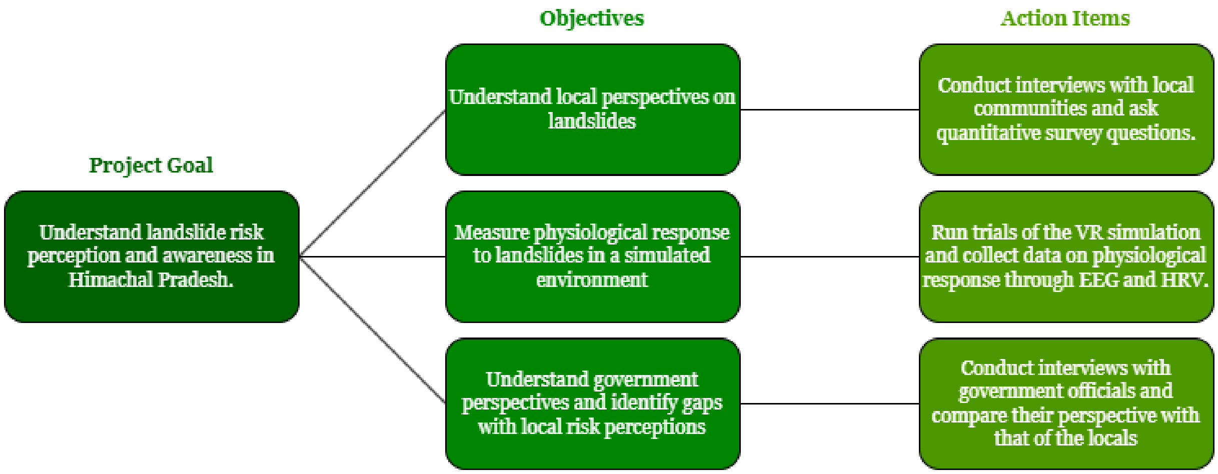

Figure 13: Summary of project goal, objectives, and corresponding tasks.

Objective 1: Understand local perspectives on landslides

In order to quantify local risk perception and awareness of landslides, a general risk perception survey was created consisting primarily of Likert scale questions. This enabled a clear analysis of attitudes toward landslides and their impacts on people's daily lives. As not all participants were able to speak English, this survey was administered verbally by the authors, calling in local participants to discuss the questions in Hindi and enter participant responses in English.

In addition to the general survey, participants were asked open-ended interview questions. This allowed participants to contextualize and add nuance to supplement their survey responses. Interview questions were also tailored to the respondent's role in the issue, whether a villager, researcher, or taxi driver. This portion of the research also served as a powerful way to allow those most affected by this issue a platform to speak about their experiences.

Objective 2: Measure physiological response to landslides in a simulated environment

Three landslide scenarios were chosen to simulate for this project: driving on a road when a landslide occurs, walking when a landslide occurs, and experiencing a landslide while in your home. Pre-simulation surveys were developed for each of these three situations to collect participants' general demographic information such as age, gender, etc. The pre-simulation survey also collected information on participants' existing risk perception, past experience with the scenario (i.e. their experience with driving/walking/living in a landslide-prone area), as well as their past experience with VR.

Members of the ISTP team from IIT Mandi developed the three VR landslide simulations for the Oculus Rift S headset using the Unity game engine. The driving simulation consists of a car driving down a road in a landslide-prone area, where landslides trigger at certain points with a set probability. The participant can control the car using a Logitech G29 steering wheel. The walking simulation is the same, but instead, the participant walks down a shorter road using the Rift S controllers. The final scenario places the participant inside a building, where a landslide will occur near the home and a sound queue will be given.

Before the simulation experience began, the participant's brain activity and heart rate variability (HRV) were measured in a resting state. Brain activity was measured with an electroencephalogram (EEG), which measures the interaction of neurons, dividing the five major brain-wave frequencies into bands that represent activity in different regions of the brain. HRV was measured using a heart-rate monitor. The EEG used for this project was the Muse Band Pro, and the HRV monitor was the emWave Pro. EEG and HRV values were also collected throughout the duration of the simulation. In the driving and walking simulations, positional and collision data was also collected to monitor what the participants chose to do in response to the landslide.

The raw EEG data was split into the absolute band powers by taking the logarithm of the Power Spectral Density of each channel. The analysis focused on the θ (4-8Hz), α (7.5-13Hz) and β (13-30Hz) channels. Relative band powers were calculated by taking the proportion of power within a specific frequency band. The averages of these powers over the pre-simulation and simulation periods yielded the α-to-β ratio and the % change in Frontal α to Temporal θ. α-to-β ratio was used to measure alertness and stress in the simulation, while Frontal α to Temporal θ ratio was used to measure engagement in the simulation.

Kubios was used to extract the Mean RR and Sympathetic Nervous System (SNS) Index from the HRV data. The Mean RR is the average interval between heartbeats, a shorter RR interval corresponds to a higher heart rate. The SNS Index reflects the activity of the sympathetic branch of the nervous system, and is activated when something stressful occurs. These values were used to determine the stress levels of participants when being in landslide-prone areas.

The positional and collision data from the simulation was used to measure changes in the participants' responses during a landslide in the driving and walking scenarios. The positional data was compared with an ideal path for each scenario without the occurrence of a landslide. Using the timestamps in the collision data, 2.5 seconds of data before and after a collision with a landslide were extracted from the positional and EEG data, and 15 seconds of data before and after from the HRV data to represent the physiological state of the participant during the landslide. These were compared with the participant's normal physiological state as measured during the pre-simulation control period to understand the participants' response.

Post-simulation surveys were also developed to collect feedback on participants' experience with the simulation. The survey prompted participants to assess various aspects of the simulation, including its immersiveness, realism, and its impact on their perception of the risks associated with driving/walking/living in a landslide-prone area.

Objective 3: Understand government perspectives and identify gaps with local risk perceptions

Interviews were conducted with disaster management authorities to better understand their perception of the current threat posed by landslides, their assessment of the state of landslide risk management, and their evaluation of the effectiveness of ongoing risk management initiatives. This perception was then compared to the local population's perceptions in order to identify gaps in the current response system.

4 Results

Objective 1: Understand local perspectives on landslides

There were 13 respondents to the general survey, all of whom were from local communities around Kammand Valley. All participants were male whose ages ranged from 20 to 65 with an average of 37.3. Respondents' education levels varied from High School Diploma to Masters Degree, and occupations also varied vastly including farmers, businessmen, and guards.

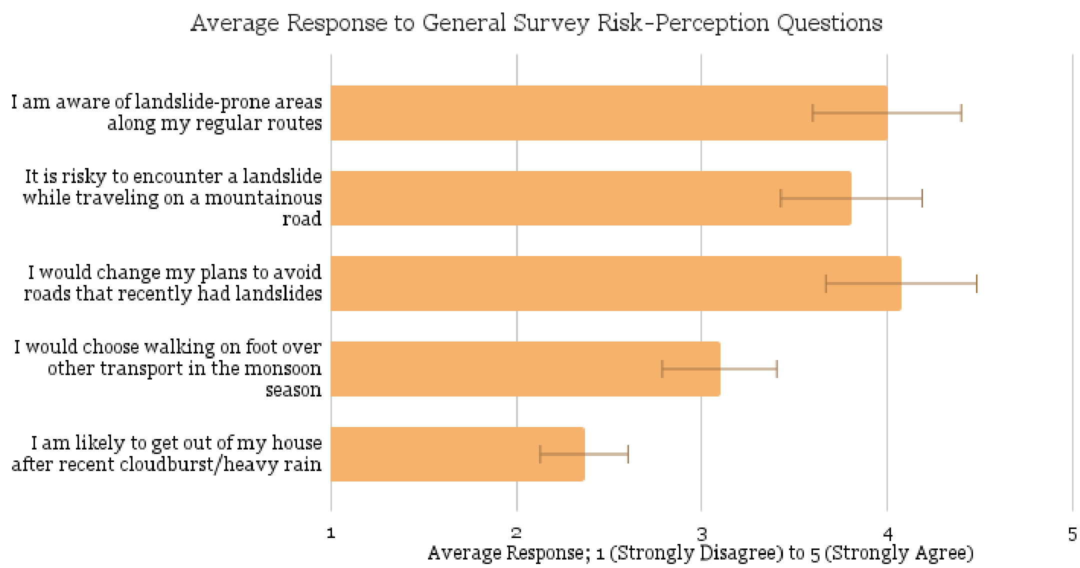

Figure 14: Averages of all responses to general landslide risk perception survey questions

Participants' responses to risk-perception survey questions (seen in Figure 14) showed a strong understanding of the gravity of risk posed by landslides. Participants showed risk-averse behaviors when presented with a high-landslide-risk scenario: on average, respondents ranked the riskiness of encountering a landslide on a mountainous road 3.808 out of 5; participants ranked their likelihood to adjust travel plans due to recent landslides an average of 4.077 out of 5; participants ranked the likelihood they would leave their homes following a major rain event an average of 2.365 out of 5. Participants were also acutely aware of the risks posed to them in their daily lives, when asked about awareness of landslide-prone areas along their regularly traveled routes on a scale of 1-5, the average response was 4.

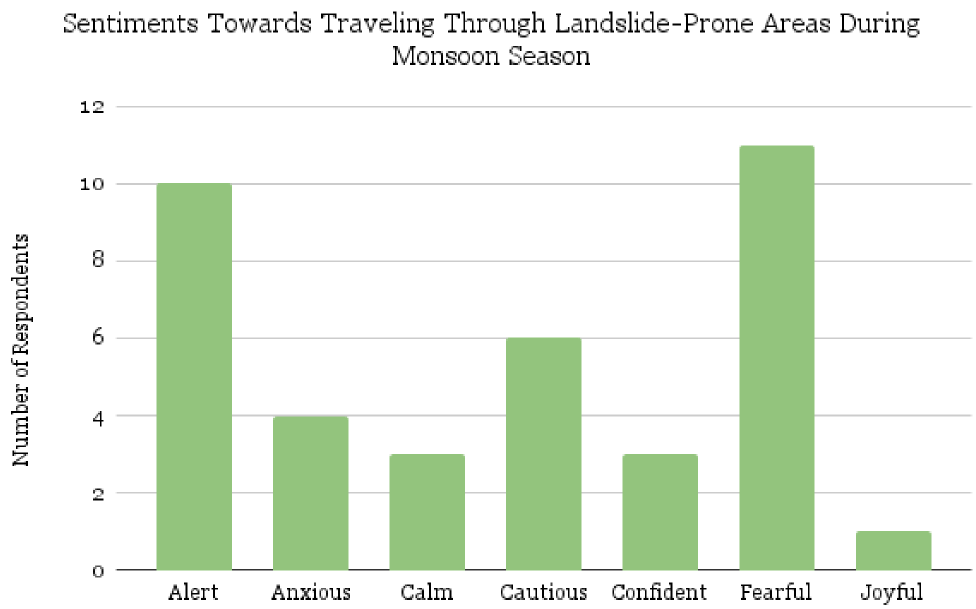

Figure 15: Respondent's description of their emotional state while traveling in landslide risk conditions

As seen in Figure 15, locals primarily characterized their emotional state when traveling through high-landslide-risk conditions as fearful (11 participants) and alert (10 participants). Some participants also felt cautious (6 participants) and anxious (4 participants). Few participants felt calm (3 participants), confident (3 participants), and joyful (1 participant). Of these few participants, most ranked their ability to predict landslide hazards higher than average, either a 3 or 4 out of 5, which could explain this discrepancy in emotional state. The fearful and cautious emotional state of the local population as they travel through landslide-prone conditions further demonstrates their understanding of the level of danger posed by these disasters.

When asked about weather conditions that would dissuade respondents from traveling, the weather conditions described were all rainy conditions (as seen in Figure 16). The most common response was heavy rain (12 participants), with the second most common being cloud bursts, which are sudden, short periods of very heavy and intense rainfall (11 participants). Wariness of high-precipitation weather events demonstrates an awareness of the correlation between rainfall and increased landslide risk.

Participant interviews further clarified the extent of landslide risk perception and understanding in these local communities. Respondents explained there are some warning signs of

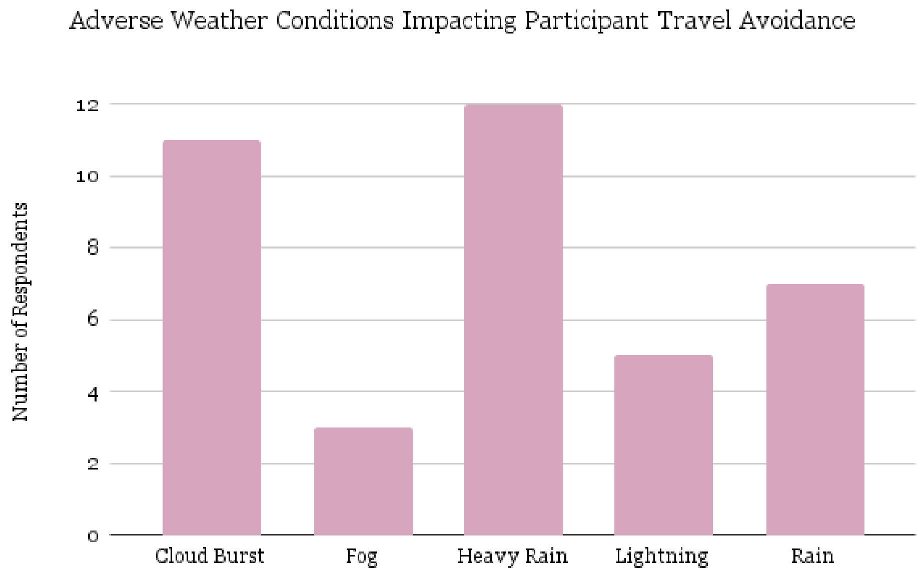

Figure 16: Weather conditions' impact on participant travel plans

potential landslides areas which can be observed by those very familiar with the terrain, such as trees and vegetation beginning to lean in a different direction than normal, wildlife becoming suddenly quieter in the area, or a faint crackling sound in the area. Participants also shared what they believe to be some potential causes for the sudden increase in landslides. Most people pointed to the increased road cutting and urbanization in the area as a primary cause. Some villagers believed the landslides to be divine retribution, claiming "they are angering the gods by doing so much construction and dumping waste" (Shegli Village, Personal Interview, March 20, 2024; translated from Hindi by author). Others blamed the urbanization for other reasons, explaining that the construction disrupts the delicate harmony of the Himalayan ecosystem. Some participants indicated that the new roads and construction disrupted vital natural water drainage systems, others indicated the construction disrupts the balance of the way the soil and rocks lay to create the slope. One interviewee from Kamand Village described feeling apprehensive about the construction of a new 4-lane highway near IIT Mandi, expressing concern about how it could affect the landscape and slope stability unless it was reinforced well. He explained that they should only build a single-lane route to avoid cutting more of the mountain than is necessary, stating that in general road construction needs more research to avoid landslide hotspots. These respondents explained that causing these disruptions in one area will not limit the damage it causes to that area, but will have cascading impacts across the entirety of the Himalayas.

Figure 17: Photo of a villager from the Shegli village being interviewed

Though respondents were aware of historically landslide-prone areas and conditions, they expressed that environmental and terrain changes have caused soil stability to become unpredictable. Major landslide events have begun occurring in previously geologically sound areas. This greatly increases the threat landslides pose to communities that consider themselves to be in a safe location and may not be prepared to deal with such an event. One respondent (pictured in Figure 17) described how his brother and sister-in-law were killed as their home was destroyed by a landslide as they slept, assuming they would be safe despite the rains as the area had been previously unthreatened by the slopes. Other interviewees shared similar stories and expressed increased concern regarding their safety in their own homes, with one respondent stating "when the rains come now, I don't sleep (...) I don't let my family sleep" (Shegli Village, Personal Interview, March 20, 2024; translated from Hindi by author).

Figure 18: Aftermath of the 2023 Shiv Bawdi temple landslide in Shimla.

Shimla was seen as a safe haven, spared from the past 10 years of devastating landslides that ravaged Himachal Pradesh. As such, the community in Shimla was completely unprepared for the monstrous landslide event on August 13th, 2023 that destroyed the Shiv Bawdi temple and took 20 lives (pictured in Figure 18). A student from Himachal Pradesh University, a college in the area where the slide occurred, reported changes in the community's behavior after the landslide occurred, with people being more cautious walking near mountains during severe weather conditions and rumors spreading surrounding the incident. He additionally shared that "the locals feel that this landslide was an act of God because the people were worshiping when it occurred" (Shiv Bawdi landslide site, Personal Interview, April 2, 2024), demonstrating the degree to which the event disturbed the community.

The local population in landslide-prone areas is very aware of both the risks landslides pose to them and their communities as well as what conditions and areas are historically conducive to these events. However, due to the sudden and rapidly changing environment which they are unprepared to deal with, the community now perceives the greatest risks posed by landslides to be the risk posed to them in their homes and communities.

Due to time and travel constraints, the number of people that were able to participate in the survey and interviews was limited. As a result, the variety of demographics was also lacking, and the sample was not accurately representative of the entirety of the population this project aims to reach. There is also some lack of consistency in the wording of interview questions between different interview sites. Following each interview experience, the survey would be slightly changed and improved. Though the essence of the question remained consistent, it is possible the shifted wording could have created some discrepancy in participant responses.

Objective 2: Measure physiological response to landslides in a simulated environment

Figure 19: Third-person view of a landslide occurring in the walking simulation.

Figure 20: Participant taking part in the walking simulation.

There were a total of 53 participants for the virtual reality simulations. 20 participants were assigned driving in a landslide-prone area, 20 were assigned walking in a landslide-prone area, and 13 were assigned to the indoors scenario, where they were inside a house when a landslide occurred nearby.

Simulation Survey Results

49 participants submitted the pre-simulation and post-simulation surveys, all of whom were undergraduate students. The average age of participants in the driving simulation was 20, 19 for the walking simulation, and 21 for the building simulation. The majority of participants were male, with 15 males and 2 females for the driving scenario, 16 males and 3 females for the walking scenario, and 12 males and 1 female for the indoors scenario.

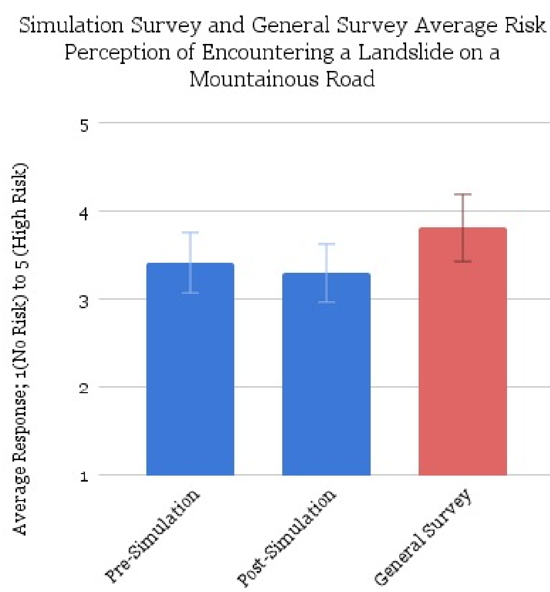

Figure 21: Comparison between pre-simulation, post-simulation, and general survey responses to risk perception of encountering a landslide on a mountainous road.

The pre-simulation and post-simulation surveys for the three scenarios were analyzed to understand the effect of the simulation on participants' risk perception and the quality of the VR experience. When asked how they perceived the risk of encountering a landslide, the average response in the pre-simulation survey was 3.41, and this decreased to 3.29 in the post-simulation (Figure 21). The simulation had the opposite effect on participants and decreased their risk perception about landslides. Respondents in the general survey had a higher average perception of the risks at 3.81 out of 5. The respondents to the general survey were all local stakeholders who have experience with landslides, while all respondents to the simulation survey were students that mostly hadn't had any personal experience with landslides. The simulation did not adequately represent the dangers posed by landslides to participants who were experiencing them for the first time in the virtual environment.

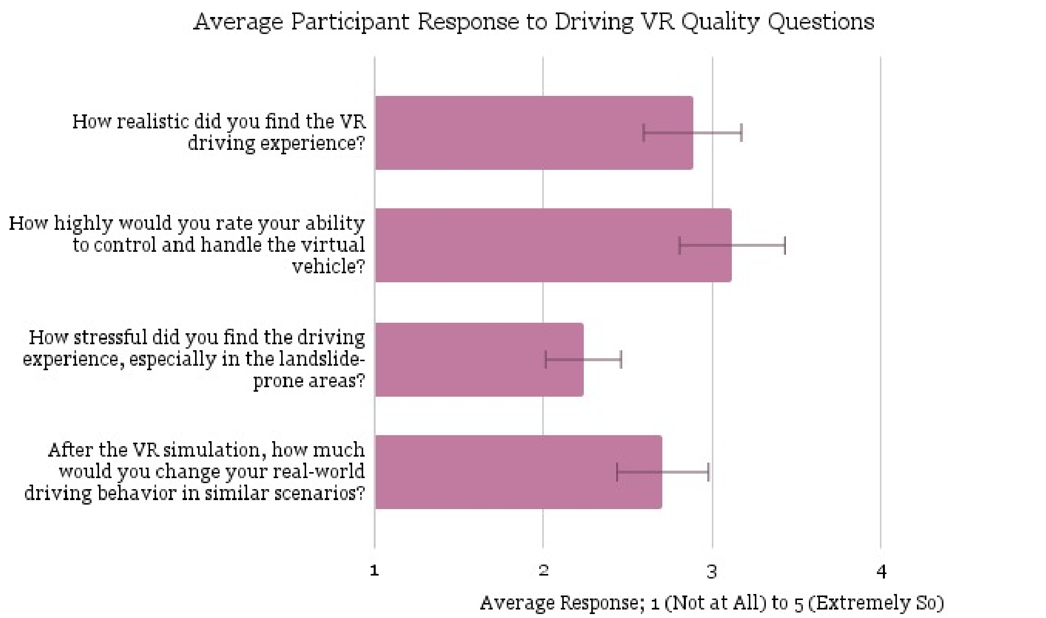

Figure 22: Participant responses to VR Experience Questions from the Driving Survey.

Figure 22 depicts participant responses to the VR experience quality questions for the driving simulation. Participants in the driving simulation did not rate their experience highly. When asked how realistic they found virtual reality simulation, they responded with an average of 2.88 out of 5. Subjects rated their ability to control the virtual vehicle with the steering wheel controller a 3.11 out of 5. When asked how stressful they found the experience, the average rating was 2.24 out of 5. The driving simulation also did not have the intended effect of changing participant behaviors. When asked how much they thought the simulation would affect real-world driving behavior, the average response was 2.71 out of 5.

Participant responses to the experience quality questions for the walking simulation (Figure 23) were very similar. Respondents rated the realism of the walking simulation about the same as the driving simulation, with an average rating of 2.89 out of 5. The simulation did not evoke

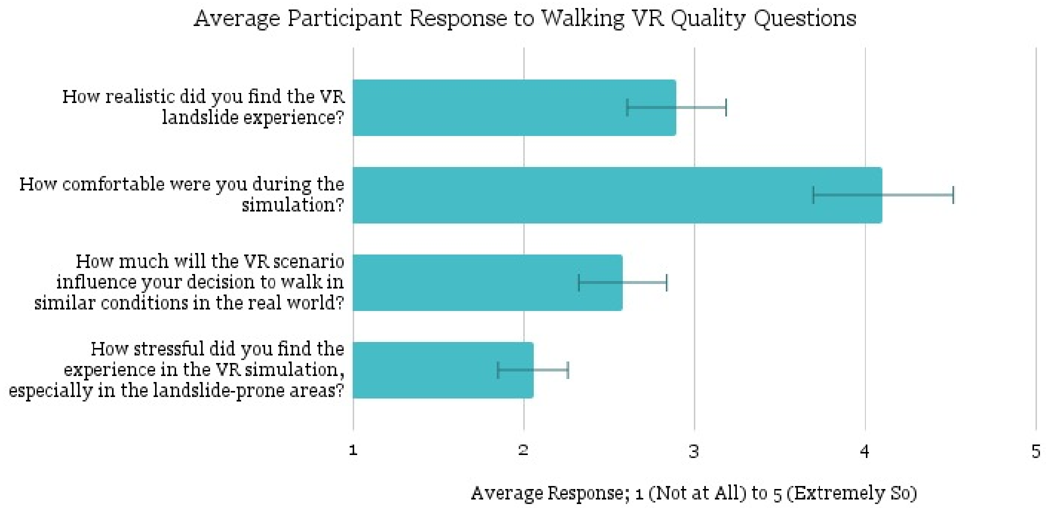

Figure 23: Participant responses to VR Experience Questions from the Walking Survey.

much of a response, with respondents rating the effect it had on their decision-making 2.58 out of 5. Participants found the walking simulation less stressful, rating their stress levels 2.05 out of 5.

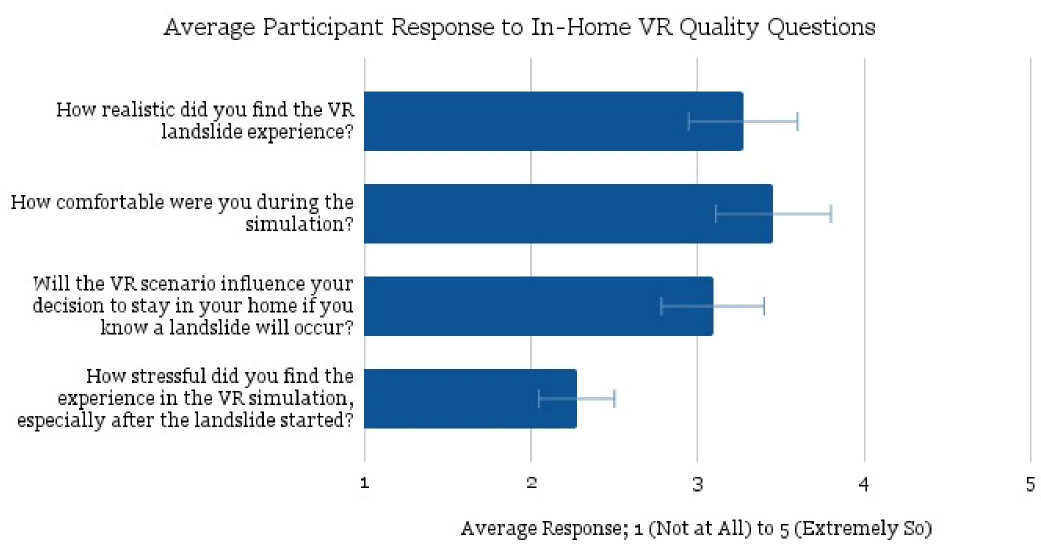

Figure 24: Participant responses to VR Experience Questions from the Indoors Survey.

Participants rated the realism of the indoor scenario much higher than driving or walking, with an average rating of 3.27 out of 5 (Figure 24). On top of that, the respondents rated the influence of the virtual reality scenario a 3.09 out of 5. However, subjects rated their comfort levels slightly lower than the walking scenario at 3.45 out of 5. The stress levels were low like the other simulations, with a rating of 2.27 out of 5.

Virtual Reality Results

The analysis of the EEG data focused on the α-to-β ratio and the % change in Frontal α to Temporal θ. The α-to-β ratio increased for the driving and walking scenarios, indicating an increase in the relative power of the α band (Figure 25). Stress is negatively correlated with α-to-β ratio, indicating participants were less stressed when immersed in the simulation compared to the baseline. An increase in the α band indicates heightened cognitive processing and attention when traveling in the simulation. This result is unexpected, as it is expected that participants should feel more stressed when traveling through landslide-prone areas, resulting in a decrease for all three scenarios. However, survey responses also indicated that participants did not feel stressed. For the indoor scenario, the α-to-β ratio decreased (Figure 25). A shift toward higher β and a decrease in α-to-β ratio during the simulation suggests that participants were more alert and under stress when trapped in the house during a landslide.

Figure 25: Change in mean α-to-β ratio before and during the simulation for each of the three scenarios.

An increase in Frontal α to Temporal θ ratio of participants for the driving and walking simulations (Table 1) indicates increased cognitive engagement and alertness in the simulation. Participants were aware of the risks posed by landslides and anticipating one to occur as they traveled on the road in a landslide-prone area, and were required to process more information. The decrease for the building scenario shows participants had less cognitive load when being indoors, and were not as alert about the landslide risks.

Table 1: Change in Frontal α to Temporal θ for each of the three simulations.

Change in Frontal α to Temporal θ		
	Pre-Simulation	During Simulation
Driving Scenario	3.77	4.12
Walking Scenario	3.80	4.60
Indoors Scenario	3.68	3.51

The HRV analysis focused on Mean RR value and SNS Index. The Mean RR values slightly decreased during the simulation (Figure 26), indicating that the time between successive heartbeats decreased and participants' heart rate increased during the simulation. The SNS Index increased during the simulation for all three scenarios, with the greatest change for the indoors scenario (Table 2). This indicates that participants were stressed when traveling through a landslide-prone area in the simulation. The SNS Index is also responsible for the fight-or-flight response, which is invoked in response to a perceived threat, indicating that the VR simulation was able to accurately portray the dangers of landslides and invoke a physiological response.

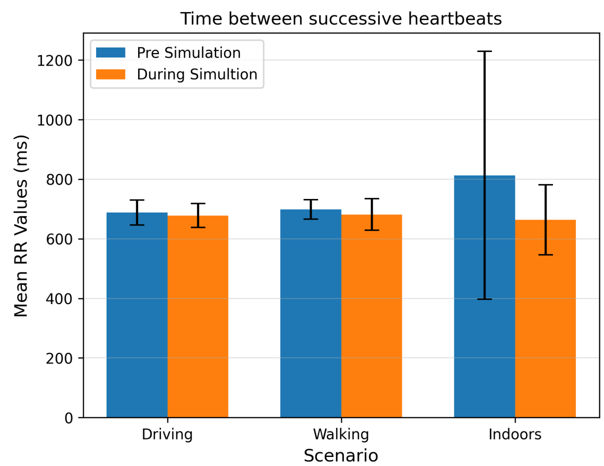

Figure 26: Change in Mean RR (ms) values before and during the simulation for each of the three scenarios.

Table 2: Change in SNS Index before and during the simulation for each of the three scenarios.

Change in SNS Index		
	Pre-Simulation	During Simulation
Driving Scenario	0.83	0.90
Walking Scenario	0.79	0.81
Indoors Scenario	-0.20	0.69

The positional and collision data collected in the VR simulation was used to understand participants reactions to landslides in the simulation. For the driving scenario, the average euclidean distance of the participant from the path in the simulation was much higher in the 5 second window when they collided with a landslide, at 535.97 km and 91.41 km over-

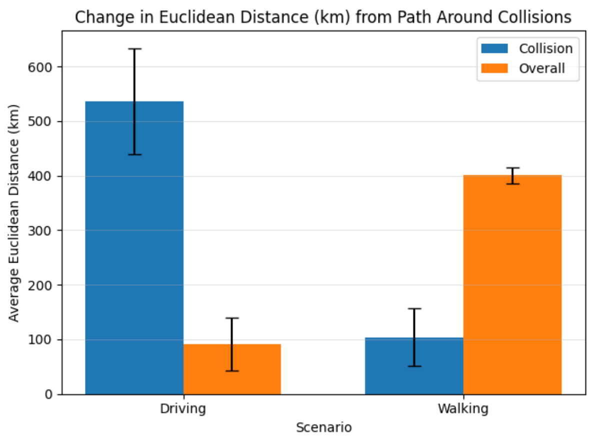

Figure 27: Average Euclidean Distance (km) of participants from the path during the simulation in a collision and overall in the driving and walking scenarios.

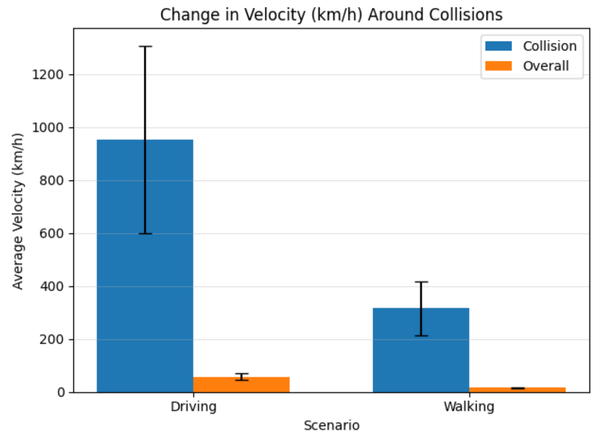

Figure 28: Average Velocity (km/h) of participants from the path during the simulation, 2.5 seconds before and after a collision with a landslide and overall in the driving and walking scenarios.

all in the simulation, while for the walking scenario the distance decreased, at 104.19 km in a collision and 400.45 km overall (Figure 27). However, the average velocity of participants in both scenarios greatly increased during the time of a collision (Figure 28), showing participants panicked when encountering a landslide. The euclidean distance increased during collisions for the driving scenario because participants in the driving scenario accelerated to get around landslides and were hit by debris. On the other hand, for the walking scenario, those trying to run through were caught in the landslide, while others went around the debris.

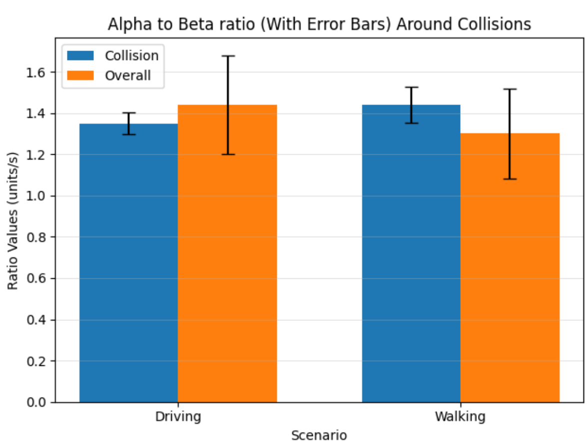

Figure 29: Change in mean α-to-β ratio 2.5 seconds before and after a collision with a landslide and overall in the driving and walking scenarios.

The α-to-β ratio 2.5 seconds before and after a collision with a landslide decreased during the driving scenario, but increased in the walking scenario (Figure 29). This indicates participants felt more stressed when they were in a landslide in the driving simulation, but were less stressed in the walking scenario during a collision. The Frontal α to Temporal θ ratio increased during collisions with landslides (Figure 3). Participants had an increase in cognitive activity when caught in landslides compared to traveling in the simulation.

Table 3: Change in Frontal α to Temporal θ during collision

Change in Frontal α to Temporal θ		
	Collision	Overall
Driving Scenario	5.73	4.12
Walking Scenario	4.94	4.60

The average Mean RR in the simulation during the time of a collision was slightly higher than average for the overall simulation, while the averages were the same for the walking simulation (Figure 30). Landslides in the simulation did not have much of an effect on the participants heart-rate.

The average SNS Index during a collision was higher than the average for the overall simulation for both the walking and driving scenario (Table 4). This indicates that participants were stressed when encountering landslides in the simulation.

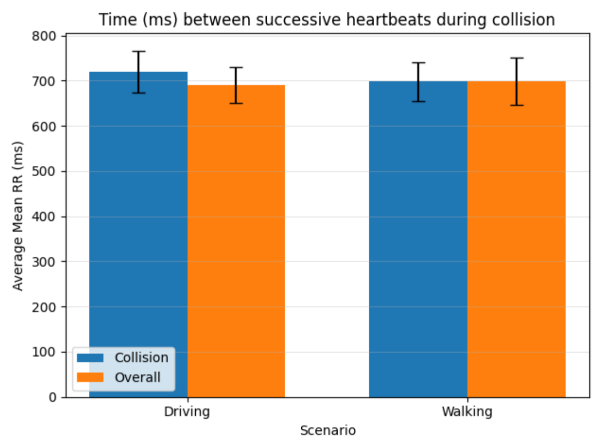

Figure 30: Average Mean RR (ms) values during the simulation 15 seconds before and after a collision with a landslide and overall during the driving and walking simulations.

Table 4: Average SNS Index 15 seconds before and after a collision with a landslide and overall during the driving and walking simulations.

Average SNS Index		
	Collision	Overall
Driving Scenario	1.45	0.90
Walking Scenario	1.11	0.81

Virtual reality has a lot of potential for measuring the physiological response of individuals to landslides. The results from the HRV data indicate that the simulation evoked stress from participants, while EEG results were mixed but show that it raised their awareness levels when traveling through a landslide-prone area or being indoors when faced with landslide risks. The collision data from the simulation further supports this, indicating heightened physiological response when participants were directly caught in landslides. However, the results from the simulation survey contradict this, with participants stating that they did not find the simulation experience stressful.

These results are limited by the design of the simulation. The simulation is not very realistic, missing crucial warning signs before landslides including crackling noises in the environment and animals suddenly becoming silent. The landslide dynamics were not accurate, making it easy to drive straight through the landslides or walk around them. The control of the car and player character in the simulation could also be improved, limiting the immersion of participants in the simulation and restricting their ability to react to landslides.

The participant demographics also do not reflect the populations most at risk to landslides. All 53 participants were undergraduate students, due to the limited timing of data collection and difficulty bringing individuals from local communities into the data collection lab. Local populations are much more aware of the risks posed by landslides and would be more responsive to landslides in the simulation.

Data collection in the VR simulation could be improved with better equipment to measure physiological response. The EEG measurement with the Muse Band Pro often cut out, causing large amounts of missing data. The analysis indicated participants had lower stress levels during the simulation then before it, contradicting the HRV data, which is likely due to these measurement errors. The HRV monitor also reported higher than average values for all participants, which caused inaccuracies in the data.

Objective 3: Understand government perspectives and identify gaps with local risk perceptions

There are significant communication gaps between the local communities, hindering effective dissemination of vital information. Some villagers shared that when landslides occur near villages higher up on the mountain, people from those regions will WhatsApp call others in lower regions that may be in the path of the slide. Interviewees shared that those who are contacted may not always receive these messages, especially if the disaster is occurring at night or if the power is out. It is also difficult for those receiving these messages to quickly and effectively share this information with others in their region.

An interview was conducted with an official from the Disaster Management Authority in Mandi and the Disaster Management Cell in Shimla. The main focus of these organizations is saving lives when natural disasters, including landslides, occur. When these officials were questioned regarding efforts in specifically the Kamand Valley and Shegli Panchayat regions, they claimed these regions had not seen an abnormal increase in landslides in recent years. This was in direct contrast to what the locals of these areas shared during their interviews, see a photo taken by an interviewee of a landslide in the Shegli Panchayat in Figure 31. These government officials shared that landslide data and statistics are monitored through a toll-free number that locals can call when they witness a landslide event. This would then allow the proper disaster management personnel to be deployed to the site as well as allow the government to keep an accurate count of the landslides in the area. The locals seemed to be unaware of this resource, as when asked about what efforts the government had taken to help them manage the risks posed by landslides, they claimed there were none.

Figure 31: Photo of a landslide through a village in the Shegli Panchayat region taken by a villager

Government officials who were interviewed and the local population agree that the road construction practices and urban development are significant contributors to landslide occurrences in most regions. The official from the Disaster Management Cell stated “the road cutting is a major reason for the triggering of landslides in most locations because of the strata of the whole state” (Shimla Disaster Management Cell, Personal Interview, April 3, 2024) Though officials are aware of the repercussions of this construction, they stated that the problem would persist because the roads were still needed, and any time buildings need to be constructed in mountainous areas it is necessary to cut the slope. These officials noted that geologists surveyed the area to attempt to mitigate the risks, however the thoroughness of these surveys is unclear; local community members voiced their concerns that the construction work was not taking the natural topography or geology of the region into consideration, instead seemingly brute-forcing their way through the mountains.

Both government and local participants feel there is room for improvement in current early warning system initiatives. Most locals had not seen or heard of any landslide EWS, and those that had shared that, after experiencing some false positives and false negatives, they were not inclined to keep faith in the system. Government officials expressed that they felt the current warning systems are unreliable and unhelpful. A government official in Shimla spoke about the results of the EWS installation: “If I talk about the actual results, it is a very controversial issue, because we are not getting the kind of results that we require. We require immediate results that should immediately be transported to the people of that area, so that they may evacuate on time. All the early warning systems that we have installed, they respond to minor changes that happen on the slopes, and after that change happens or if the destabilization of that slope happens, it takes only a few seconds for that whole landslide to trigger and vanish everything in its path. (...) Despite that, we have installed [the EWS], but the results are not very good, I would say” (Shimla Disaster Management Cell, Personal Interview, April 3, 2024). Locals also took issue with the placement of the roadside EWS, stating that when traveling through an area they know to be prone to landslide risk or when traveling in potentially hazardous conditions, they already know to be careful and trust their own instincts more so than the EWS.

Though locals expressed dissatisfaction with the current EWS, they were still receptive to the potential of an EWS or some other technological risk management intervention. As seen in Figure 32, participants had low faith in their own ability to anticipate potential hazards

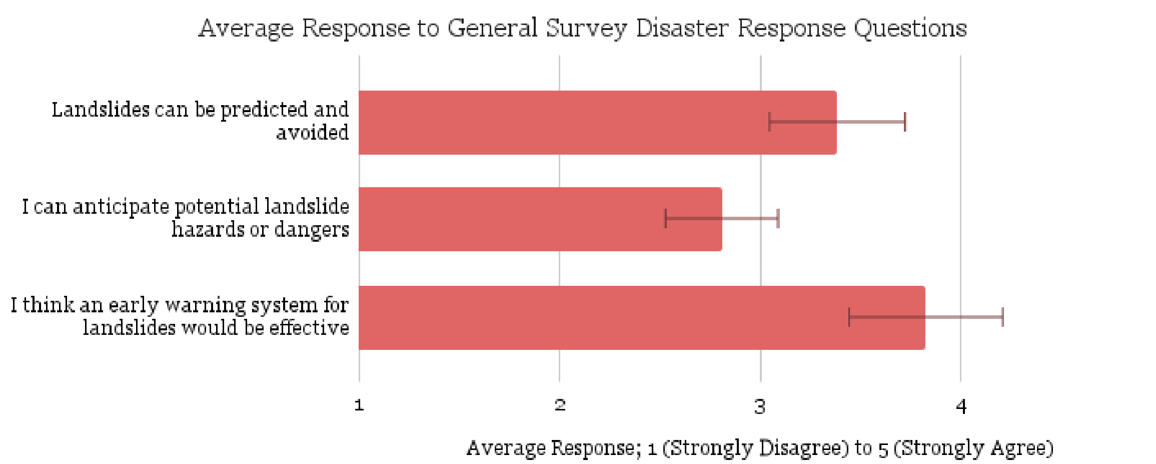

Figure 32: Averages of all responses to landslide disaster response questions

or dangers, but they believed that landslides could be predicted and avoided, and believed an emergency warning system for landslides could be effective. This shows there is great potential to develop technological intervention that the local population could be receptive to.

5 Conclusions

The impacts of landslides on local communities in Himachal Pradesh is impossible to fully grasp without speaking to those who have actually seen it. The experiences these people have gone through are harrowing, villagers described the ground rising and swallowing homes that had stood for decades, rivers of earth flowing down the mountains and crushing the homes of their relatives as they slept, rocks tumbling from the sky onto unsuspecting travelers below. It is difficult to understand the impact these disasters have on the people and communities that survive them without sitting across from them as they retell and relive some of the worst tragedies they have had to bear witness to.

5.1 Interviews and Surveys

Field interviews revealed the local population is very familiar with and aware of risk posed in their locality. They are also aware of the deadly and swift moving nature of landslides and understand the gravity of the risk posed to them in landslide conditions. Interviews also indicated the largest gap between current landslide risk intervention and local risk perception to be in risk management in residential areas, as a majority of current risk intervention is occurring in roadside risk monitoring. Interviews with government officials and villagers further revealed this gap between intervention and prevention could be a direct reflection of the gap in communication between relevant government authorities and local populations. In order to report landslide events to the local government, locals are expected to call a toll-free number during or directly after the disaster. Villagers are not doing this with enough consistency for the government to have an accurate picture of what regions are at the greatest risk and require the greatest support.

Survey results further supported this, and showed the local population is willing and ready to accept technological assistance in improving their current risk management strategy. This indicates potential for further assistance and intervention by the government and IIT in collaboration with the local population.

5.2 Virtual Reality Simulation and Surveys

The preliminary analysis of virtual reality simulations as a tool to analyze risk perception revealed the future application the technology could have to study risk perception specific to landslides. The simulations designed for this study were able to successfully elicit an emotional response from participants, specifically during times of collisions, elevating stress levels in participants and causing them to be more alert when traveling through landslide-prone areas. However, the realism of the simulation limited this effect, and did not fully convey the risks of landslides in mountainous areas. The insights gained from this study can inform future work that furthers the development of the virtual reality simulation to measure risk perception about landslides in Himachal Pradesh.

5.3 Recommendations

5.3.1 General Recommendations

The government needs to have more contact with local communities regarding landslides and the risks they pose. There exists a clear disconnect in the way these communities experience the effects of landslides and the government's understanding of the situation. From our interviews with individual community members, a lot was learned about the impact it has on their lives and the lack of effort made by the government to address the issue. The only way for the government to get a clear grasp of this is to engage in dialogue with these local stakeholders. By incorporating local perspectives into policymaking and strategy development, authorities can ensure that mitigation efforts are tailored to address the specific needs and vulnerabilities of affected communities.

The ineffectiveness of current early warning systems indicate the need for further development. Most participants interviewed stated that these systems did not help, were too late, or were not implemented in areas that add to their knowledge. The implementation of these systems could be expanded to target susceptible areas with less landslide history, and to places other than the side of the road to help local communities that need the warnings the most. In addition, these systems need to be properly maintained as many are in a damaged state despite being recently implemented. Effort also needs to be made to educate the community on these systems. Without trust in these systems and effective response mechanisms from local communities and authorities, warnings will not be taken seriously.

5.3.2 Crowdsourced Landslide Alert App

A crowdsourced landslide alerts app could help to bridge gaps in communication between the local people and the government and gaps in communication between local villagers and communities. This app would allow locals to report potential landslide risks or actively occurring landslides with the press of a button. Warning signs reported by different users could be input into machine learning models that predict when a landslide will occur based on past incidents, and display warning messages on the application. When users report an active landslide, alerts can be sent out and would be visible to anyone else in the region using the app. This would streamline the distribution of landslide warnings, allowing it to be seen by anyone that might be impacted instantly. This would also ensure the proper disaster management authorities would have the most accurate information as soon as possible, allowing them to save more lives and target risk management assistance in real time.

This app could be paired with a siren system in each village consisting of a loudspeaker mounted on a pole, a solar panel to power the system, and a large battery pack. Villagers could monitor the app during high-risk periods, such as heavy rain, and activate the siren manually when an alert is activated in an area that would require the village to evacuate. This would not only further streamline the distribution of information, it decreases the likelihood of people perishing in their sleep because they were unaware of the risk. A siren alert system would also significantly simplify the evacuation of children in emergency situations, as they can be clearly instructed on how exactly to react when the siren sounds as opposed trying to instruct them in the chaos of active evacuation. The siren also ensures children and other individuals that may be a bit farther from the village are also aware of the risk.

The application also serves as a database for keeping track of landslides in Himachal Pradesh. When interviewing government officials, it was found that they were not aware of the scope of the problem in certain regions due to the lack of reporting after a landslide occurred. Although local communities are advised to call a toll free number to report the incident, many do not do this after it has already occurred or are not aware of this process. By integrating this into the alert system, it will incentivize more people to report the incident. When a report is made through the click of the button, the application can get the current geolocation of the user and upload them to a database along with a timestamp of when the landslide occurred. This can be used to create a hazard map of landslide hotspots and better inform disaster management efforts. The data collected from these incidents can also be used to improve predictive models.

5.3.3 Further Virtual Reality Applications

The Virtual Reality simulation showed a lot of potential at understanding an individual's response to landslides, but needs more iteration to improve the realism of the landslide scenarios and account for external factors, making it more immersive. The current landslide implementation in our simulation is lacking the natural warning signs that indicate a landslide is about to occur. VR could be improved through the addition of simulated pre-landslide warnings including ground shaking, rumbling noises, and having the sounds of birds and animals that suddenly quiet before the disaster. The landslides themselves could be further improved through more accurate landslide dynamics, and making the landslide as sudden and aggressive as real life. The road conditions can also be modified to be more accurate to real scenarios, placing the road along the edge of the cliff and adding other cars and people to the virtual environment.

Future research could expand on the virtual reality tool and utilize the simulation to raise awareness about landslide warning signs and represent the damage they cause. Landslides are becoming increasingly common in Himachal Pradesh during the monsoon season, and have begun to pop up in communities that have not had experience with landslides. They are not aware of the warning signs to look out for, or the appropriate response measures to take when a landslide occurs. The driving, walking, and building scenarios encompass the common situations an individual may encounter a landslide in, and if the simulation is improved, it can allow local communities to learn through experience without the associated risks.

The VR simulation could also prove useful in testing EWS prior to large-scale implementation, as the EEG and HRV data could be used to determine what EWS configuration elicits the greatest stress response. It could also be used to test the efficacy of landslide response training programs, as the stress and positional data could indicate which participants can remain calm and exhibit the correct behavior in response to a slide event. These insights could identify significant issues with existing landslide risk mitigation efforts and help to identify the most effective solution to these issues.

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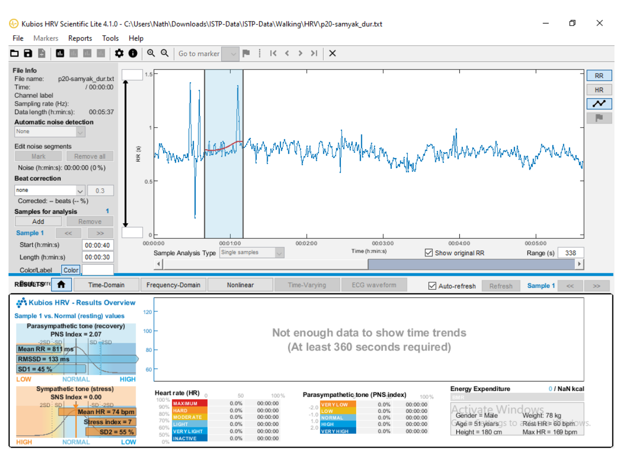
Appendix A: EEG and HRV Analysis

Measuring the HRV and EEG shows the subject's internal response to the landslides. EEG measures the electrical activity within the brain through the amplitude or frequency of brain waves. Each band is one of the five major brain-wave frequencies and represents activity in different regions of the brain. In measuring HRV it is important to track the R-R intervals between heartbeats. Increased brain activity and HRV can be reliably used to understand participant stress levels (Attar 2021).

Muse Band Pro, the device used for EEG measurement.

emWave Pro, the HRV monitor that was used.



HRV Analysis using Kubios Scientific.

Appendix B: Interviews

Rather than conducting the general survey, structured interview questions were prepared for the interviews with the Disaster Management Authority in Mandi, Disaster Management Cell in Shimla, and a student in Shimla that took us to the Shiv Bawdi temple landslide site from August of 2023. The questions for disaster management officials were targeted at understanding the government perspective on the issue and the current response methods that were in place. The interview at the Shiv Bawdi Temple site aimed to gauge the effect that the disaster had on the local community.

Mandi Disaster Management Authority Interview Questions

- Is the disaster management authority more focused on landslide prevention, risk management, or search and rescue?
- What is the disaster management authority's plan to respond to landslides?
- How is it different in urban settings vs rural villages?
- How does the Disaster Management Authority create awareness among people regarding susceptible landslides. What are the different policies regarding that?
- What is the observed effectiveness of the response?
- What is the disaster management authority's response time to a landslide when it occurs?
- What changes have you seen with landslides in the past 10-20 years?
- How have your responses to disasters changed accordingly?
- What technologies have been employed to predict landslides in Himachal?
- How effective are these landslides' early warning systems?
- Is the improper drainage of the area a reason for landslides?
- What is the major reason for severe landslides? What actions have been taken in this regard?

- When doing the field visits we noticed a lot of locals explaining how man-made activities, such as the construction of highways, dams, etc contribute to landslides. What are the disaster management authority policies on these activities?
- In repeated landslide locations such as Kamand and Shegli have there been any proposals regarding strengthening slopes near populated areas?

Shimla Disaster Management Cell Interview Questions

- Is the disaster management authority more focused on landslide prevention, risk management, or search and rescue?
- What is the disaster management authority's plan to respond to landslides?
- How is it different in urban settings vs rural villages?
- How does the Disaster Management Authority create awareness among people regarding susceptible landslides? What are the different policies regarding that?
- What is the observed effectiveness of the response?
- What is the disaster management authority's response time to a landslide when it occurs?
- What changes have you seen with landslides in the past 10-20 years?
- How have your responses to disasters changed accordingly?
- What technologies have been employed to predict landslides in Himachal?
- How effective are these landslides' early warning systems?
- How does the disaster management authority think the state of landslides will progress in Himachal Pradesh?
- Is the improper drainage of the area a reason for landslides?
- What is the major reason for severe landslides? What actions have been taken in this regard?
- When doing the field visits we noticed a lot of locals explaining how man-made activities, such as the construction of highways, dams, etc contribute to landslides. What are the disaster management authority policies on these activities?

Shimla Shiv Bawdi Temple Interview Questions

- How do landslides affect the Indian Institute of Advanced Studies and Himachal Pradesh University?
- How common are landslides in the area?
- In a lot of the areas we previously visited, landslides only became common in the past 10 years. Is it the same here?
- How do the Indian Institute of Advanced Studies and Himachal Pradesh University prepare students for landslides?
- What communication do these institutions give to students about landslides?
- What is the protocol for a student if they experience a landslide?
- What technologies have been employed to predict landslides near the institution?
- Have there been any incidents involving students with landslides?
- How do you feel about the government response to landslides?
- Can you tell us what you know about the landslide that happened at the temple in August of last year?
- What was the government response like?
- Did the local community notice signs before the landslides occurred?

Appendix C: General Survey Questions

The general survey was conducted alongside unstructured interviews with local stakeholders to understand the risk perception of the general population in Kamand Valley. Community members answered multiple choice and Likert-scale questions about their perception of the risks in different landslide scenarios.

General Survey

Demographic Questions

Gender:

- Male
- Female

Age: _______________

Highest Education Level Attained:

- Less than high school
- High School
- Senior Secondary
- Bachelor's Degree
- Master's Degree
- Ph.D or higher

Occupation: ___________________________________

Risk Perception Questions

The following questions are based on the monsoon season:

1. **I am aware of landslide-prone areas along my regular routes.**
   Strongly Disagree 1 2 3 4 5 Strongly Agree

2. **How do you feel when traveling through a landslide-prone area in the monsoon season?**

- Cautious
- Fearful
- Alert
- Calm
- Anxious
- Confident
- Joyful

3. **It is risky to encounter a landslide while traveling on a mountainous road.**
   Strongly Disagree 1 2 3 4 5 Strongly Agree

4. **Landslides can be predicted and avoided.**
   Strongly Disagree 1 2 3 4 5 Strongly Agree

5. **I can anticipate potential landslide hazards or dangers.**
   Strongly Disagree 1 2 3 4 5 Strongly Agree

6. **I think an early warning system for landslides would be effective.**
   Strongly Disagree 1 2 3 4 5 Strongly Agree

7. **I would change my plans to avoid roads that recently had landslides.**
   Strongly Disagree 1 2 3 4 5 Strongly Agree

8. **I would choose walking on foot over other transport options in the monsoon season.**
   Strongly Disagree 1 2 3 4 5 Strongly Agree

9. **Driving Limitations: Are there any specific driving scenarios or conditions you avoid (e.g., highways, heavy traffic, rain)?**
   - Yes
   - No

10. **If yes, is it any of the following scenarios:**
    - Rain
    - Heavy Rain

- Cloud Burst

If you selected none of the above scenarios or have other scenarios that were not listed, please specify: ________________________________

11. **Walking Limitations: Are there conditions you consider dangerous while walking in mountainous terrain (rain, lightning, cloud burst)?**

    - Yes
    - No

12. **If yes, is it any of the following scenarios:**

    - Rain
    - Fog
    - Lightning
    - Cloud Burst

    If you selected none of the above scenarios or have other scenarios that were not listed, please specify: ________________________________

Appendix D: Simulation Survey Questions

The simulation surveys were taken by participants before and after taking part in one of the three virtual reality scenarios. First, participants answered questions that aimed to measure the demographics of the respondents. Participants then responded to Indian personality questions that aimed to classify their Ayurvedic personality type.

Participants were then given a pre-simulation questionnaire tailored to the simulation they were taking part in. In the pre-simulation part of the survey, participants would answer questions on their risk perception of landslides, experience in the scenario, and factors that could impact their decision making in the simulation. After the simulation, participants were given a post-simulation questionnaire asked about the virtual reality experience, aiming to assess the effect that it had on them and the realism of the scenario. These questions were used to understand an individual's reaction in a landslide scenario that could not be quantified through the EEG and HRV data.

Demographic Questions

Gender:

- Male
- Female

Age: _______________

Highest Education Level Attained:

- Less than high school
- High School
- Senior Secondary
- Bachelor's Degree
- Master's Degree
- Ph.D or higher

Occupation: ___________________________________

Major/Specialization: ___________________________________

Indian Personality Survey

1. **How will you describe your body build?**
   - I have thin build
   - I have a medium build
   - I have a large build
2. **How will you describe your weight?**
   - I tend to have a low body weight. It's difficult to keep weight on.
   - My weight is normal. I've maintained my general weight for the last 10 years.
   - I am on the heavy side. It's difficult for me to lose weight.
3. **How will you describe your hair structure?**
   - My hair is thin, dry, frizzy, and brittle.
   - My hair is fine and prone to early graying.
   - My hair is thick, full, and a little oily.
4. **How will you describe your skin?**
   - My skin is thin; I can see my veins. I tend to have dry skin and wrinkles.
   - My skin is warm. My cheeks are red and warm to the touch. I am prone to skin problems.
   - My skin is thick; I cannot see my veins. It is cold or cool to the touch, and smooth with few wrinkles.
5. **How will you describe your eyes?**
   - I have small eyes; they tend to dart around. I don't hold a steady gaze.
   - I have an intense and penetrating gaze. I tend to look directly at people.
   - My eyes are large and pleasant. I tend to gaze warmly at people.
6. **How will you describe your mouth/tongue?**

- My tongue is thin and can have a dark coating. I tend to have a dry mouth; my lips dry out and crack.
- My tongue is rosy, medium thick, and pointy and can have a yellowish coating. I have a warm, moist mouth; my lips are thin and reddish, and tend to get inflamed.
- My tongue is thick and rounded and can have a white coating. My lips are smooth, moist, and thick.

7. **How will you describe your body joints?**

    - My joints creak and crack. I am bony and not very flexible.
    - I am flexible and have loose joints.
    - My joints are well lubricated and thickly padded.

8. **How will you describe your nails?**

    - My nails crack and can split easily. They are dry and thin. The nail bed is whitish.
    - My nails are flexible. They tend to grow long. The nail bed is reddish.
    - My nails are strong, thick, and shiny with a large cuticle.

9. **How will you describe your body temperature?**

    - I tend to feel cold even on hot days.
    - I feel hot. I wear shorts and T-shirts, even in cold weather.
    - I feel comfortable in most climates, but I most dislike cold, damp days.

10. **How will you describe your behavior when you are stressed?**

    - I have butterflies in my tummy. I am anxious and worried. I forget to eat. I blame myself when things go wrong.
    - I get agitated and frustrated. I feel impatient with myself and others. I blame others when things go wrong.
    - I withdraw. I overeat. I blame myself or others when things go wrong, but I convince others that nothing is wrong.

11. **How will you describe your behavior/mood on usual days?**

- I am spontaneous, enthusiastic, and lively. I am fine with change.
- I am intense and purposeful. I like to convince people. I get easily frustrated with others. I like things to go my way.
- I am easygoing, good-natured, and calm. I like routine. I tend to nurture others, sometimes at the risk of not caring for myself.

12. **How will you describe your sleep patterns/dreams?**

    - I awaken easily, and it is hard to get back to sleep. I have flying dreams. Some of my dreams are filled with anxiety and worry.
    - I sleep for short periods of time and feel rested. I dream of challenges, competition, heat, and fire.
    - I sleep deeply, sometimes 10 hours or more, and it is difficult to wake up. My dreams are slow, easygoing, romantic, and caring.

13. **Risk assessment: Imagine that you had a lottery ticket that would pay you either $20,000 or $0, each with probability 1/2. For how much money will you sell this ticket? (Please enter your response only in numeric value and do not use currency signs like dollar signs)** ________________________________

Driving Simulation Survey

Pre-Simulation Questionnaire

1. **Driving Skill/Experience Assessment: How many years have you been driving?**

    - Less Than 1 year
    - 1-3 years
    - 4-7 years
    - 8-10 years
    - More than 10 years

2. **How often do you typically drive?**

    - Daily

- Weekly
- Monthly
- Rarely
- I have my license but don't drive

3. **Terrain Experience: How often do you drive in mountainous or hilly terrains? (Here, 1 is very frequently, 2 is frequently, 3 is occasionally, 4 is rarely and 5 is never)**
   Very Frequently 1 2 3 4 5 Never

4. **Have you had any personal experience with landslides (e.g., witnessed one, been in an affected area, etc.)? (Here, 1 no experience, 2 is minimal experience, 3 is some experience, 4 is moderate experience and 5 is extensive experience)**
   No Experience 1 2 3 4 5 Extensive Experience

5. **How do you feel when traveling through a landslide-prone area? (Select all that apply)**
   - Stressed
   - Fearful
   - Anxious
   - Cautious
   - Alert
   - Calm
   - Confident
   - Other ____________________________________

6. **What are the most significant challenges you face when driving in hilly terrain? (Select all that apply)**
   - Steep inclines and declines
   - Narrow and winding roads
   - Limited visibility due to curves or terrain

- Slippery or icy roads
- Altitude-related issues (e.g., altitude sickness)
- Vehicle overheating or brake problems
- Other ________________________________

7. **Are you aware of landslide-prone areas along your regular routes? (Here, 1 is not aware at all, 2 is little awareness, 3 is moderately aware, 4 is fairly aware and 5 is very aware)**
   Not aware at all 1 2 3 4 5 Very Aware
8. **Weather Conditions: How comfortable are you driving under adverse weather conditions (e.g., rain, fog, snow)? (Here, 1 is very uncomfortable, 2 is Uncomfortable, 3 is neutral, 4 is comfortable and 5 is very comfortable)**
   Very Uncomfortable 1 2 3 4 5 Very Comfortable
9. **Have you ever encountered a landslide while driving in heavy rain in a landslide-prone area? (Here, 1 is never, 2 is rarely, 3 is occasionally, 4 is frequently and 5 is very frequently)**
   Never 1 2 3 4 5 Very Frequently
10. **Night Driving: How often do you drive at night? (Here, 1 is very frequently, 2 is frequently, 3 is occasionally, 4 is rarely and 5 is never)**
    Very Frequently 1 2 3 4 5 Never

    Accident History: Have you ever been involved in a vehicular accident as a driver?

    - Yes
    - No

    (If yes) Please briefly describe the nature of the accident(s) and any lessons learned.

    ____

11. **Risk Perception: How risky do you perceive driving on mountainous roads? (Here, 1 is no risk, 2 is low risk, 3 is moderate risk, 4 is high risk and 5 is extremely high risk)**
    No Risk 1 2 3 4 5 Extremely High Risk

12. **Landslide Perception: How risky do you perceive the possibility of encountering a landslide or rockfall while driving on a mountainous road? (Here, 1 is no risk, 2 is low risk, 3 is moderate risk, 4 is high risk and 5 is extremely high risk)**

    No Risk 1 2 3 4 5 Extremely High Risk

13. **Night Driving Perception: How risky do you perceive driving on mountainous roads at night? (Here, 1 is no risk, 2 is low risk, 3 is moderate risk, 4 is high risk and 5 is extremely high risk)**

    No Risk 1 2 3 4 5 Extremely High Risk

14. **Confidence Level: How confident are you in your ability to navigate potential hazards or dangers while driving in a virtual reality mountainous setting? (Here, 1 is not confident at all, 2 is somewhat confident, 3 is moderately confident, 4 is confident and 5 is extremely confident)**

    Not Confident at all 1 2 3 4 5 Extremely Confident

15. **Emotional Anticipation: How anxious or nervous do you feel about participating in a virtual reality driving simulation involving potential hazards? (Here, 1 is not anxious at all, 2 is slightly anxious, 3 is moderately anxious, 4 is very anxious and 5 is extremely anxious)**

    Not anxious at all 1 2 3 4 5 Extremely anxious

16. **Defensive Driving Course: Have you ever taken a defensive driving course or any other advanced driving training?**

    - Yes
    - No

17. **Self-assessment: How would you rate your overall driving skills compared to the average driver? (Here, 1 is much worse, 2 is somewhat worse, 3 is about the same, 4 is somewhat better and 5 is much better)**

    Much Worse 1 2 3 4 5 Much Better

18. **Hazard Anticipation: How confident are you in your ability to anticipate potential road hazards or dangers while driving? (Here, 1 is not confident at all, 2 is slightly confident, 3 is moderately confident, 4 is very confident and 5 is extremely confident)**

    Not Confident at all 1 2 3 4 5 Extremely Confident

19. **Driving Limitations: Are there any specific driving scenarios or conditions you avoid (e.g., highways, heavy traffic, rain)? If so, please specify.** ___________________________

20. **How risky do you perceive driving in landslide-prone areas? (Here, 1 is not risky at all, 2 is low risk, 3 is moderate risk, 4 is high risk and 5 is extremely risky)**
    Not risky at all 1 2 3 4 5 Extremely Risky

21. **Do you believe that landslides can be predicted and avoided? (Here, 1 is strongly disagree, 2 is disagree, 3 is neutral, 4 is agree and 5 is strongly agree)**
    Strongly Disagree 1 2 3 4 5 Strongly Agree

Post-Simulation Questionnaire

1. **After the VR experience, how risky do you perceive driving in landslide-prone areas? (Here, 1 is not risky at all, 2 is low risk, 3 is moderate risk, 4 is high risk and 5 is extremely risky)**
   Not risky at all 1 2 3 4 5 Extremely risky

2. **Post-experience, do you believe that precautions can mitigate landslide risks while driving? (Here, 1 is strongly disagree, 2 is disagree, 3 is neutral, 4 is agree and 5 is strongly agree)**
   Strongly Disagree 1 2 3 4 5 Strongly Agree

3. **VR Experience Quality: How realistic did you find the VR driving experience? (Here, 1 is not realistic at all, 2 is slightly realistic, 3 is moderately realistic, 4 is very realistic and 5 is extremely realistic)**
   Not realistic at all 1 2 3 4 5 Extremely Realistic

4. **How comfortable were you during the VR drive? (Here, 1 is very uncomfortable, 2 is uncomfortable, 3 is neutral, 4 is comfortable and 5 is very comfortable)**
   Very Uncomfortable 1 2 3 4 5 Very Comfortable

5. **Would you recommend this VR experience for educational purposes to others? (Here, 1 is definitely wouldn't, 2 is probably wouldn't, 3 is neutral, 4 is probably would and 5 is definitely would)**
   Definitely wouldn't 1 2 3 4 5 Definitely would

6. **Feedback on Driving Behaviour in the VR: How confident were you while driving in the VR setting? (Here, 1 is not confident at all, 2 is slightly confident, 3 is moderately confident, 4 is very confident would and 5 is extremely confident)**
   Not Confident at all 1 2 3 4 5 Extremely Confident
7. **Did the VR scenario influence your driving behaviour? (Here, 1 is not at all, 2 is slightly, 3 is moderately, 4 is considerably and 5 is significantly)**
   Not at all 1 2 3 4 5 Significantly
8. **After the VR simulation, would you change your real-world driving behaviour in similar scenarios? (Here, 1 is definitely wouldn't, 2 is probably wouldn't, 3 is neutral, 4 is probably would and 5 is definitely would)**
   Definitely Wouldn't 1 2 3 4 5 Definitely Would
9. **Driving Experience Assessment: How would you rate your overall driving experience in the VR simulation? (Here, 1 is very negative, 2 is negative, 3 is neutral, 4 is positive would and 5 is very positive)**
   Very Negative 1 2 3 4 5 Very Negative
10. **Realism: To what extent did the VR driving experience resemble real-life driving for you? (Here, 1 is not at all, 2 is somewhat, 3 is moderately, 4 is closely and 5 is exactly like real life)**
    Not at all 1 2 3 4 5 Exactly like real life
11. **Handling and Control: How would you rate your ability to control and handle the virtual vehicle? (Here, 1 is very difficult, 2 is difficult, 3 is neutral, 4 is easy and 5 is very easy)**
    Very Difficult 1 2 3 4 5 Very Easy
12. **Situational Awareness: How aware were you of the surroundings and potential hazards while driving in the VR simulation? (Here, 1 is not aware at all, 2 is slightly aware, 3 is moderately aware, 4 is very aware and 5 is extremely aware)**
    Not aware at all 1 2 3 4 5 Extremely aware
13. **Stress Level: How stressful did you find the driving experience in the VR simulation, especially in the landslide-prone areas? (Here, 1 is not stressful at all, 2 is slightly**

stressful, 3 is moderately stressful, 4 is very stressful and 5 is extremely stressful)

Not stressful at all 1 2 3 4 5 Extremely stressful

14. **Confidence Level: How confident did you feel while navigating the virtual roads, particularly in the landslide-prone sections? (Here, 1 is not confident at all, 2 is slightly confident, 3 is moderately confident, 4 is very confident and 5 is extremely confident)**

    Not confident at all 1 2 3 4 5 Extremely confident

15. **Environmental Interaction: How well do you think the VR simulation captured the environmental factors (like landslides and weather conditions) during your drive? (Here, 1 is poorly captured, 2 is somewhat captured, 3 is moderately captured, 4 is well captured and 5 is perfectly captured)**

    Poorly captured 1 2 3 4 5 Perfectly captured

16. **Night vs. Day Experience: How would you compare your driving experience between the day and night scenarios? (Here, 1 is night is much harder, 2 is night is somewhat harder, 3 is both are the same, 4 is day is somewhat harder and 5 is day is much harder)**

    Night is much harder 1 2 3 4 5 Day is much harder

17. **Learning Experience: Did the VR driving experience enhance your understanding or awareness of driving in landslide-prone areas? (Here, 1 is not at all, 2 is slightly enhanced, 3 is moderately enhanced, 4 is considerably enhanced and 5 is significantly enhanced)**

    Not enhanced 1 2 3 4 5 Significantly Enhanced

18. **Risk Perception: After the VR simulation, how risky do you now perceive driving on mountainous roads? (Here, 1 is no risk, 2 is low risk, 3 is moderate risk, 4 is high risk and 5 is extremely high risk)**

    No Risk 1 2 3 4 5 Extremely High Risk

19. **Landslide Perception: After the VR simulation, how risky do you now perceive the possibility of encountering a landslide or rockfall while driving on a mountainous road? (Here, 1 is no risk, 2 is low risk, 3 is moderate risk, 4 is high risk and 5 is**

extremely high risk)

No Risk 1 2 3 4 5 Extremely High Risk

20. **Night Driving Perception: After the VR simulation, how risky do you now perceive driving on mountainous roads at night? (Here, 1 is no risk, 2 is low risk, 3 is moderate risk, 4 is high risk and 5 is extremely high risk)**

    No Risk 1 2 3 4 5 Extremely High Risk

21. **Confidence Level: After the VR simulation, how confident are you in your ability to navigate potential hazards or dangers while driving in a virtual reality mountainous setting? (Here, 1 is not confident at all, 2 is slightly confident, 3 is moderately confident, 4 is very confident and 5 is extremely confident)**

    Not Confident at all 1 2 3 4 5 Extremely Confident

22. **Emotional Response:How anxious or nervous did you feel during the virtual reality driving simulation involving potential hazards? (Here, 1 is not anxious at all, 2 is slightly anxious , 3 is moderately anxious, 4 is very anxious and 5 is extremely anxious)**

    Not anxious 1 2 3 4 5 Extremely anxious

23. **Reality Assessment:How realistic did you find the virtual reality driving simulation? (Here, 1 is not realistic, 2 is slightly realistic , 3 is moderately realistic, 4 is quite realistic and 5 is very realistic)**

    Not Realistic 1 2 3 4 5 Very Realistic

24. **Please provide any additional thoughts or feedback on your experience during the virtual reality driving simulation.**

    ____

Walking Simulation Survey

Pre-Simulation Questionnaire

1. **Do you have any disability that affects your ability to walk?**

    - Yes
    - No

2. **If yes, what disability do you have?** _______________

3. **How often do you walk on a road to get to a destination instead of driving?**
   - Rarely
   - Once a month
   - Once a week
   - 2-4 days a week
   - 5 days a week
   - 6-7 days a week

4. **How likely are you to choose walking over another method of transportation if you knew there was a recent landslide your route?**
   Never 1 2 3 4 5 Always

5. **Terrain Experience: How often do you walk on mountainous or hilly terrains? (1 is never, 2 is very little, 3 is sometimes, 4 is often, 5 is very often)**
   Never 1 2 3 4 5 Very often

6. **How comfortable are you with walking long distances (1 km+)? (1 is very uncomfortable, 2 is uncomfortable, 3 is neutral, 4 is comfortable, 5 is very comfortable)**
   Very uncomfortable 1 2 3 4 5 Very comfortable

7. **How often do you run?**
   - Rarely
   - Once a month
   - Once a week
   - 2-4 days a week
   - 5 days a week
   - 6-7 days a week

8. **Do you have any issues after walking 1 km+?**
   - Shortness of Breath

- Chest Pain
- Pain/Aching in your calves, thighs, joints
- Heart Palpitations
- Weakness
- Other: _______________

9. **Have you had any personal experience with landslides (e.g., witnessed one, been in an affected area, etc.)? (1 is no experience, 2 is little experience, 3 is some experience, 4 is decent experience, 5 is very experienced)**
   No Experience 1 2 3 4 5 Very Experienced

10. **Have you ever encountered a landslide while walking in heavy rain in a landslide-prone area?**
    - Yes
    - No

11. **Emotional Anticipation: How anxious do you feel about participating in a virtual reality simulation involving potential hazards? (1 is very anxious, 2 is anxious, 3 is neutral, 4 is excited, 5 is very excited)**
    Very anxious 1 2 3 4 5 Very excited

Post-Simulation Questionnaire

1. **VR Experience Quality:** How realistic did you find the VR landslide experience? (1 is not realistic, 2 is slightly realistic, 3 is moderately realistic, 4 is very realistic, 5 is extremely realistic)
   Not Realistic 1 2 3 4 5 Extremely Realistic

2. **Comfort Level:** How comfortable were you during the simulation? (1 is very uncomfortable, 2 is uncomfortable, 3 is neutral, 4 is comfortable, 5 is very comfortable)
   Very uncomfortable 1 2 3 4 5 Very comfortable

3. **Will the VR scenario influence your decision to walk in similar conditions in the real world?** (1 is no influence, 2 is little influence, 3 is moderate influence, 4 is high influence,

5 is extreme influence)
No influence 1 2 3 4 5 Extreme influence

4. **VR Experience Assessment:** How would you rate your overall experience in the VR simulation? (1 is very poor, 2 is poor, 3 is average, 4 is good, 5 is excellent)
   Very poor 1 2 3 4 5 Excellent

5. **Situational Awareness:** How aware were you of the surroundings and potential hazards while walking in the VR simulation? (1 is not aware, 2 is slightly aware, 3 is moderately aware, 4 is very aware, 5 is extremely aware)
   Not aware 1 2 3 4 5 Extremely aware

6. **Stress Level:** How stressful did you find the experience in the VR simulation, especially in the landslide-prone areas? (1 is not stressful at all, 2 is slightly stressful, 3 is moderately stressful, 4 is very stressful, 5 is extremely stressful)
   Not Stressful 1 2 3 4 5 Extremely Stressful

7. **Emotional Response:** How anxious did you feel during the virtual reality simulation involving potential hazards? (1 is not anxious at all, 2 is slightly anxious, 3 is moderately anxious, 4 is very anxious, 5 is extremely anxious)
   Not anxious at all 1 2 3 4 5 Extremely anxious

Building Simulation Survey

Pre-Simulation Questionnaire

1. **Has your local community been affected by landslides in the past?**
   - Yes
   - No

2. **Has your home ever been hit by a landslide?**
   - Yes
   - No

3. **How safe do you feel in your home if you know that a landslide might occur nearby?**
   (1 is very unsafe, 2 is unsafe, 3 is neutral, 4 is safe, 5 is very safe)
   Very Unsafe 1 2 3 4 5 Very Safe

4. **Do you have a safe place to go to if you know that a landslide will occur?**
    - Yes
    - No
5. **If yes, is it nearby?**
    - Yes
    - No
6. **If your home was harmed by a landslide, do you have another place to stay?**
    - Yes
    - No
7. **Are there any items in your home you would be worried about losing in the event of a landslide?**
    - Yes
    - No

    If yes, what items?
    - Money
    - Family Heirloom
    - Food
    - Electronic Item
    - Jewelry
    - Livestock (Poultry/Cattle)
    - Other: _______________
8. **How comfortable are you leaving your community if you lost your home due to a landslide?**

    Very uncomfortable 1 2 3 4 5 Very comfortable

9. **Have you had any personal experience with landslides (e.g., witnessed one, been in an affected area, etc.)?** (1 is no experience, 2 is little experience, 3 is some experience, 4 is decent experience, 5 is very experienced)
   No Experience 1 2 3 4 5 Very Experienced

10. **Have you ever encountered a landslide in your home during heavy rain?**
    - Yes
    - No

11. **Emotional Anticipation:** How anxious or nervous do you feel about participating in a virtual reality simulation involving potential hazards? (1 is very anxious, 2 is anxious, 3 is neutral, 4 is excited, 5 is very excited)
    Very Anxious 1 2 3 4 5 Very Excited

Post-Simulation Questionnaire

1. **VR Experience Quality: How realistic did you find the VR landslide experience?**
   Not Realistic 1 2 3 4 5 Extremely Realistic

2. **Comfort Level: How comfortable were you during the simulation?**
   Very Uncomfortable 1 2 3 4 5 Very Comfortable

3. **Will the VR scenario influence your decision to stay in your home if you know a landslide will occur?**
   No Influence 1 2 3 4 5 Extreme Influence

4. **VR Experience Assessment: How would you rate your overall experience in the VR simulation?**
   Very Poor 1 2 3 4 5 Excellent

5. **Situational Awareness: How aware were you of the surroundings and potential hazards while being in the VR simulation?**
   Not Aware 1 2 3 4 5 Extremely Aware

6. **Stress Level: How stressful did you find the experience in the VR simulation, especially after the landslide started?**
   Not Stressful 1 2 3 4 5 Extremely Stress

7. **Emotional Response: How anxious did you feel during the virtual reality simulation involving potential hazards?**
   Not Anxious 1 2 3 4 5 Extremely Anxious

Appendix E: Informed Consent Agreement for Participation in Research Study

Investigators: Nathaniel Itty, Shivangi Sirsiwal, Matthew Rosenberger

Contact Information: nitty@wpi.edu, ssirsiwal@wpi.edu, mhrosenberger@wpi.edu

Title of Research Study: Analysis of Landslide Risk Perception in Himachal Pradesh

Sponsors: Dr. K V Uday (Indian Institute of Technology Mandi; uday@iitmandi.ac.in), and Dr. Varun Dutt (Indian Institute of Technology Mandi; varun@iitmandi.ac.in)

Introduction: You are being asked to participate in a research study. Before you agree, however, you must be fully informed about the purpose of the study, the procedures to be followed, and any benefits, risks or discomfort that you may experience as a result of your participation. This form presents information about the study so that you may make a fully informed decision regarding your participation.

Purpose of the study: This research aims to determine how people behave and make choices when living in regions susceptible to landslides. in Himachal Pradesh. Landslides are a massive danger in the region, causing damage to infrastructure and harm to local communities. Understanding the communities risk perception is essential to implementing proper response measures and minimizing these risks. By collecting and analyzing data about the population, this study aims to make recommendations to the government about adequate risk mitigation strategies.

Procedures to be followed: This study will consist of three parts: a pre-simulation questionnaire, the virtual reality simulation, and the post-simulation questionnaire. First, participants will be presented with the pre-simulation questionnaire to provide information on their demographics, peresonality, driving/walking experience, landslide experience, and risk perception. Then, participants will be set up in the simulation by sitting in the lab setup and wearing the head-mounted display. They will also be connected to the EEG and HRV monitor. Once they are setup, the participants will take part in the virtual reality simulation. After the simulation, participants will be given the post-simulation questionnaire to provide feedback about their experience in the simulation.

Risks to study participants: Virtual Reality sickness can occur when wearing the head-mounted display and running the simulation. Exposure to the virtual environment can cause symptoms similar to motion sickness including nausea, disorientation, general discomfort, eye strain, and drowsiness.

Benefits to research participants and others: People who participate in this study will contribute to reducing the risks posed by landslides and be a part of the design of more effective landslide response measures.

Record keeping and confidentiality: Google Drive will be utilized to keep track of responses and shared between the investigators. Each person will be assigned a unique identification numbers to link the data to them. Records of your participation in this study will be held confidential so far as permitted by law. However, the study investigators, the sponsor or it's designee and, under certain circumstances, the Worcester Polytechnic Institute Institutional Review Board (WPI IRB) will be able to inspect and have access to confidential data that identify you by name. Any publication or presentation of the data will not identify you.

Compensation or treatment in the event of injury: There is no anticipated risk of injury associated with this research.

For more information about this research or about the rights of research participants, or in case of research-related injury, contact:
Primary Investigators:
Nathaniel Itty, Email: nitty@wpi.edu
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Ruth McKeogh, Tel. 508 831- 6699, Email: irb@wpi.edu
Human Protection Administrator:
Gabriel Johnson, Tel. 508-831-4989, Email: gjohnson@wpi.edu

Your participation in this research is voluntary. Your refusal to participate will not result in any penalty to you or any loss of benefits to which you may otherwise be entitled. You may decide to stop participating in the research at any time without penalty or loss of other benefits. The project investigators retain the right to cancel or postpone the experimental procedures at any time they see fit.

By signing below, you acknowledge that you have been informed about and consent to be a participant in the study described above. Make sure that your questions are answered to your satisfaction before signing. You are entitled to retain a copy of this consent agreement.

______________________________ Date:____________________

Study Participant's Signature