

**Prevention of Mass Wasting Destruction in Rural/Village Areas Along the Andean
Mountain Range**

South Florida

AP Capstone Research

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Introduction

Background

To preface this study, it is important to establish a background that would best establish the issue that this paper is exploring. This section will be divided into 2 main parts: (1) this section will cover plate tectonics, how they formed the Andes, and the term “mass wasting;” (2) this section will cover the statement of the problem, which discusses the hazards directly imposed on Andes locals and the factors that make the Andes particularly susceptible to landslides in comparison to regions surrounding it.

Debris flows and other forms of mass wasting have been claiming lives of thousands in the Andes through many centuries. The Andean Cordillera was formed because of the convergence of the South American-Nazca and South American-Antarctic plate boundaries. A convergent boundary forms when two tectonic plates move towards each other—forming a trench, one must get pushed down by the other. The denser, basaltic oceanic Nazca and Antarctic plates sink underneath the less dense, granitic South American plate. There are two outcomes because of this: accretion, and hotspot formation of volcanoes. As the Nazca and Antarctic plates slide under, the top of their surface scrape against the South American plate, forcing rocks onto its edge. Compression sediments onto the edge packs the continent more tightly and the continental crust gets compressed and spreads out vertically, creating mountains.

Additionally, when the Nazca plate gets sucked under the South American plate, water seeps deep underground along with the rock. The hot water and partially melted rock mix to form magma, which rises to the surface and conglomerates into magma chambers. With enough magma collected, volcano chains form. The Andes has three distinct volcanic regions: the

Northern, Southern, Central, and Austral zones (Stern, 2004). The Northern volcanic zone is contained within the countries of Colombia and Ecuador, the central volcanic zone contains the countries of North Chile, Bolivia, and Peru, with the Southern and Austral zones containing parts of Argentina and Chile.

These volcanoes and high-elevation mountain ranges are susceptible to what is known as mass wasting. The term is described as “movement of rock and soil down slope under the influence of gravity,” (Mass Wasting, 2019). There are multiple types of mass wasting, but this report concerns the quick moving types that cause the most immediate destruction and claiming of lives. The two types observed in this study are debris flow and lahars. Debris flow is largely caused by the flowing of water from excessive thunderstorms and melting of glaciers, while lahars are mainly caused by the excretion of pyroclastic material from volcanos conjoining and forming fast moving, semi-solid bodies of destruction.

Statement of the Problem

For the past millennia, destructive mass wasting events have been documented. Many tragedies have led to massive death tolls: the Armero tragedy, 40,000 deaths; the Ancash disaster, 70,000 deaths; the Vargas Disaster, 30,000 deaths (AFP, 2015), (Ericksen, 1970), (*December 1999*, 2016). The mortally destructive effects of these mass wasting events highlight why action must be taken, disorganization and failure of local and governmental agencies in the prevention of these disasters is evident enough through recurrences of these events. Looking at multiple solutions that governments could add to their arsenal would greatly lessen mass wasting mortality rates. The Andes is particularly susceptible to these movements of rock due to La Niña cycles as well as the elevation and slope of its mountains. To quickly summarize, La Niña is a phenomenon caused by a “build-up of cooler-than-normal” temperatures in the tropical Pacific

that get carried east by strong trade winds (*La Niña*, 2023). These winds bring intense storms to the Andean region, which can lead to an increased risk of landslides. Additionally, there is one more factor that must be considered in the statement of the problem. Climate change has profoundly increased the number of natural disasters in the past century. With this increased rate, the threat of mass wasting is ever present, and is becoming more important to address by the day (Moreiras et al., 2021).

These problems affect multiple stakeholders. In the aftermath of mass wasting disasters, citizens are left negatively affected psychologically, economically, and culturally in addition to being physically displaced. There have been a multitude of studies that explore and experiment with individual solutions to mass wasting disaster. The following section will discuss these solutions and then observe the common gap among those sources.

Literature Review

Preface

This literature review is devised into eight different sections, the first seven will deal with different possible solutions that would address mass wasting destruction. In order, they are: (1) Acoustic Flow Monitoring Systems (AFMs), (2) berms, (3) Geographical Information Systems (GIS), (4) infrasound sensors, (5) multinational effort plans, (6) land use regulation, and (7) planting vegetation. The last section (8) will cover the gap, research question, and the resulting hypothesis based on the different solutions discussed.

AFMs

“The Acoustic Flow Monitor (AFM) is a portable system that was designed by the U.S. Geological Survey Cascades Volcano Observatory to detect and monitor debris flows,” (USGS, 2024). AFMs can be made cheap with materials easily available to the public. These devices are

relatively small, about the size of a regular printer. At the heart of an AFM, lies a Raspberry Pi which can easily be bought from online vendors for as little as \$20. A Raspberry Pi is a little computer that can be used with virtually any programming language, it can be coded to do whatever you want. In the case of an AFM, you can code it to read from cameras, thermometers, the humidity of the surrounding air to get data. Stark changes in any of these data could signify a flow. This technology is often seen as “outdated,” since it hasn’t been used in over 40 years because of the many false trips it is prone to (USGS, 2024). One example could be a deer run by the AFM would think it is a debris flow moving past. It is mostly used recreationally.

Berms

These are essentially walls of aggregate stone placed to prevent debris flow. There are basically two types: deflection walls and lateral berms. The former is a little different from the latter by “that they deviate the flow path to another area of the debris fan avoiding going straight,” (*LaRiMit*, 2023). Lateral berms attempt to slow down flows before they reach buildings or stop them completely. It requires a lot sturdier structure to block debris flow, which makes the first option slightly better. These structures have been previously used in the Andean region for hundreds of years, with the first use dating back to early Incan civilization. In the current modern age, where civilization is much larger, it is important to call into question whether these are still viable on a large scale. When building a berm, it is important to understand the angle a potential debris flow or lahar is coming from, and its speed. These two factors heavily influence the size of the berm that is needed to block or redirect the flow.

GIS Technology

These systems provide insights into landslide hazard areas through the use of multiple monitoring and management systems. Graphical Information Systems are used all around the world for digital maps, and they can best be related to a combination of layers. Each layer contains a map of certain data. In the case of landslides, the software layers would include “landslide early warning, landslide risk and vulnerability analyses, and critical infrastructure damage assessments,” (Hamid Assilzadeh et al., 2010). Combining these layers would generate a singular map. This map would be called a hazard map, as all the data combined would show areas that could be prone to debris flow. GIS can be used in tandem with other solutions because of its important insights. One drawback is that sometimes the different layers of data are not updated at the same time, which could lead to outdated data and incorrect hazard maps.

Infrasound Sensors

Infrasonic waves occur in the lithosphere and atmosphere and refer to sound waves below the frequencies of sound that humans can hear. They are generated in nature through volcanoes, earthquakes, landslides, and even explosions such as nuclear blasts (Infrasonic Sound, 2024). In an experimental study by Qiao, a block of sandstone experienced different shear loads. In each case, “infrasonic wave events were identified, and the characteristic parameters of infrasonic waves were extracted to analyze the features of the infrasonic wave response during the shear failure of sandstone,” (Qiao et al., 2021). In other words, according to Qiao, the results yield that the whole process of shear failure was associated subsequent infrasound events that were captured by an infrasound sensor, thus showing the infrasound sensor’s effectiveness. Infrasound sensors are typically placed in a circular array that communicates with a required central tower (Fu et al. 2020).

Multinational Effort Plans

This solution is defined as a plan that has operations in more than one country to combat societal structures or issues (Edwards, 2014). These are typically operated by multinational corporations (MNCs). One such example would be the World Meteorological Organization and its *Enhancing Adaptive Capacity of Andean Communities through Climate Services* (ENANDES) plan that is similar to this proposed solution. These plans would enact strategic priorities such as disaster risk reduction, capacity development, and evacuation routes (ENANDES, 2020). These plans are typically funded by foreign countries. In the example of ENANDES, it is funded by Switzerland. These plans also have terms that vary, but usually last around a decade. One drawback is that any infrastructure created will have to be maintained by that country after the term is over.

Land Use Planning

Authorities should utilize a combination of consultations with licensed engineers, geologists, and other resources to identify potential landslide risk areas. Zoning regulations can then be placed after the fact to limit development in these areas. These zoning areas must be patrolled and maintained by the government to prevent as much squatting as possible (*Identifying Locations*, n.d.). Squatting “describes moving into a property without any legal claim or title to the property,” (Mmiller, 2024). Squatting was responsible for the Vargas disaster. (*December 1999*, 2016). Additionally, building codes should be emplaced to prevent over steeping of slopes or damaging slope integrity (Puente-Sotomayor, 2021).

Planting vegetation

According to civil engineering assistant professor Jie Huang, using trees would theoretically prevent landslides from occurring (UTSA, 2015). This is because the roots of trees can hold soil and prevent the soil from moving (Washington State University, 2024).

Additionally, the trees themselves would also prevent wind erosion, which is especially important due to drafts caused by the different elevations of the Andes mountains range. One drawback is that the Andes do not always host an environment for which trees can grow. Some of the possible debris flows from the Andes doesn't necessarily have to have soil in it, it could be crushed minerals, or the mass wasting event could be a lahar.

Gap, Research Question, and Hypothesis

While analyzing different sources found on scholarly websites, it was found that there was a lack of research surrounding the most cost-effective, and efficient solutions for mass wasting in the Andean mountains. This study was designed to research that gap. And therefore, the research question is, what technologies can be used to efficiently prevent and lessen the effects of mass wasting on rural Andean civilizations. It is hypothesized that the most effective solution will be a multinational effort plan that uses GIS tools to identify potential mass wasting hazards.

Methodology

Design

To conduct a study to find the most cost-effective preventative measures for mass wasting, the researcher chose to use interviews. The study does not rely on the opinion of the public, but only comprehensive analysis from experts, therefore any surveys, case studies,

ethnographies, and focus groups would be outside of the scope of the research question. Content analysis has the potential to bring in research bias. Moreover, a content analysis ineffectively looks deeper into each solution, the expertise of each of the interviewees assesses this discrepancy. An experiment would not be possible due to capital restraints. Therefore, the only feasible method that would most effectively find the solution would be interviews (*Research Guides*, 2023). The participants would be scientists, engineers, and professors who are well versed on, or actively work with, the prospected technology. Using the responses from the interviews, the researcher will have arrived at a conclusion that includes the best prospect or combination of prospects.

Subjects

Originally, the goal would have been to have three interviewees from each solution. However, upon implementation, it was discovered that a high degree of non-response bias was encountered. This is due to the population of the interviewees, who are mostly busy college professors or experts working in the field with little internet connection. However, according to Professor Malterud of the University of Copenhagen, only one interviewee is required per solution, due to the phenomenon of “information power.” In essence, the more information that a sample holds, the less of a need for a larger sample size (Malterud, 2016). Getting high quality sample data requires less interviews to take place. The interview questions should be structured in such a way that all possible information that would be needed for the study would easily be answered using direct questions. This allows the researcher to add the delimitation of requiring only one researcher instead of three.

Tools

All the questions are framed as open-ended, short response queries. In each interview, the individual will be asked to state some of their qualifications and educational history for the purpose of the interview; how does it make them qualified to discuss the topic at hand? The subjects will be interviewed with a sequence of twelve questions to address the ability of each technology. The following two questions require hard response answers of statistics for cost. The rest are questions that correspond with the rest of the decision matrix criteria. After this data is collected, the data from the transcripts would be evaluated and placed into a decision matrix, and therefore find the most economical solution.

Procedure

Over the course of three months, from November 2023 to January 2024, the researcher contacted various individuals from the possible solutions listed above, if the expert did not reply in 10-14 days, the researcher would move onto contacting the next expert. The questions will be attached to the email for the purpose of interviewee preparation as well as to inform the interviewee of the nature of the study and the questions asked. Both parties agree to a specified time and date, then proceed to discuss within a Zoom or Google Meet. The questions will be asked in a sequential manner, starting with the qualifications of the interviewee that makes them qualified to be interviewed, benefits and implications of the proposed solution, installation, repair costs, etc. Probe questions will be used as necessary to gain as much knowledge as possible for the study. It is expected that the interview will take around 30 minutes for each interviewee and will be held over the course of a few weeks. A form to gain permission to use their interview to inform the public would also be sent. Additional confirmation will be asked before the beginning of the interview to eliminate discord. If an interviewee does not respond

when the researcher attempts to contact, or they choose not to be interviewed, a substitute should be found. The first two questions (see Appendix A) were held to determine the credibility of the interviewee as well as set the nature of the dialogue of the interview.

Using a decision matrix, the responses to each of the questions thereafter will be used for evaluation. The decision matrix will host multiple criteria, each measured on a scale from 1-5. The highest emphasis was placed upon cost and local feasibility. This study is looking to find the most cost-effective solution, it also aims to not displace any current locals. Semi-high emphasis was placed upon inefficiencies and alternate applications. They are also important, but not as important as the primary criteria. The highest score from the resulting row echelon matrix will be used to determine the most cost-effective solution.

Ethical Considerations

In the case of IRB registration, there is no need to address any risk assessment, as there are no consequences on the daily lives of those who participated thereafter. Even so, the privacy of each subject is highly regarded and so each subject will be informed of the nature of the interviewee and made sure of the understanding how and why they are being interviewed. In addition to this, it shall be emphasized the voluntary participation of this study. Each subject is allowed to leave at any time if they choose to do so, will full confidence that their interview will be discarded and not available to the public. This also extends to the interviewees themselves. Each of the interviewees will be unaware of how many other individuals there are in the study, their names, and their qualifications. Each subject will be asked to keep the questions and their answers confidential for the sake of research and the paper. The interview questions will be worded in an unbiased manner in hopes of preventing as much bias in the subject's response as possible. It must be acknowledged that since the data will be collected from interviews that are

held in a back-and-forth conversation with real human subjects, there would still be a degree of response bias regardless of what is done in preparation. The nature will be kept purely formal in an interview style, with slight comments before and after the interview.

Findings & Analysis

From September 2023 to January 2024, the researcher delivered emails to professors and experts in the geological field requesting interviews. Eight complete responses were received, one for each distinct solution. The acoustic flow monitoring system, hydrologic monitoring, and GIS technologies interviews were all received by USGS researchers (see Appendix B, C, D). For land use regulations, the response was received by an official from the Bogota city council and city planning (see Appendix E). The other 3 responses are awaiting interviews. Using the table below, the summaries of each technology can be compared. Information about each is filled into a set of categories, and this information will result in a rating based on the key criteria.

Table 1

Summary of Key Results

Name	Cost (3)	Local Feasibility (3)	Inefficiencies (2)	Alternate Apps. (2)
Acoustic Flow Monitoring System	\$8000	Depends on location from source	Outdated; would have to build on one’s own; prone to trips	Avalanche monitoring
Berms	N/A	Needs extensive area to be effective	Extensive construction	Flood protection

Multinational Effort Plans	N/A	Builds human infrastructure capacity	Typically have terms for how long they last	Resilience building
GIS Technologies	\$1k-17k	Does not affect locals, remote	Often relies on outdated information	Mapping, vegetation monitoring
Infrasound	\$20-40k USD	Relatively close to origin	100m x 100m area	Detecting a variety of natural disasters
Land Use Regulation	N/A	Not very feasible on a universal scale	Squatter settlements, adequate training	Environment conservation/prevention of urban sprawl
Planting Vegetation	\$12k-15k USD/acre	Adds to environment	Requires capital, many years of growth, limited areas	Environment conservation

An important thing to consider is that local feasibility is in reference to how local populations in the Andes will react to a solution. Whether it is how accurate the device is without producing false alarms, or if it interferes with day-to-day life, this must be considered in the final solution. Once again, it is important to reiterate that many deaths are caused by ignorance of warnings. To find the best solution would be to counteract this. It must also be noted that for some solutions such as land use regulation, it will be difficult to calculate a cost because it would

be challenging a pre-established government system and would introduce new infrastructure to an entire hierarchy of bureaucracy, therefore only a rough estimate is given. As we shall see later, these solutions are most likely unfeasible because of their scale.

For cost, the solutions that stood out for being most cost-effective were AFMs, GIS, and infrasound systems close behind. In the table, there were a few “N/A” rows, this is due to the interviewees not knowing the exact cost because of the sheer size of these solutions. In terms of local feasibility, most of the solutions relatively didn’t affect the local population, except for berms and land use regulations, which would require massive displacements of peoples. Looking at the inefficiencies category, each solution came with its own quirks. Most had moderate to high inefficiencies; however, infrasound had the least inefficiencies compared to the rest of the solutions. This would be due to its accuracy in reading infrasonic waves. In the alternate applications criterion, the solutions that stood out were infrasound and GIS technologies, simply for their versatility in tackling many other natural disaster issues.

There is no quantitative measuring system for how well the solution will be liked by a population, therefore using the interview transcripts compiled into a decision matrix, the researcher graded each solution on a scale of 1-5, with 5 being highly trustable and containing low discrepancy.

Table 2

Decision Matrix Table with Final Scores

Name	Cost (3)	Local Feasibility (3)	Inefficiencies (2)	Alternate Apps. (2)	Total
Acoustic Flow Monitoring System	5	4	1	3	35
Berms	1	2	2	3	19
Multinational	2	5	3	2	31
GIS Technologies	5	5	1	5	42
Infrasound	4	5	4	5	<u>45</u>
Land Use Regulation	1	1	3	4	20
Planting Vegetation	1	4	3	4	25

Conclusions

The purpose of this study was to determine a low-cost, effective set of solutions that would best handle the destruction of mass wasting disasters in rural villages of the Andes

Mountain range. After an analysis of interviews with researchers, a decision matrix was formed to calculate the results. The initial hypothesis of a combination of GIS technologies and multinational effort plans was proven to be incorrect. For one, as stated in *Table 1*, many GIS mapping tools sometimes are forced to rely on old data as sometimes the data isn't updated in real time, or there has been a lack of updates. This poses a false alarm threat to the locals and should not be considered as a strong solution. Additionally, while multinational effort plans bolster the idea of having a collective unity between locals and authorities, as well as having a well-planned evacuation route, these plans typically have term limits. For example, ENANDES has a term limit until 2030 (WMO, 2023). These limits are unfortunately a byproduct of lack of continuous funding.

Solutions

The conclusion which rejected the hypothesis was found to be infrasound, which had the highest matrix score of 45. Its cost effectiveness and efficiency can be handed to a few reasons. For one, infrasound doesn't take as much area relative to the other solutions studied. Additionally, they are less likely to have false trips because they rely on a specific frequency of seismic waves. These waves would be very hard to recreate, you would need massive amounts of energy to do so.

To implement this solution, these infrasound systems would have to be strategically placed not too far from the "snout," but also relatively close to the population it is monitoring to ensure no false warnings (see Appendix H). Debris flow and lahars pose a great threat to the Andean region due to the stark nature of its mountains which is why this solution is important to implement. Again, these threats are further accentuated due to climate change, calling for urgency to this matter.

Recommendations

Through the research found in this study, it is recommended that future research should investigate preventing false alarms. To preface this matter, it is important to consider that the priority behind these solutions is to save human lives. Therefore, for every bit of uncertainty from data, there will be a degree of caution. This caution will inevitably lead to some false alarms. However, the researcher suggests that despite the uncontrollable uncertainty, there are still some other methods that could be used to decrease the probability of false alarms. It was found that false alarms were often due to a lack of updates to certain technologies. Some data from GIS tools were found outdated and AFMs have not been used for decades. Both systems are cheap and work relatively well otherwise, but they cannot be implemented because they would negatively affect the relationship between Andean locals and authorities and contribute to distrust. Actively updating these techs to get rid of the false alarm issue would make them extremely viable for Andean countries in preventing mass wasting destruction.

Additionally, the sometimes-negative relationship between Andean locals and authorities should also be studied. Often, many farmers and shepherds choose to ignore the warnings sent out by officials because of the many false alarms that occur (Siegel, 1989). This phenomenon contributes greatly to the mass wasting destruction problem and must be looked at itself. This issue seems to be deeply rooted in the structure of society in the Andes and it is suggested that a field study would be effective in collecting data to find solutions that would address this problem. These research areas would add more to the conversation and potentially further eliminate the risk behind mass wasting.

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Appendix A: Sample Sent Email

Dear [Mr./Dr./Professor Last Name],

I hope this email finds you well. My name is John [REDACTED], and I am a senior conducting research at [REDACTED] High School in [REDACTED], Florida. My topic of study is preventing mass wasting destruction in rural/village areas along the Andean mountain range and my method of study is through interviews.

I ask you to participate in my interview survey. I have chosen you for your history and expertise in [solution method]. The interviews will be conducted on a date of your choosing. As a starting point for planning, I can suggest _____ at _____ p.m. The software used to organize the meeting will preferably be Zoom or Google Meet, but I am certainly open to alternative methods of communication.

As part of my research, I value the privacy of each individual. If you choose to participate in my survey, I will send you a short, two-question Google Form regarding recording consent.

The duration of the interview will be short (15-20 minutes), but if you do not have the time and would still like to recommend another expert in the field, please let me know! Additionally, if you have any further questions, please feel free to contact me via replying to this email or through phone number at +1 (561) [REDACTED]. Thank you so much for your time!

Best,

John [REDACTED]

[REDACTED] High School Class of '24

Appendix B: Interview Questions

- 1) Do I have permission to record you for the purpose of this interview?
- 2) How did your education background prepare you as a specialist in your area of study?
- 3) What previous work or research have you done in this area, and is there any other qualifications that you can state for the purpose of this interview?
- 4) What is the best cost estimate for the solution that you present?
- 5) What would be the cost of maintenance?
- 6) What difficulties would you face while trying to implement this solution?
- 7) To what extent would it affect the inhabitants of the area?
- 8) To your knowledge, how would authorities react in trying to implement this technology?
- 9) What alternative applications does this technology hold?
- 10) What makes this solution so practical?
- 11) What makes it unpredictable?
- 12) Is there any other possible information pertinent to this solution?

Appendix C: Permission to Record Form

Permission to Record Waiver

As part of the interview study, the researcher will record the interviews in order to best track the answers from each individual. By signing this form, you will be giving consent to being recorded and have your replies to each question used in the conclusions of an academic paper. The electronic signature on this form will function as a regular signature.

s27817600@stu.palmbeachschools.org [Switch account](#) 

* Indicates required question

Email *

Record s27817600@stu.palmbeachschools.org as the email to be included with my response

E-signature (First, last) *

I understand the above statement and agree to having my interview recorded. I acknowledge that there is no commitment to this and in the event that I change my mind, my interview recording will be discarded.

Your answer _____

Today's date (Month, day, year) *

Date

mm/dd/yyyy 

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Appendix D: Acoustic Flow Monitoring System Interview Transcript

What previous work or research have you done in this area, and are there any other qualifications that you can state for the purpose of this interview?

I have an undergraduate degree in geology and geophysics. I have a PhD in earth and space science from the University of Washington. I did a year of postdoctoral research at University of Washington and another year of postdoc at Cascade Volcano Observatory which is where I am currently. I went to Hawaii for a couple years to be a network seismic manager. And I am the science lead for Mount Rainier network which has several monitoring stations that are out, in a configuration to detect first and then to track as they flow down river valleys.

What is the best cost estimate for the solution that you present?

You would have to build one, there is not one who is actually making them. You would have to buy one, like Raspberry Pi. You can get a Raspberry Shake and Boom or Pi. In terms of actually getting an acoustic flow monitor, I think your best bet would be to get a Raspberry Shake and Boom and using the microphone. Those AFMs that are out there have been built by individuals and those individuals have moved on, they have all retired, because all that equipment is old.

What difficulties would you face while trying to implement this solution?

Well so, there is a evolution of instrumentation that has occurred recently. We have gotten away from AFMs, as they have traditionally been implemented and that is because they have basically been a black box that is really hard to work with. The equipment to use it was obsolete, and it was really hard to maintain and keep running. What we have done here in the United States and what we are telling our international partners, is basically to replace them with a seismometer. It is a bit more expensive on the forehand. Which are fairly modular. You are looking for about

8000 dollars for a computer recording from a geophone, 2000+ dollars, and a radio. If you are lucky you can connect to internet, or a cell modem radio that can be used to give a people a heads up as to get out of the way. You need to get close enough to the drainage.

To what extent would it affect the inhabitants of the area?

What are the capabilities of the community you are trying to warn. If is very simple for individuals to get to high ground from where they are, you can put an instrument closer to the village because they don't need as much time. And what happened because of that, if it gets to that station, then you know that people need to get to high ground. The closer you get to that source, the more likely that a false alarm will occur and distrust in the system may form.

To your knowledge, how would authorities react in trying to implement this technology?

The USGS only advises with the science, we are not responsible for evacuating anybody. That is all the emergency managers that are there. It is a partnership that we have, and together educate the local community, governments, and municipalities. You have to train using tabletops and evacuation drills. You have to give them training for their specific setting. Anyone who comes in from the outside, you will be viewed with skepticism. You have to build relationships and trust with individuals that will be potentially impacted. Our international group does this a lot, it is really important that they have relationships built before an eruption occurs. Relationship building is hard when there is language and cultural barriers. That is the hardest part of this whole thing, is getting the locals to buy it.

What alternative applications does this technology hold?

Any kind of surface movement, I have been dabbling a lot in avalanches. And so, avalanche protection is another that might hold some utility. Trying to figure out how to calibrate just

regular waterflow would be useful, instead of a stream gauge. Largely we have gotten away from the AFMs.

Are there any other comments you have on this technology?

We are in the process of using laser range finders in order to judge if a flow has gone by instead of tripwires, leading to less false alarms.

Appendix E: Berms Interview Transcript

What previous work or research have you done in this area, and are there any other qualifications that you can state for the purpose of this interview?

My research in this area has occurred over 23 years. I primarily focused on civil engineers, geological hazards, and mitigation strategies. I've conducted lots of fieldwork in many regions prone to landslides in the Caribbean and have collaborated on various projects related to slope stabilization. As for education, I have a PhD, and am affiliated with the University of Florence.

What is the best cost estimate for the solution that you present?

I'm not exactly sure because we are talking about massive amounts of rock that would need to be strategically placed and cemented. A project such as the one you are talking about is not calculable off the top of my head. You would need an extensive plan to show much money you need. These berms can become really massive which is why you would have to look into that.

What difficulties would you face while trying to implement this solution?

Well, you would need the necessary permissions and approvals for construction in certain areas. You would probably need permits for these parts. Engineers would also need to be involved to make sure the berms do not have the opposite effect intended. These are massive rocks built together. And for this reason, you would need long term maintenance and monitoring to make sure that the berms do not have the opposite effect.

To what extent would it affect the inhabitants of the area?

Residents may experience a disruption based on the construction activity. Also, depending on the slope nearby, the berms would need to be upscaled, and this might not be possible due to existing

infrastructure, which might lead to some people being displaced. This is often characteristic of places seen like the Caribbean, and I'd imagine the Andes as well, where many buildings are built on the sides of mountains. You can't make people leave there and build a berm unless they have an incentive.

To your knowledge, how would authorities react in trying to implement this technology?

As I said, you would probably need necessary paperwork and bring in engineering.

What alternative applications does this technology hold?

Well, you could also potentially block avalanches. Seeing that avalanches are similar to landslides but that they are snow, you could also do something with that.

Are there any other comments you have on this technology?

Appendix F: GIS Technology

What previous work or research have you done in this area, and is there any other qualifications that you can state for the purpose of this interview?

I formerly worked at Italian National Research Council, or the CNR. I also did research in multiple areas such as computing in mathematics, natural science, engineering information science and databases. The current project is 'Landslide hazard assessment. I also have PhD.

What is the best cost estimate for the solution that you present?

The principles for GIS systems rely on many things like data availability and the scale of map you are wanting to look at. Many of the costs encountered would be expenses related to data acquisition, software licensing and development, and maintenance. I've encountered that a map array would cost anywhere around \$1k-17k.

What difficulties would you face while trying to implement this solution?

Ensuring the accuracy of the prediction models is something that is quite challenging. Often times, would run into data that has not been updated, any this could lead to exceptions in our data layers. I think also with landslides, you would need to establish effective communication channels with the government to tell people of warnings and disaster, otherwise it would be useless.

To what extent would it affect the inhabitants of the area?

I see residents only benefiting from improved awareness and alerts with updates. There is always the issue of false alarms, but I believe that technology will get better with time. Almost

everything is handled off site, a lot of it remote, making it really easy to use because you rely on satellite.

To your knowledge, how would authorities react in trying to implement this technology?

Authorities should react warmly to this; many authorities are not trusted due to false alarms.

What alternative applications does this technology hold?

I have actually different articles on the use of GIS systems, they can be used to monitor rain, hurricanes, changes in temperature, all kinds of disaster.

Appendix G: Infrasonic Interview Transcript

What previous work or research have you done in this area, and is there any other qualifications that you can state for the purpose of this interview?

I have a PhD in geophysics, volcano geophysics specifically. I have been working in volcano geophysics, and more recently, landslide geophysics, for the past 11 years with the US Geological Survey.

What is the best cost estimate for the solution that you present?

It depends on the scale of the installation. So if you wanted to monitor one drainage, you could probably do it with one single infrasonic array. If it was something we would deploy at a volcano in the US, funded by the USGS, it would probably cost something around \$20k-\$40k.

What is the maintenance cost?

Yeah sure, there is always, with any real time system. If it is DC powered, or battery AC powered, there is always some sort of annual maintenance. It could be batteries that need to be replaced, or solar panels, all the way up to instruments, which would be most costly.

What difficulties would you face while trying to implement this solution?

Usually, for something like a medium-sized drainage, an array is four or more sensors spatially separated. They would have to be 20-30m apart. So, you would need an area that is 100m by 100m at least, maybe more. Ideally, it would be relatively flat, not right next to the drainage. But close enough that if a flow was coming from the drainage, you would be able to track the front of a flow, or the "snout," where the brunt of the infrasonic is coming from, and the array is tracking it as it moves down stream. The area of the Andes is not a huge issue, you would just need a

relatively flat area, not a huge drop like one sensor below a cliff. The algorithm assumes that all the sensors are on the same plane. You can add a “z” component though, if necessary.

To what extent would it affect the inhabitants of the area?

To your knowledge, how would authorities react in trying to implement this technology?

It probably depends on how the local people would feel about the technology. It is fundamentally a microphone; it records in a fairly wide band. All the signals we are interested in is fairly low frequency, so it captures below what we can hear. I think sometimes, I work overseas, I have helped deploy these infrasound arrays at volcanoes in other countries to help them with volcano monitoring. It has never been an issue, but there is always working with local scientists, and explain how the technology works and how the processing works. Basically, like transferring all the knowledge over to them. So, they oversee the maintenance and the data. We also have some codes that they can use but mainly we turn those over to them, and they run those codes. Then they are the ones doing the analysis. You can't just give someone a solution; you have to train them. We have worked a lot in Ecuador, they have a lot of experience, but they haven't don't that much infrasound monitoring. So, they asked us for some of that infrasound monitoring.

What alternative applications does this technology hold?

Oh yeah, there is a whole bunch. Earthquakes make a whole bunch of infrasound. Big landslides, volcanic eruptions, there are a lot of natural processes, some hazardous, some not, bolides coming from the atmosphere.

Are there any other comments you have on this technology?

AFMS are a good complementary technology to the infrasound I was talking about. Having seismic of AFM on the same channel is also a good idea.

Appendix H: Multinational Effort Plans Interview Transcript

What previous work or research have you done in this area, and is there any other qualifications that you can state for the purpose of this interview?

My background includes over two decades of experience in meteorology and climate science, I also focused on international cooperation and capacity-building initiatives. I hold a Ph.D. in Atmospheric Sciences. Previously have been involved in various multinational projects aimed at improving weather forecasting, disaster risk reduction, and climate resilience.

What is the best cost estimate for the solution that you present?

It is not easy to calculate how much these plans will be. ENANDES, the project I have been working on, currently has US\$ 7,400,000 of funding. I'd imagine that other plans would be around that. Especially since a landslide plan is remarkably similar to ENANDES. The main difference I see is that although ENANDES more focuses on the aftermath of climate change and the natural disaster risk it poses in the aftermath. This proposed landslide plan would more act on prevention rather than after.

What difficulties would you face while trying to implement this solution?

As with any multinational plan, there need to be cohesion between entities. With ENANDES, a foreign entity such as Switzerland was used to bring them altogether. You must be ensuring effective coordination and communication among participating countries that each have their own diverse socio-economic, political cultures. Additionally, addressing capacity gaps in terms of technical expertise, infrastructure, and institutional frameworks requires long-term commitment and sustained support from all parties involved. Oh, and also not to mention you

need a good conversation with the peoples themselves. Political sphere and civilian sphere is relatively separate, so you need to make sure you interact with the people as well.

To what extent would it affect the inhabitants of the area?

By leveraging existing networks and partnerships, ENANDES could explore synergies with other initiatives addressing related challenges such as water management, agriculture, and public health. I think this suits the greater public good. Which is also some alternative applications that ENANDES holds.

What alternative applications does this technology hold?

Appendix I: Land Use Regulation Interview Transcript

What previous work or research have you done in this area, and is there any other qualifications that you can state for the purpose of this interview?

Sure. I have a PhD in geographical sciences. Specifically, my research has been focused on assessing land cover and land use change across South America, going back in time a few decades. That is kind of where my area of expertise lies. I have close to a decade of research experience on that topic of looking through satellite imagery to analyze land use change.

What is the best cost estimate for the solution that you present?

It is a difficult question because you are talking about regulation, but at the same time you are saying squatter settlements, and those are usually outside of legal frameworks. It is like the same as saying that you have a law that says you cannot steal; how do we get people to not steal. You already regulate it, but they are breaking the law. But there are both issues present in cities, squatter settlements and lack of land use policies, as well as cities that don't take into account the environmental concerns. Also, there is an issue with people abiding by the law. Although it is a huge investment to make it suitable, it is a very good investment from some perspectives. It is not always a bad investment; it is still good to look into it.

What difficulties would you face while trying to implement this solution?

One major issue that you would be talking about is having the information about it, it is not obvious for many locations where it is okay to build and where it is not okay to build. You would need to take into account the type of soil, precipitation levels, all sorts of things that cities or regulators might not have enough data for the entire area they are looking over. There are a lot of

other priorities in those locations sadly, and the people settling in those locations are again, most likely squatters.

To what extent would it affect the inhabitants of the area?

You would need a full infrastructure of people from the bottom-up and top-down. Having the training at local universities and trade schools would be costly. Just one more thing I would add, they will be exaggerated as cities grow. When a city is first settled, it is usually settled on the most flat and safe land, like a valley. But as cities grow, they will expand into less suitable areas for building and human land use.

To your knowledge, how would authorities react in trying to implement this technology?

We are talking about general terms so there is no fast rule. I am from Bolivia, in the city of La Paz where we have a lot of mountains and there are a lot of landslides with the issues you are talking about. There are certain cases where you are well off, they often don't have the training to look at the land and look at a certain parcel of land to determine if it is good enough to build on.

What alternative applications does this technology hold?

What I do is assess is what are places that are better remaining natural versus converting to land use. I believe that is something that you can get from this solution. Looking at it from a cost benefit analysis, in terms of landslide protection, sometimes it may be suitable but also there could be a species that lives there, so this solution would help address that. It will also teach worthiness of protecting a natural area.

Appendix J: Planting Vegetation Interview Transcript

What previous work or research have you done in this area, and is there any other qualifications that you can state for the purpose of this interview?

My research in this area spans several years, focusing on the role of vegetation in stabilizing slopes and reducing landslide risk. I've conducted field studies and experiments to assess the effectiveness of different plant species in preventing soil erosion and slope failure. My qualifications include a Ph.D. in Environmental Engineering and tenure as a faculty member at the University of Texas at San Antonio, where I specialize in geotechnical and environmental engineering.

What is the best cost estimate for the solution that you present?

The cost of planting vegetation for landslide mitigation can vary depending on factors such as the size of the area to be covered, the type of vegetation selected, and the site-specific conditions. Generally, the expenses would include the cost of plant materials, labor for planting and maintenance, and possibly engineering assessments for slope stability. A detailed cost estimate would require a thorough site evaluation and analysis. Generally, though, I would put estimates to \$12k-\$15k per acre.

What difficulties would you face while trying to implement this solution?

Factors such as soil type, climate, and slope gradient can influence the effectiveness of vegetation in stabilizing slopes. Additionally, securing access to the site for planting and ongoing maintenance efforts could pose logistical challenges. And the Andes is a mountainous area, you can't plant trees everywhere.

To what extent would it affect the inhabitants of the area?

While landslides only kill 25 people a year in the United States, there are definitely more in other places. I think the Andes needs it particularly so including vegetation would be well. The planting of vegetation for landslide mitigation can have positive effects on the inhabitants of the area by reducing the risk of landslides and protecting lives and property. By stabilizing slopes and preventing soil erosion, vegetation can help maintain the integrity of infrastructure, such as roads, buildings, and utilities, thereby enhancing community safety and resilience to natural hazards.

To your knowledge, how would authorities react in trying to implement this technology?

What alternative applications does this technology hold?

Vegetation plays a crucial role in ecosystem restoration, biodiversity conservation, and climate change adaptation. Additionally, green infrastructure solutions, such as vegetated swales and bioretention basins, can help manage stormwater runoff, improve water quality, and enhance urban resilience to flooding and heatwaves.