# Using Remote Sensing Technologies in Relocating Lubra Village and Visualizing Flood Damages

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# Abstract

**Keywords — Flash floods, Lubra Village, remote sensing, 3D modeling, village relocation, cultural preservation, climate change.**

As weather patterns change across the world, there are communities impacted by climate change that are left unnoticed. In the Himalayan mountain range, communities have suffered, experiencing an increase in flash flooding and droughts. For Lubra Village in Lower Mustang, the community faces the threats of flash flooding. Over the last ten years, the amount of flash flooding has increased, occurring more than once each monsoon season. After every flood, concrete-like sediment is left behind, hardening across the riverbed and increasing its elevation. As the riverbed elevation increases, this sediment encroaches on Lubra Village's agricultural fields and ancient mud buildings, making them more vulnerable to flood damages. In the last monsoon season alone, the village has seen the flood swallowing several fields, as well as damaging two homes. In order to keep the community safe, the community themselves have been in discussion of relocating the village entirely to a new and safer location. However, relocating the village is a challenging task, where complex nuances exist in both aspects of civil engineering and communal opinions. To investigate this issue further, we look to conversing with the community to understand their needs and perspective. From them, we will be able to develop a plan that amplifies the voices of Lubra Village. Additionally, we use the power of remote sensing and 3D digital modeling to visualize the village and the new proposed location sites. These models will then be used by the architecture planning and development team to better understand the terrain and layout of the village. From these models, the team will be able to make more informed decisions on how to plan and develop the new village. Finally, we briefly explore other pertinent issues in redirecting the flow of the flood, predicting the new riverbed elevation after the next monsoon season, and further visualizing flood damages through detailed modeling.

# Acknowledgements

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Third, I would like to give a huge shoutout to the Jomsom main district hospital for keeping me alive during week one and week three of my expedition. Altitude sickness in combination with a stomach bug during week one, followed by food poisoning in the third week... Let's just say I am extremely grateful for them.

Then, I would like to thank SIT staff for always being available to answer any logistical questions I had when traveling through Lower Mustang. Furthermore, I would like to express my gratitude in their teachings and support over the last three months. Their approach to experiential teaching has helped shape how I approach this type of work, and is something I will be able to carry to any problem I face.

Next, I would like to thank my co-researcher and dear friend Yungdrung Tsewang Gurung La. Without him, this report would have been nearly impossible to complete. Not only do I want to thank him for the quality of work and attention that he brought to each day spent together, but I want to thank him for watching out for me as I navigated Lubra Village and Lower Mustang. If I needed anything, I could always count on him to be there, a characteristic that I find to be rare in most people. It was an absolute pleasure to work together, and I am beyond ecstatic to continue this work with him over the next few months.

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With that, thank you.

# Contents

# 1 Introduction

As we walked, I could feel the sun glare down on my cap, unable to reach my already peeling face. Stones and loose soil shifted with every step, occasionally succumbing to our weight, sending pebbles down the cliff and dust into the air. We had to be careful, for one misstep would send us tumbling 700 meters into the valley. My eyes remained at my feet to ensure a safe journey down. However, every few minutes, I couldn't help but steal a glance at my surroundings. In the distance west of us, the Dhaulagiri mountain range sat, soaking in sunlight on their white covered faces, greeted by an occasional cloud. Gently pressing us from the south and east, the Annapurna mountain range impassively observed our movement, unable to be disturbed as the warmth of the sun blanketed their peaks. Gratitude and awe filled my body at the restful giants, and I thanked them for sharing their beauty with me.

The further we trekked from Muktinath, the more my co-researcher Yungdrung Tsewang Gurung told me about his village, Lubra. Considered to be one of the few fully Bön practicing villages in Nepal, Lubra Village nurtures over 800 years of cultural and ancestral significance. Originally established in the 12th century, it is believed that after Lama Tashi Gyaltsen came from Tibet through Dolpo, making the area suitable for settlement after subduing the land's unruly local spirits. Furthermore, he determined that if a planted walnut tree would grow, then he knew that the Bön religion would survive here. And soon after

Figure 1: Lubra Village (April, 2022).

the tree's flourishing, so began the lifeline of Lubra where the tree still exists today. [4] As for its name, Lubra refers to the uniquely snake-line textured cliffs across from the main village. In the Mustangi dialect of central Tibetan language, 'lu' means serpentine naga spirits, and 'brak' means rock cliffs, forming the meaning 'snake valley', or Lubra. [4]

Sitting at an altitude of approximately 2,950 meters, the current day village and its 56 active inhabitants rely heavily on agriculture to survive. [5] Each of the families are individually farmers with their own allotted land, while also carrying the responsibility of communal jobs, involving one member from each family. [13] Only a handful of mud buildings and guesthouses—the majority of the village—and its adjacent crop fields reside on the edge of the Panda Khola River. A school, two monasteries, several stupas, a children's hostel, and water tanks span the rest of the land. [5] As I began to imagine the full picture of Lubra Village, we surmounted the final hilltop, and there five kilometers in the distance, Lubra Village sat on the valley slope at the feet of its neighboring and towering cliff sides.

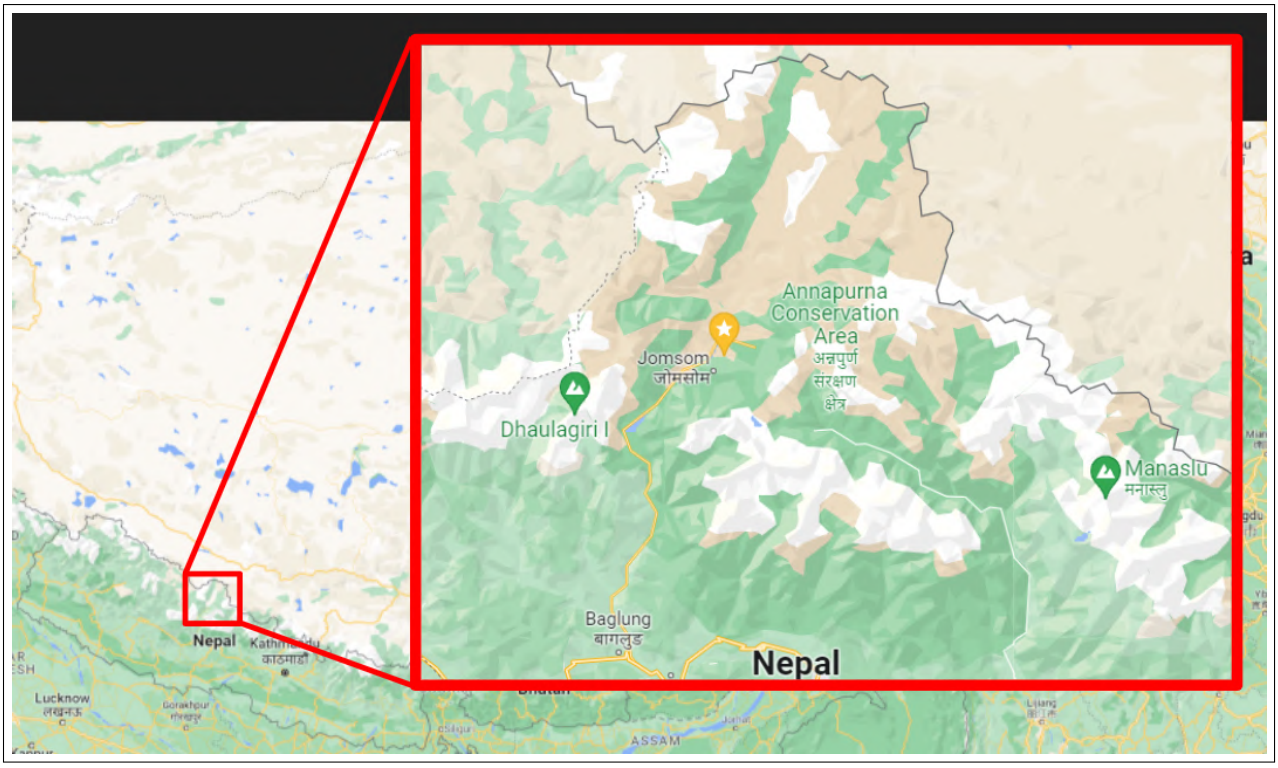


Figure 2: Location of Lubra Village.

# 2 Flash Flooding

Making our descent into the valley, Yungdrung La[i] expressed concern and worry for his village. Every year between mid-June to mid-September, the entire valley faces flash flooding disasters. What is normally the three to five meter wide Panda Khola River turns into a creeping 150 meter wide flood. During these monsoon seasons, water flows through the valley to meet with the Kali Gandaki River, carrying all types of sediment and stone with it. The increase of water turns this valley into a concrete mixer, as the sediment-stone-water mixture turns into a type of viscous sludge (see figure 3). As this sludge collects high in the valley, water may not be able to find passage, causing this muddy water to build. Eventually, the sludge gives way, bringing down a rush of aqueous concrete. These flood bursts repeat without fail over two months. These flash floods span the entire riverbed, and swallow any obstacle in its path (see figure 4). [4, 5]

Increasing floods are thanks to no other than climate change. Increasing global temperatures has been altering the water cycle across all regions in the Himalayas, and its impacts can be directly seen in Lubra Village. [4] Because of the Dhaulagiri mountain range, the region of Mustang has sat dry for the longest time in the barrier's rain shadow[ii]. However, rain patterns are changing, and what used to be light rain has turned to destructive, pouring showers just over the last six to seven years. [10, 11, 13] Furthermore, glacial runoff has been increasing over the last five years. [4] With a growing increase of water flowing through Lubra valley, the village has been facing more and more flash floods each year.

Other indicators of changing weather patterns are seen through the perspective of locals. As Yungdrung La and I reached the Panda Khola riverbed, he motioned to Mt. Nilgiri, hiding behind the ridge to our left. "I used to see ice on Nilgiri, but now the peak is naked." [8] Seeing no snow and ice scares long-lived members of the village, where they have the experience to distinguish how weather patterns were 50 years ago to now. No snowfall means old glacial snow is unable to remain compact, leading to quicker and easier melting. Although snow patterns have not been easily determined, locals are confident that snowfall is decreasing. [9, 13]

As well as changes in snowfall, increased temperatures have been seen in the south of Marpha, a village known for its apple production. Increasing temperatures have forced farmers to stop planting apples because the crop will not survive. Furthermore, this increase in temperature lures mosquitoes to lay and hatch, causing an increase of mosquitoes during the peak monsoon season in Jomsom. [13]

[i] An honorific and respectful term when addressing someone in Tibetan.
[ii] A region of reduced rainfall due to a topographical guard such as a mountain range [15]

Figure 3: Sludge-like mixture of sediment, stone, and water. [2]

Figure 4: Flash flooding spanning the entire riverbed adjacent to Lubra Village. [2]

## 2.1 Flood Damages

For Lubra Village, this is a fatal disaster. Located on the edge of the Panda Khola River bank, families are sitting ducks, vulnerable to the destruction of these flash floods. For decades, floods have occurred in the valley once every three to five years, and the village lived safely. However, over the last eight to ten years, one or more flash floods have occurred each year. When a monsoon season concludes, newly brought sediment sets and hardens like concrete at the foot of the village, increasing the height of the riverbed. As the riverbed encroaches on the village, Lubra is more susceptible to damage. Over the last decade alone, the riverbed has increased an astounding 12 meters in elevation, having already destroyed several fields of crops (see figure 5). [5]

Figure 5: Fields destroyed by flooding from the last monsoon season in 2021.

As a direct consequence of climate change, the surge in flash floods is eating away at the village at a quicker rate (see figure 6). Last season, the monsoon began around June 14th, lasting for over two months. [10] Here, the first houses were damaged, leaving two families to take shelter in another family's guest house for three months. Jzikmey, a 25 year old local of Lubra, suffered with his family as his home felt the rush of the flood, filling the lower most room with wet sediment. Having lived his entire life in Lubra, he felt pain for his family and home, but resided with not being able to do much about it. "It is what it is," he expressed with sadness. "If the next monsoon is like the last one, the rest of my house will be gone." [14]

Because the majority of buildings are stacked upon each other going up the valley slope, the main village stands as one entire building. Each building depends on one another for structural and foundational strength. Because of the village's architecture, however, damage to one home immediately threatens the structural integrity of the entire village, threatening the safety and security of several families and their homes. The next two monsoon seasons alone could leave several families without homes of their own. Jzikmey looked on, "In ten years, if the monsoons continue as they do, the entire village will be gone." [14]

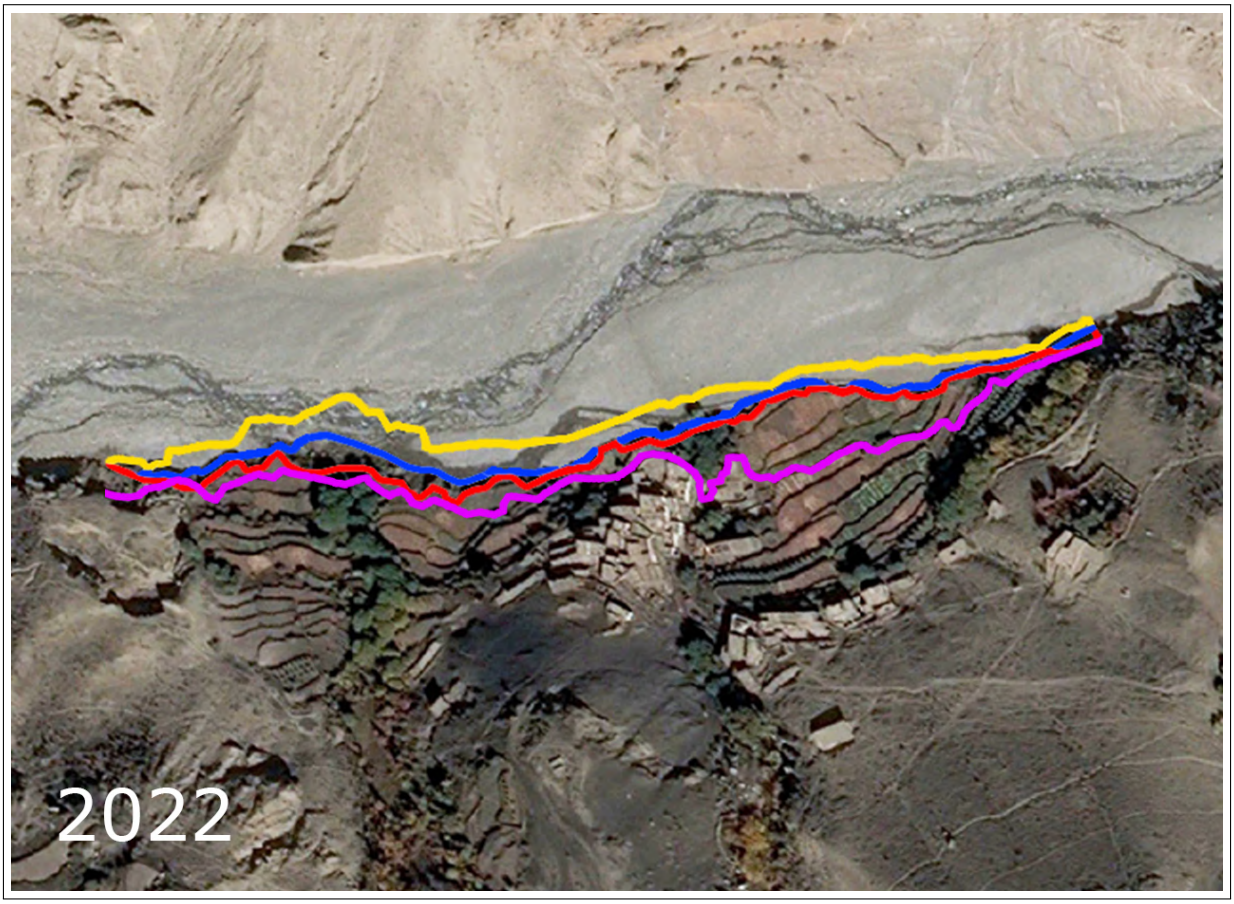


Figure 6: Land changes recorded during the 1950s (yellow line), 2002 (blue line), 2018 (red line), and 2022 (purple line). [1]

With increased flooding and rainfall, traditional mud homes are having more trouble in both the winter and monsoon season. In the last three years, original mud roofs leak more and more due to rain damage, creating additional fear in the community. Mud fences and walls continue to wear away from monsoons of increasing intensity. [13] Additionally, roads have been entirely wiped out. For example, before the last monsoon of 2021, a road was built from the Kali Gandaki River across the riverbed to reach Lubra Village. With a budget of 30 lakh[iii], road construction finished after three months of work. Only two months later, the entire road and everything that was put into it was completely destroyed by the following monsoon season. [5] Along with roads and residential homes, the community's livelihood is further threatened as flooding consumes agricultural fields, rendering them unusable. And if all of that wasn't bad enough, a 70 year old chorten[iv] of significant religious importance once standing 25 meters tall, finds itself submerged in concrete, destined to fossilize in the debris (see figure 7).

[iii] 1 lakh is 100,000 Nepalese Rupees, and is approximately equivalent to 800 US dollars. In US dollars, a budget of 30 lakh is approximately $24,000.

[iv] Tibetan for stupa.

Figure 7: An image of the chorten that once stood at the front entrance of Lubra Village. The base is covered in flood sediment (2015).

As their spiritual livelihood faces the consequences of flooding, the Lubra community connect these damages with their spiritual beliefs. Some members believe that the floods and consequences from climate change are due to disturbed spirits, and rely on traditional knowledge over scientific data and conclusions. For example, for a good supply of water, ritual is performed near the primary water source or the home of a spirit related to the water source.[12] When examining this issue, it is crucial to understand how all members of the community feel and try to understand what they believe, as spirituality and religious belief is integral in creating solutions that work best with the community's needs. We will discuss this further in a later section.

The damage done in recent years shows that the riverbed will continue to rise, and the need for a solution is evident and imperative. As flash floods threaten livelihoods of the community, increasing damage threatens the security of culture and traditions as well. Decades of culturally significant land are being wiped out, and Yungdrung La fears that his ancestral culture and traditions will go with it.[5]

## 2.2 Culture Under Threat

Cultural and traditional ways of living remain in Lubra as one of the only few fully Bön[v] practicing villages in Nepal. Although there are other Bön monasteries in Lower Mustang, none compare to the authenticity of how the village is traditionally and religiously maintained. [4] With that, Yungdrung La worries of its survivability in a cultural revolution, followed closely by varying social changes. In search for a more prosperous life along with reputation in their village, younger generations migrate out of Lubra Village at a young age, leaving their community and elders behind. Spending most of their youth in a culturally foreign city or country, these children learn the ways of other cultures, and rarely do these children return to their village in adulthood to settle down. For those that do, they are subject to relearning culture and traditions.[3] Because of this, there is not much left in Lubra Village to sustain these culturally significant traditions, and if the village is destroyed without any attempt of saving its significance, a lot of the tradition embedded in the land may be lost. This makes preservation of the village and its traditions imperative. In order to do so, Yungdrung and his community have begun pinpointing problems of utmost priority to solve. [5]

Reaching the main village, Yungdrung La and I explored these problems over black tea and a full plate of dal bhat[vi]. With time and thoughtful conversation, we concluded that there were four problems that we can work towards. First, in terms of the main village, we discussed plans and development of moving the entire village to a new location. Second, to slow down the damage of flooding, we looked to past initiatives of redirecting the flood, and how current methods can be improved. Third, to understand the flood further, we discussed analyzing flood patterns to predict how the riverbed will increase in elevation after the next monsoon. And finally, using technology to digitally visualize flood damages. In this paper, we will dissect relocating the village in terms of planning, development, and community opinion. For the other three problems, I will touch briefly on them in future research, and can be used as the stepping point for continuing this work. In order to investigate these issues further, we look to remote sensing technologies to gain a deeper understanding of the problem space.

[v] Pre-buddhist Tibetan belief system.

[vi] A traditional Nepalese meal consisting of rice, lentils, and other vegetables.

# 3 Research Methods

Traditionally, when we think of fieldwork, we think of interviews and in-situ observations. All of your senses activate to experience and observe your surroundings, touching, smelling, tasting, seeing, and hearing what is right in front of you. But what do you do when the area you wish to observe cannot be traditionally explored? For example, a relic is too delicate to touch, only a few photos suffice as an observation. Or, in order to observe traditional architecture, one needs an aerial view that doesn't exist to human reach. With these limitations, a lot of information can be lost when sharing our experiences and findings. And, in regards to flooding in Lubra, some believe that the village will be wiped out in 10 years max. This makes time limited, and makes the situation imperative to find a solution to help us better understand the problem for making informed plans and decisions. With an increase in innovative technologies, we can utilize the power of remote sensing technologies as the solution to observe the unobservable quickly and efficiently.

## 3.1 Data Collection

Remote sensing is the acquisition of information about an object or phenomenon without making physical contact with the object, in contrast to in situ or on-site observation. [16] A plethora of different technologies and sensors exist to observe objects without touching them. However, to explore the problems laid out above, only a drone, a phone, satellite, a GPS-tracking watch, and open-source image collections from the internet will be all we need[vii].

With these technologies, our goal is to create 3D digital models and detailed 2D maps that will allow us to explore and observe areas of interest (AOI) across Lubra Village without having to be there in person. If we have a detailed 3D digital model of an AOI along with 2D maps, we can share it with our research collaborators, allowing them to make informed decisions and plans without having to be at the site in person. These 3D models are needed for the information and insight they provide. [6]

### 3.1.1 3D Digital Modeling

To create these models, a collection of aerial images are needed of each location. To accomplish this, I flew a drone 50 to 100 meters above every AOI, capturing 4K aerial images. To ensure safe flights, flying had to be done in the morning to avoid intense winds that occur past eleven o'clock in the morning. Furthermore, these flights have to occur between eight and eleven o'clock in the morning where sunlight is optimal and the same because there needs

[vii] Important note: both the drone and phone must be capable of capturing high resolution imagery (anywhere between 1920x1080 to 4096x2160 resolution would work, where higher is better).

to be even lighting across all images used. Over the span of seven morning flights, I collected over 500 aerial images.

However, on my eighth flight, the drone malfunctioned and flew directly into the Panda Khola cliff side at speed. When recovered, the drone was inoperable with three broken arms, a missing camera, and destroyed battery. Because of this, I had to resort to just using my phone camera for creating the rest of the models. To do this, I hiked along the entire Panda Khola cliffside edge, taking photos with a combination of my phone and binoculars[viii]. Furthermore, to increase my collection of images, I requested Yungdrung La to find all images of Lubra Village over the last 20 years. These photos will be used specifically in analyzing and understanding how the riverbed elevation has changed, along with the damage it has caused.

With these collections of images, we use Agisoft Metashape[ix] to process sets of images according to the AOI we are trying to represent. Through the process of photogrammetry[x], I am able to generate and craft a point cloud[xi] into a highly realistic, 3D digital representation of the area of interest, and share them with our research team. These final 3D models will be presented in its related section throughout the rest of the paper.

### 3.1.2 2D GPS Mapping

To create detailed 2D maps, I used a combination of satellite imagery and GPS tracking data. During my time in Lubra Village, I made an effort to walk every main path to build a map of the village's trail infrastructure. Additionally, I walked the riverbed edge of the village to map the extent of current damage. These maps will be presented in its related section throughout the rest of the paper. Lastly, the use of satellite imagery will be used to improve riverbed elevation analysis and predictions, and will be discussed in detail in its related section.

### 3.1.3 Oral Interviews

One of the last methods in this project was interviews. Having conducted 12 interviews, I believe that I was able to conceptualize the issues Lubra Village is facing. However, there are still many nuances and intricacies that are still left untouched, and need to be explored further. For now, we can begin by looking at relocating Lubra Village, and what that means to the community that lives there.

[viii] I do not recommend or condone anyone from doing this, for this method is too dangerous and can lead to death without proper training.

[ix] Professional 3D modeling software used for processing images into usable models for visualization.

[x] Technique of measuring objects through photographs.

[xi] A set of data points in space that represent a 3D shape or object.

# 4 Relocating Lubra Village

Relocating the main village of Lubra is no easy task, and several factors must be considered when making any plans and decisions. We must understand how the village is structured, along with how the community interacts with the land they call home. Trying to understand these nuances through the community's perspective is imperative. At the end of the day, it's their village, not ours, so we must plan and design closely through the voices of Lubra, not ours. When it comes to relocating, the community has identified four locations to consider. We will call these locations A, B, C, and D, and will be discussed in depth in a moment. The goal of visualizing and understanding each location is to help village planners in designing a village that best suits the community.

## 4.1 3D and 2D Surveying and Mapping

To understand these locations, we can survey the village, its surrounding land, and the new locations themselves through creating 3D digital models and 2D maps from the collected imagery data. These 3D models can be used by the architect and development team when planning the new village. For example, I was able to scan the entire valley side as to allow the team to gain an understanding of land features and visualize how the main village is situated in the valley (see figure 8). See Appendix A (figures 15, 16) to view the entire 3D model of the valley. When faced with the problem of relocating, there is a need for understanding how these areas are connected. With these models, we can visually understand the village's current state, along with seeing how each location would fit in the new village infrastructure. Furthermore, using the collected GPS-tracking data, we can visualize the trail infrastructure to understand how locals navigate their community from area to area (see figure 9).

## 4.2 Choosing a Location

As we can see from the figures above, each location is different in size and distance from the main village. Within each location, land is distributed equally among the 14 families. These lands are distributed into 14 plots by the heads of the community to be used for either resettlement or development. Each family's plot is usually 15 by 15 meters in space. One issue with this, however, is the lack of official certificates issued by the government. [8] This can create a lot of issues in land security and sway opinions in relocating, which we will dissect further in a moment.

Along with differences in size and distance, there are several other factors to consider when determining which location to use for relocating the main village. These factors include but

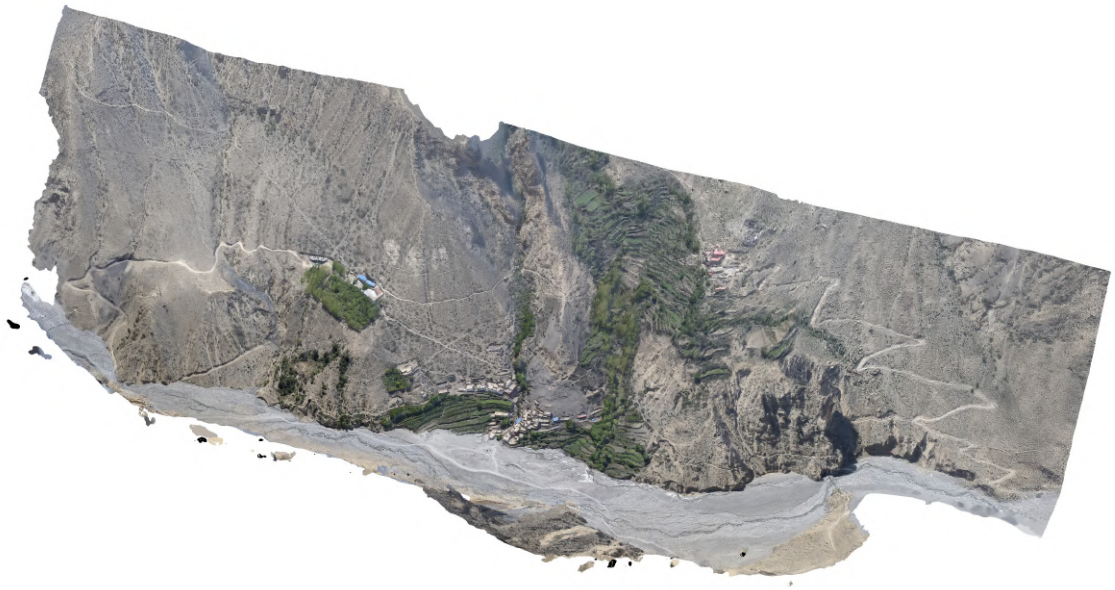

Figure 8: Lubra Village on the Valley Side: An angled perspective of the 3D digital model representing the valley side.

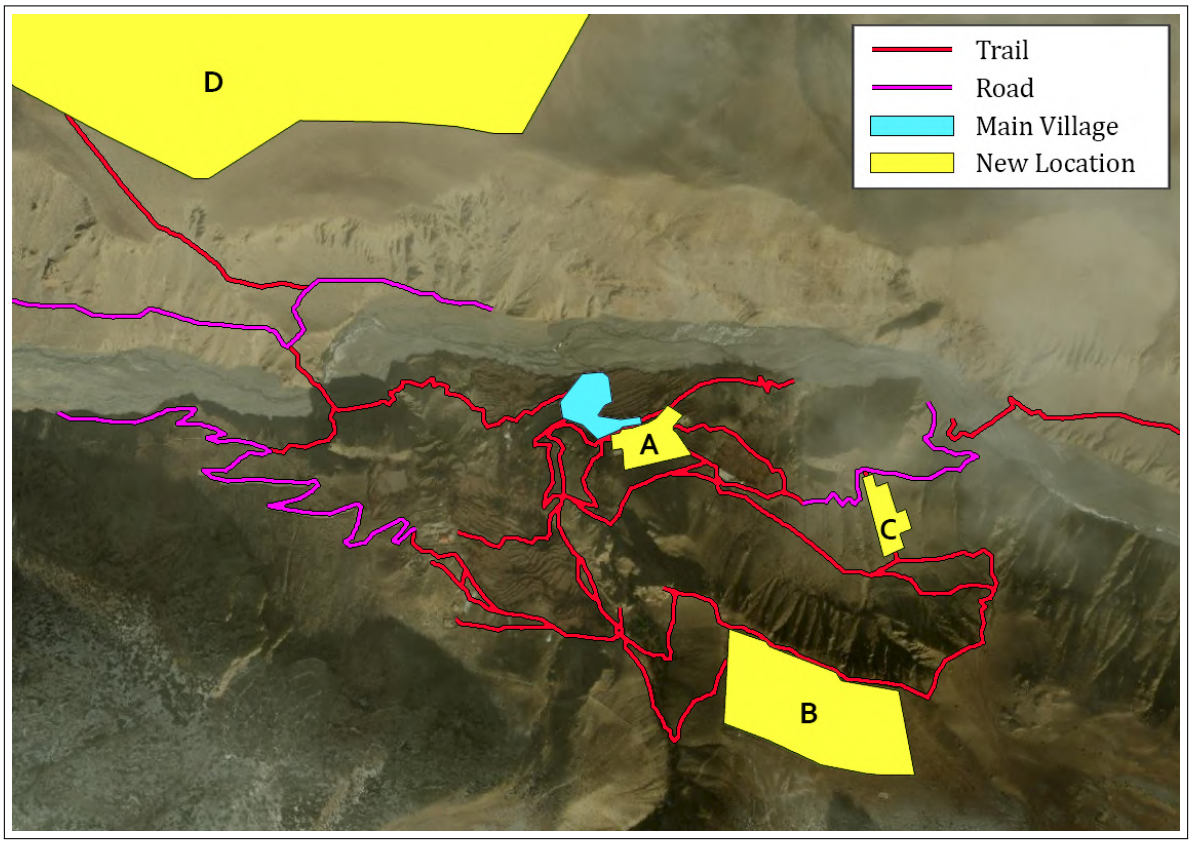


Figure 9: A map representing the trail infrastructure of Lubra Village, as well as the new proposed locations for relocation (A, B, C, and D).

are not limited to: soil strength and integrity, access to utilities (water, electricity, roads, agricultural land), closeness to the main village and monasteries, access to materials, trail infrastructure, and spiritual beliefs. All of these factors need to be considered carefully of one location, and diligently compared to one another. To understand how these factors interact with each other, and how locations are chosen, let's take a look at the children's hostel as an example.

When Lama Yangton Tashi Gyaltsen founded Lubra, he meditated in caves on top of one of the western hills. This was deemed as a sacred place of Lubra, and a monastery was built here to protect the caves. Now looking back only 20 years ago, a children's hostel was built on the west side of the village, around half a kilometer from the main village. It was originally built here because it was adjacent to the Gonpuk[xii] Monastery, increasing the quality of learning of the Bön religion, an integral part of the children's studies here. This location was chosen for its wide space and nearness to the monastery, along with its flatness. However, the top soil here is fine, and is easily dusted when kicked. This makes the foundation for buildings weak and loose, and has already caused issues. When the children first moved in, some of the building collapsed due to the shifting soil underneath, forcing students to take shelter elsewhere for well over a year. Another possible site that was considered was next to the newly built school on the eastern side of the village. This was decided against, however, because it was near the ceremonial burning ground and wasn't seen as safe to have children around. [13]

From this example, we can notice how both cultural and geophysical factors intertwine in deciding which location is most suitable to use, showing the importance of identifying all factors of a location that may influence the community's decision. With the four identified locations, we can break them down by these factors, and evaluate their pros and cons. [5]

### 4.2.1 Location A

Location A is directly adjacent east to the main village, only a stone's throw away. Here, buildings would be built vertically up and along the slope, and would seem almost like an addition to the main village. As mentioned before, the land here is distributed equally among the 14 families, each having their own 15 by 15 meter plot of land. The soil here is hard and compact, and works as a strong foundation to build on. [13] Here, Yungdrung La has already begun building the foundation of his new home. This is an optimal location for its proximity to the original village as well as the Yungdrung Phuntsok Ling monastery. However, it is still very close to the oncoming flash floods, and remains vulnerable to future damage (see figure 10). [5] See Appendix A (figures 17-19) to view the entire 3D model of location A.

[xii] Tibetan for cave

Figure 10: Location A: An aerial view of the 3D digital model representing location A.

### 4.2.2 Location B

Location B lies south and high above the village. To get there, one has to hike a 300 meter increase in elevation across one kilometer, lasting around an average 30 minutes upward. Here, a walled-off apple orchard exists on a very slight slope. Spanning approximately 66 square kilometers, the orchard is mostly flat, and has access to water piped directly from glacial runoff. About two-thirds of the orchard has apple trees and is individually sectioned out to families of the village, while the other third is communal land. The area seems like a good location in terms of space, water, and agricultural land, however, access to the land is more difficult. There has been talk, however, of a road being developed from the east side of the village near the new school. [8] The issue with this, however, is the risk of damaging soil integrity, as the increase of road development weakens the soil around it. Additionally, this location is the second farthest area from the main village (see figure 11). [5] See Appendix A (figures 20-22) to view the entire 3D model of location B.

### 4.2.3 Location C

Location C sits just under a kilometer east of the main village. Here, the terrain is slightly hilly, but is still relatively close to the main village. To get here, one only has to walk one kilometer with little elevation gain. Currently, it is staked with wooden markers to show the boundaries of the distributed land. [8] The area is quite open, and has direct road access, which is a huge plus. One problem, however, is that this location is adjacent to land that is used as ceremonial burning grounds for the dead. Because of this, some community members

feel uncomfortable moving here because of spirits that may reside there (see figure 12). [5] See Appendix A (figures 23-25) to view the entire 3D model of location C.

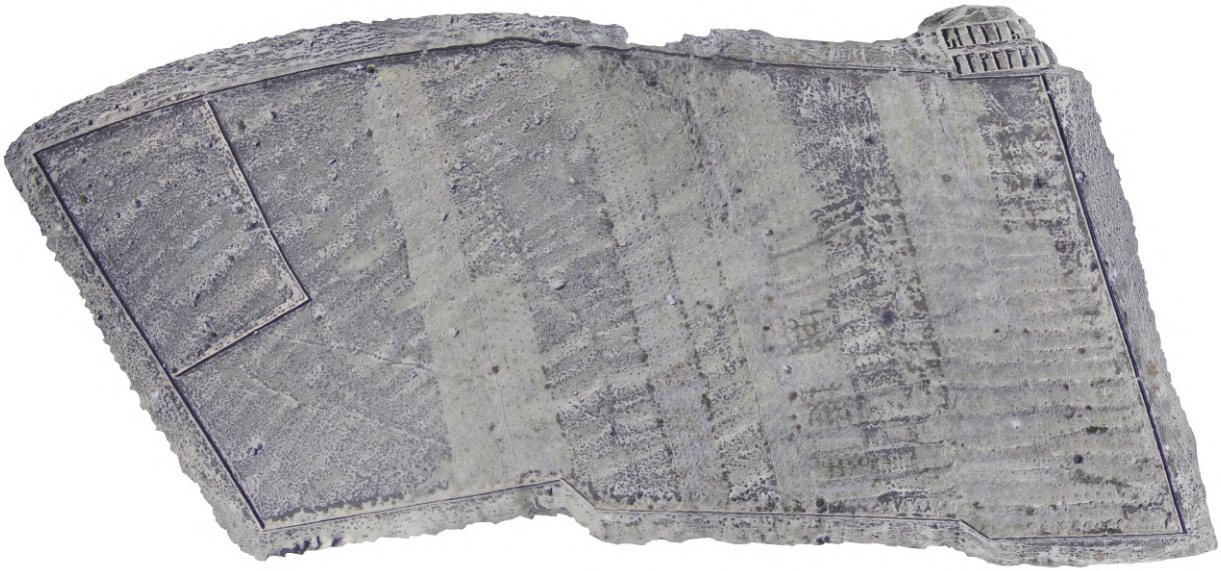

Figure 11: Location B: An aerial view of the 3D digital model representing location B.

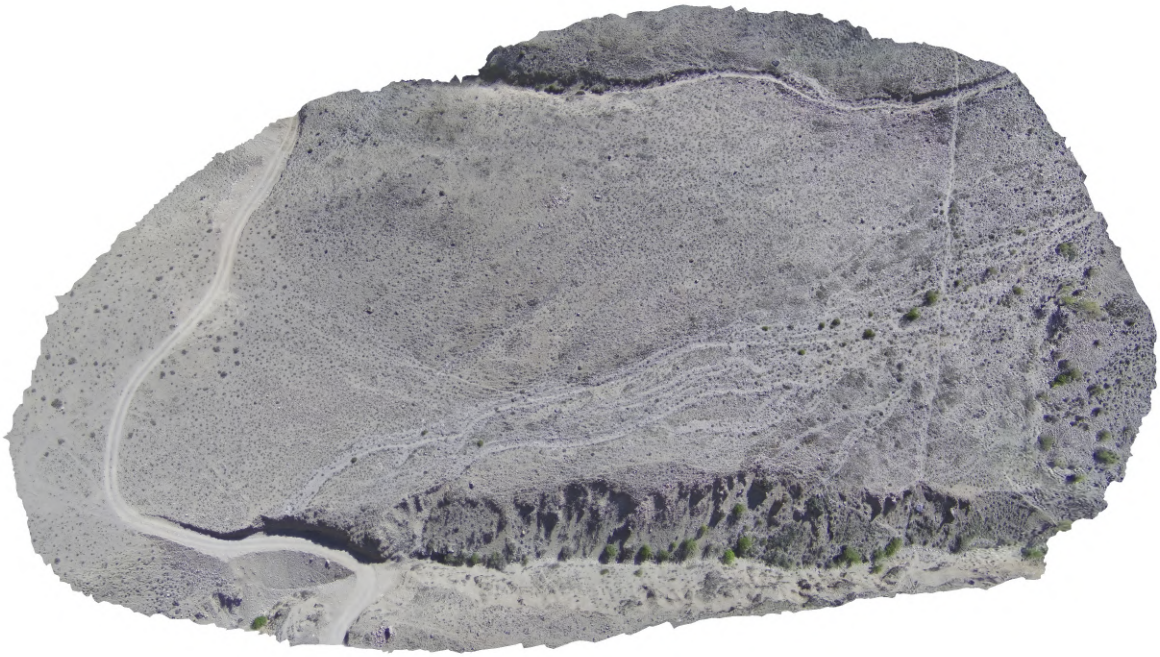

Figure 12: Location C: An aerial view of the 3D digital model representing location C.

### 4.2.4 Location D

Location D, the furthest from the village, towers the main village on the other side of the river. Here, there is a large amount of relatively vast and flat land. However, there is controversy over the plot, as there is no mutual agreement between Lubra Village and Kagbeni Village on who it belongs to. Because of this, building here at this moment in time is too controversial. Furthermore, utilities here are scarce, and the location is extremely distant from the main village. [5] For this location, a large budget is required to develop the land, including water access and road development. [14]

## 4.3 Community Opinions

### 4.3.1 Location Choice

As we can see, each location has its pros and cons, each differing in which location would be most suitable. To choose a final location, however, all families must be in agreement of which location is best to move to. [8] However, with each family having their own opinions, complete agreement is extremely difficult to achieve, especially in a short amount of time. For example, Jzikmey believes that location A is better suited, for he finds importance in staying near the Yungdrung Phuntsok Ling monastery. Staying close makes it easier to care for the monastery from this location. Furthermore, location A does not require any new road development. [14] Other families, however, believe that location D is the better suited choice for its vast space. [8]

### 4.3.2 Building Design

Along with which location is the right choice, I explored how the community wants to build on that chosen land. Specifically, I looked at the community's opinions on what style of buildings should be built. Everyone I interviewed mostly had the same opinion of wanting traditional mud homes to be built. These mud buildings are built with combined techniques of stacked stones for the foundation, rammed earth[xiii] for the walls, and then topped with earthen roofs. [4] Because Yungdrung La's new home was being constructed, I was able to create a 3D digital model representing his home in the early stages of construction (see figure 13). See Appendix A (figures 26-28) to view the entire 3D model of the construction of Yungdrung La's home.

[xiii] A combination of small gravel and mud that is rammed with a wooden post to create a compact and withstanding structure.

Figure 13: Yungdrung La's Home: An aerial view of the 3D digital model representing Yungdrung La's home.

For decoration, locals will paint the outside with red and white color, along with storing firewood on the top edge of their flat roofs. [4] One of the important reasons nowadays for maintaining this traditional style in the new village is because it will continue to attract tourists. Tourists want to see these traditional homes, and will bring more money into the community to see them. [14] One issue with maintaining full traditional homes is the issue of leaking from damaged roofs. Due to increasing rain and monsoons, how these buildings are roofed needs to be considered and improved.

When looking at roofing, there are three options, current traditional mud roofs, tins roofs, and modern concrete roofs. As mentioned, mud roofs are becoming more difficult to maintain in changing weather patterns. Ten years ago, some locals started adding plastic in the roof between the grass insulation and mud itself, but it can still be difficult to maintain. [13] Looking at alternatives, a tin roof may seem like the easiest and most logical choice. However, it's a controversial one. Although rain proof, a tin roof can be ripped off during severe wind storms. For example, the structure on the hill above the main village was built with a tin roof around 12 to 15 years ago to serve as a new community meeting hall. However, five to seven years ago, the tin roof of the community hall was torn off by a severe wind storm. Due to lack of money, the community could not afford to repair it and the remaining structure has been left unusable since. Another problem with tin roofing is that if it is torn off, then it may hurl into other homes, damaging them and putting others lives in danger. [9] One proposed solution is to maintain traditional mud building but incorporate modern design in the roof using concrete. [13] One problem with this, however, is that mud buildings are a lot more effective at retaining heat than concrete buildings (especially important during winters), so there may be significant heat loss through the concrete roof. [13, 14]

### 4.3.3 Relocation Reluctance

Even if the community agrees on where to move, village communities are generally reluctant to relocate, regardless of the circumstances. For example, because of the earthquake of 2015 in Nepal, a village in Tsum Valley was damaged, leaving the community in need of support. After a new village was constructed above the damaged one, some of the community members refused to move and continued to live in the damaged village. A similar situation is occurring in Lubra Village. Regardless of the threat of their village and homes being entirely wiped out, some may prefer to live with the disaster until they die with their village than relocate. [6] This is a huge problem, because if community members choose this mindset, then the loss of ancestral homes won't be the only problem. Not only will the home be lost, but those who carry the knowledge to revive dying traditions will die with it, wiping Lubra Village from existence entirely. No one will be alive to carry on the ancestral culture of Lubra Village.

Another issue that makes locals reluctant to relocate is land security. Although the village has individually allotted land to each family, the lack of government-issued certificates and recognition leaves families in fear. Having no certificate means that no matter how much they claim a plot of land, the government can come and remove them, invalidating land claims entirely. [6] Having guaranteed certifications of land ownership could sway opinions on relocating the village. Other issues include the complexities of planning transportation, logistics, and labor to construct a new village. [6] Additionally, some locals worry that any development could negatively disturb spirits. [12]

# 5 Conclusion

Looking at relocating Lubra Village, we can see that there are several layers involved, each overlapping with one another in their own unique way. Everything is intertwined through hundreds of years of ancestral and cultural heritage. In terms of digital visualization, we can see the effectiveness of this method, and through highly detailed models, understand the power of this method and how it can be used in understanding the community from a structural view. To make informed decisions on where and how to relocate, we can use a combination of remote sensing for digital visualization, coupled with in-person interviews and observations to understand the complexities of Lubra Village. Through these interviews, we are able to gain a deeper understanding of perspective in the community that will amplify their voices in the planning and development of a new village. Our work is guided by their needs, and cannot be done any other way.

# 6 Future Research

For this work, there is still a lot to be done. During my time in Lubra Village, I spent a lot of time thinking about the problem the community of Lubra is facing, and how technology can be used to assist. With the four identified problems, we explored relocation and what that means to the community. However, there are three other big problems that still need to be worked on. These problems include flood redirection, riverbed elevation predictions, and visualizing flood damages. We will dig briefly into each as to set up others to understand these issues and continue this work with ease.

## 6.1 Redirecting the Flood

As well as relocating the village, there is a continuing initiative to redirect the flood through man-made intervention. For example, for the last 20 years, gabion wire boxes[xiv] have been built as barriers against flooding (see figure 14). [7, 13] However, these barriers have not always been effective. As an alternative, the community has been experimenting with digging a trench to control the flow of the flood. [7] Both of these solutions have their own pros and cons, as well as accompanying community opinions on which solution is best. For future work, these issues need to be explored more in depth, for there are significant factors including budget, timeline, and labor to install the best solution. Furthermore, we can tackle this issue from an engineering standpoint by exploring the quantification of flood volume to calculate the exact dimensions of the to-be-built trench.

## 6.2 Predicting Riverbed Elevation

To understand flooding further, we can look at how the elevation of the riverbed has changed over the last 20 years. With this information, we can see a trend in how the elevation is changing, and use this information to predict where the elevation will be after the next monsoon. This will give insight on which homes will be affected next by the floods, and how much agricultural land will be left for farming. One issue with this, however, is a lack of data. There is currently no formal dataset that provides elevation changes of our area of interest. Because of this, we can look to satellite data over the last 20 years to compile these changes. This can be done by taking satellite imagery and using it to create a digital elevation model (DEM) of the riverbed every year. From this, we can analyze if there is a trend in increasing elevation, and what that looks like for the future.

[xiv] A cage, cylinder or box filled with rocks, concrete, or sometimes sand and soil.

Figure 14: Current method: Building gabion box stone barriers to control flood flow.

## 6.3 Visualizing Flood Damages

When it comes to visualizing flood damages, I would say that this is one of the most important issues to work on. Currently, there is a lack of data and lack of visuals in representing the floods that occur in Lubra. Because of this, not many people know about the flooding, and those that do, react briefly then forget about the issue a month later after the monsoon. [9] Furthermore, Mustang locals and trekkers are skeptical of the Panda Khola River being dangerous in terms of flooding. These conclusions are made, however, when the river is visually small and tame. These people don't actually see how catastrophic it can be. Additionally, other villages are skeptical because they experience climate change in terms of drought, not flooding, so they do not believe that there is damage occurring from excess water. [10]

With that, it is imperative to develop a way to visualize flooding and the damages it is causing. After acquiring the riverbed elevation prediction, we can get a general idea of where the elevation will be after the next monsoon season and beyond. We can then visualize this using a 3D model of the village to demonstrate where the new elevation will be, and show how imperative it is to act now. These visualizations can be further used in proposal development for acquiring funding, which can be used directly in efforts to relocate the village and redirect the floods.

# 7 Moving Forward

Over the next several months, I will continue to work on this project for my honors thesis, including returning to Lubra Village to acquire more aerial imagery of the riverbed and the main village. This data will be crucial in visualizing the current state of the village and the riverbed itself. Additionally, this is a great method to digitally preserve what's left of Lubra Village before it is wiped out entirely by flooding. Furthermore, I will be leading a team of software engineers and data analysts to tackle these issues from an engineering perspective. If any of this work seems of interest, if you have any critiques/suggestions, or you would like an update on the current state of the project, please feel free to reach out to me at **rwallace@macalester.edu** or **ronanlwallace@gmail.com** anytime, and I would be happy to connect.

# Appendix A: 3D Models

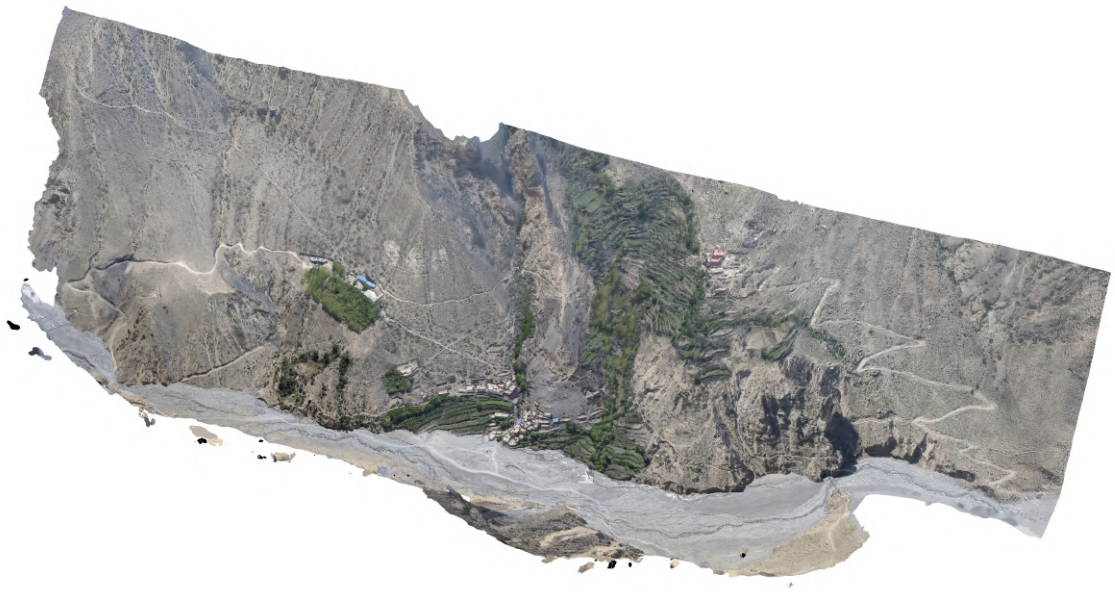

Figure 15: Lubra Village on the Valley Side: An angled perspective of the 3D digital model representing the valley side.

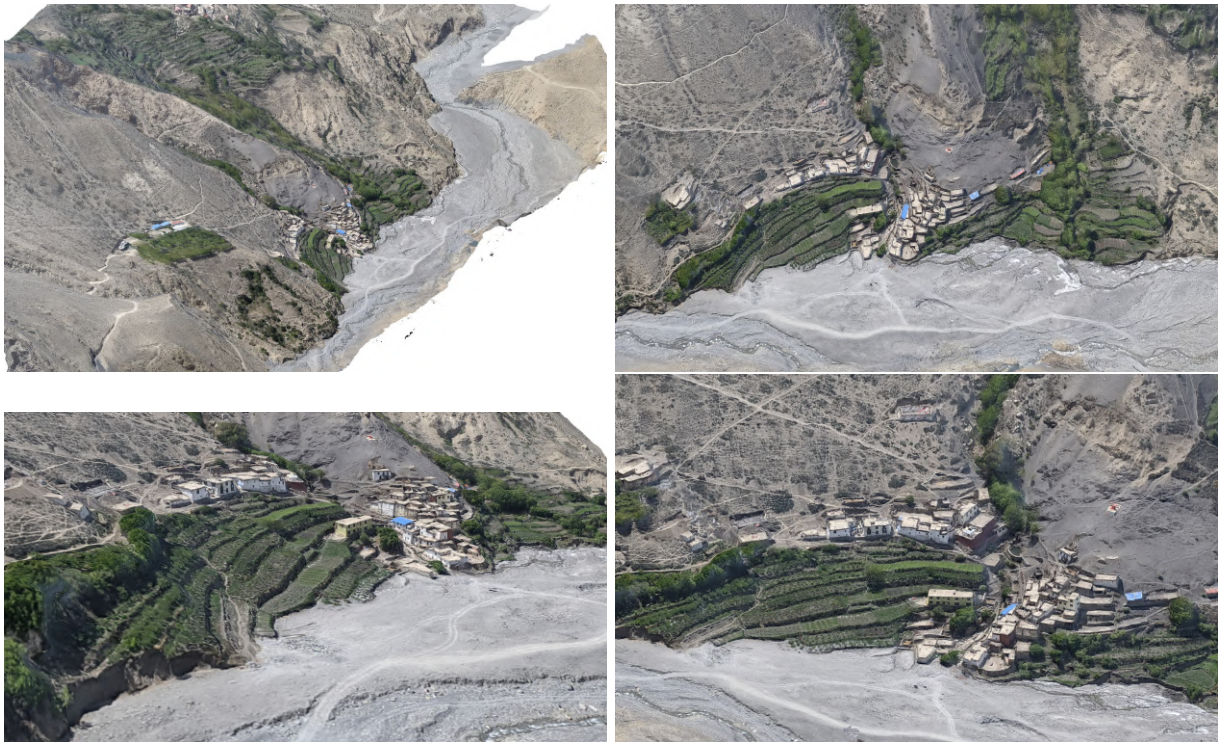

Figure 16: Lubra Village on the Valley Side: Varying angled perspectives of the 3D digital model representing the valley side.

Figure 17: Location A: An aerial view of the 3D digital model representing location A.

Figure 18: Location A: An angled perspective from each corner of the 3D digital model representing location A.

Figure 19: Location A: A zoomed-in perspective of the 3D digital model representing location A, specifically around the house under construction. The detail of this model can be seen here.

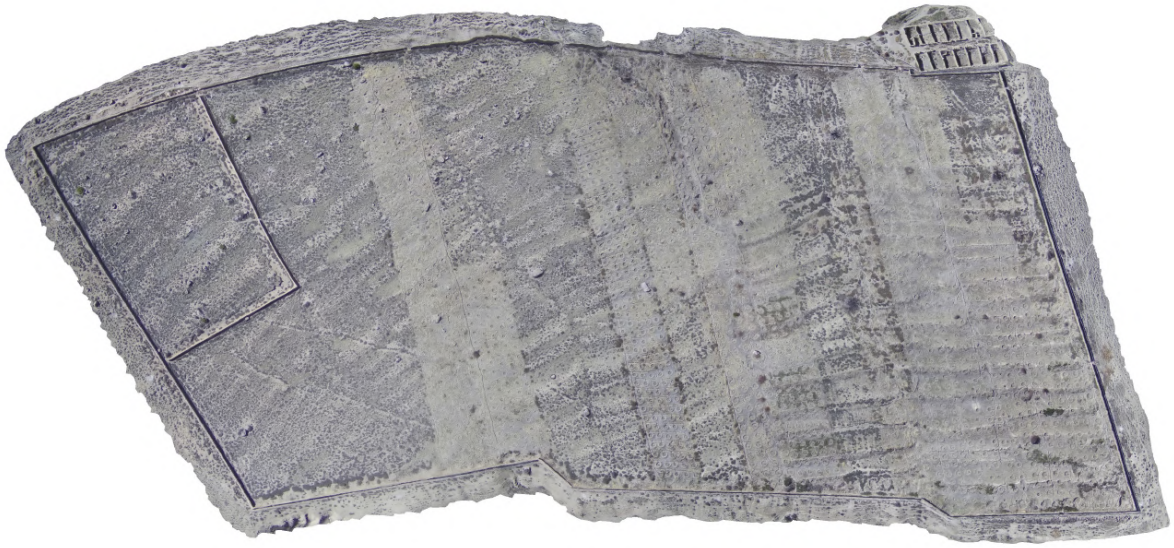

Figure 20: Location B: An aerial view of the 3D digital model representing location B.

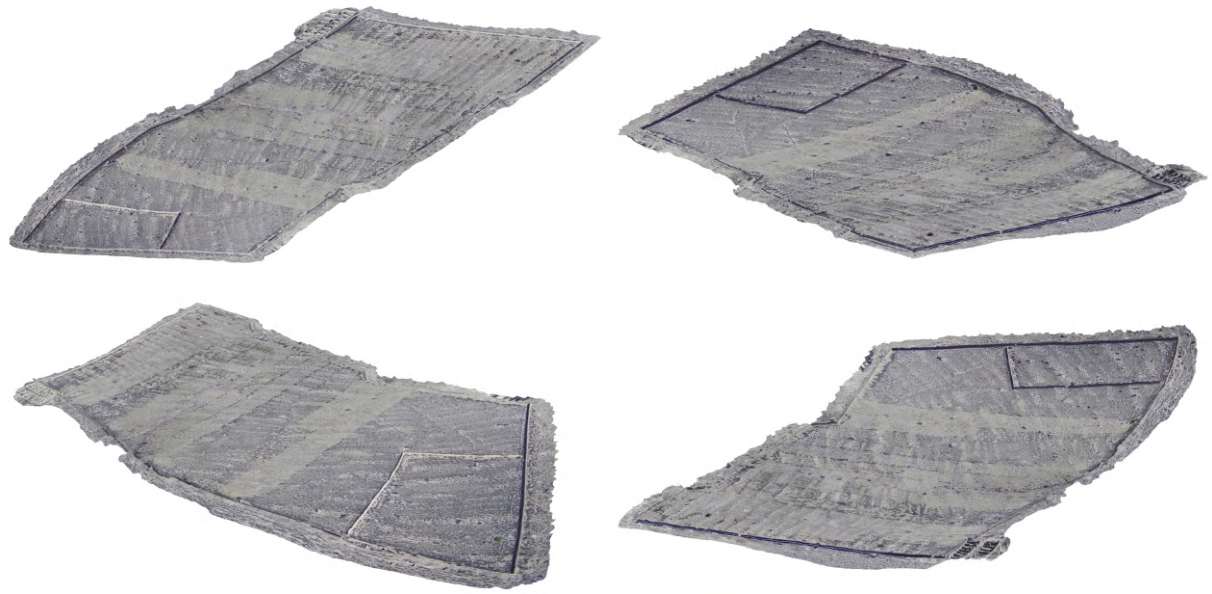

Figure 21: Location B: An angled perspective from each corner of the 3D digital model representing location B.

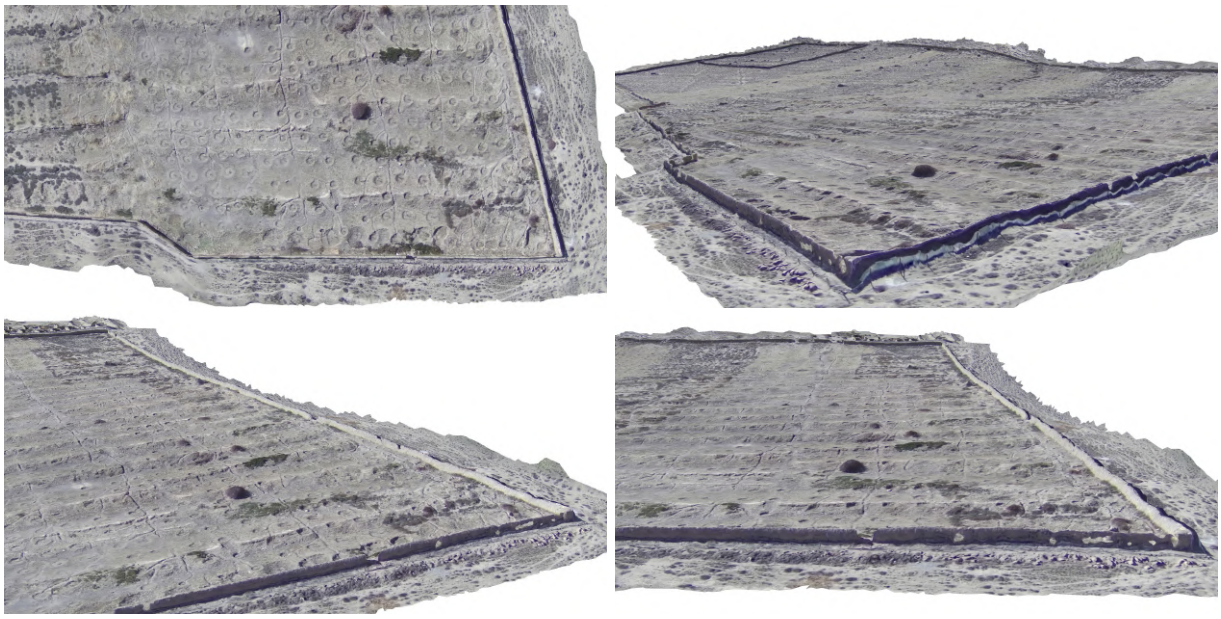

Figure 22: Location B: A zoomed-in perspective of the 3D digital model representing location B, specifically around the northwest corner of the apple orchard. The detail of this model can be seen here.

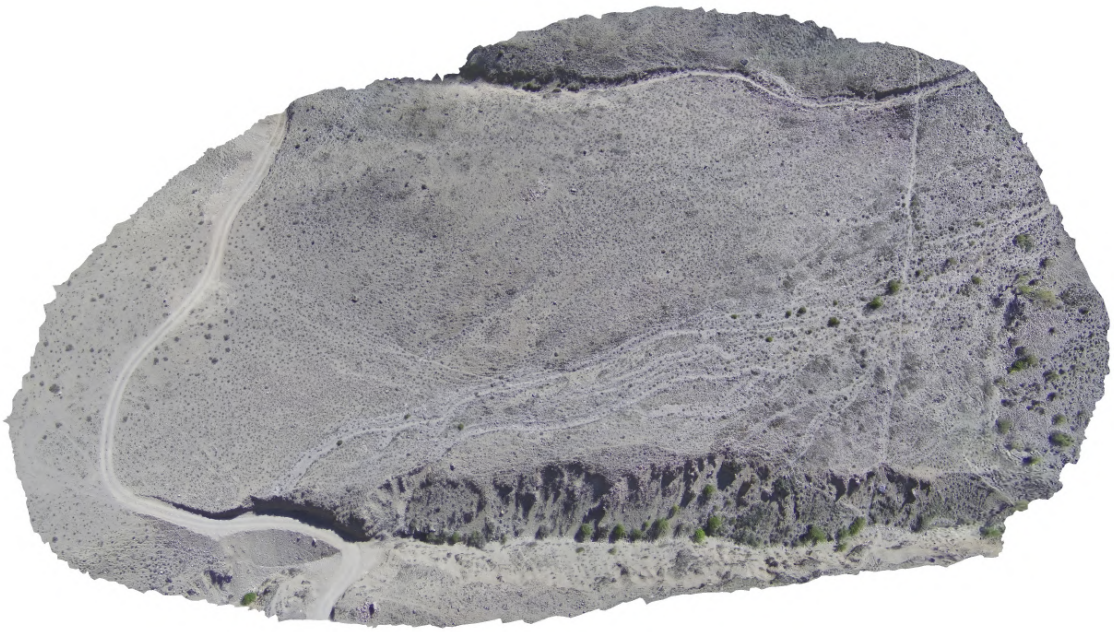

Figure 23: Location C: An aerial view of the 3D digital model representing location C.

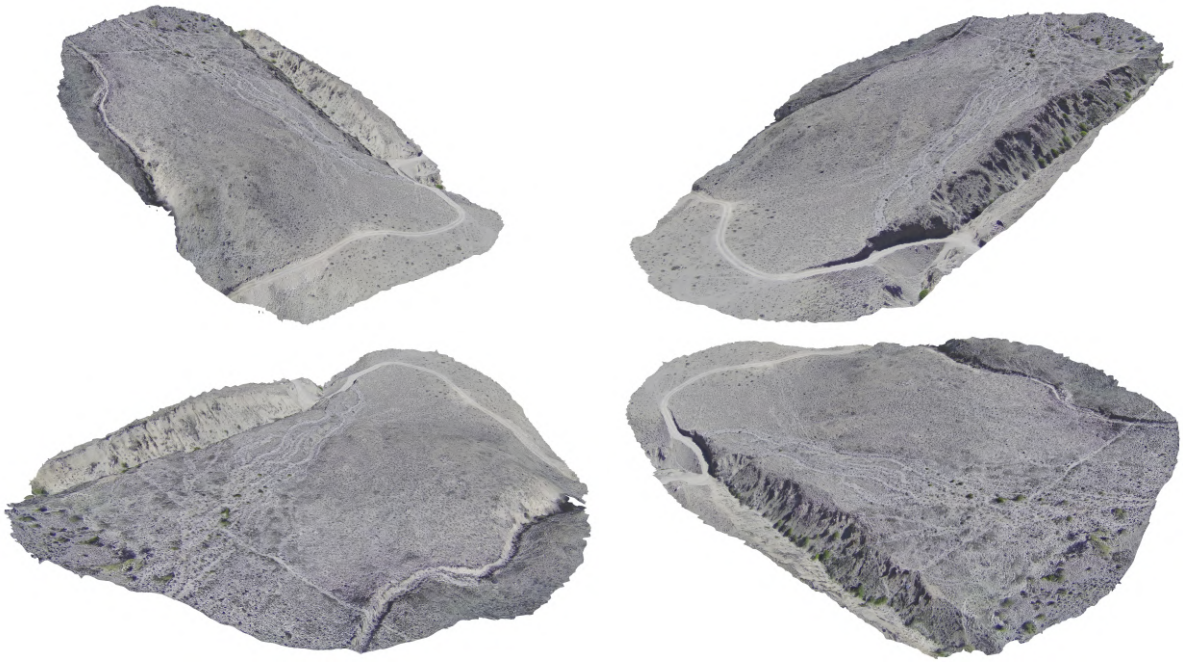

Figure 24: Location C: An angled perspective from each corner of the 3D digital model representing location C.

Figure 25: Location C: A zoomed-in perspective of the 3D digital model representing location C, specifically around the northwest corner of the apple orchard. The detail of this model can be seen here.

Figure 26: Yungdrung La's Home: An aerial view of the 3D digital model representing Yungdrung La's home.

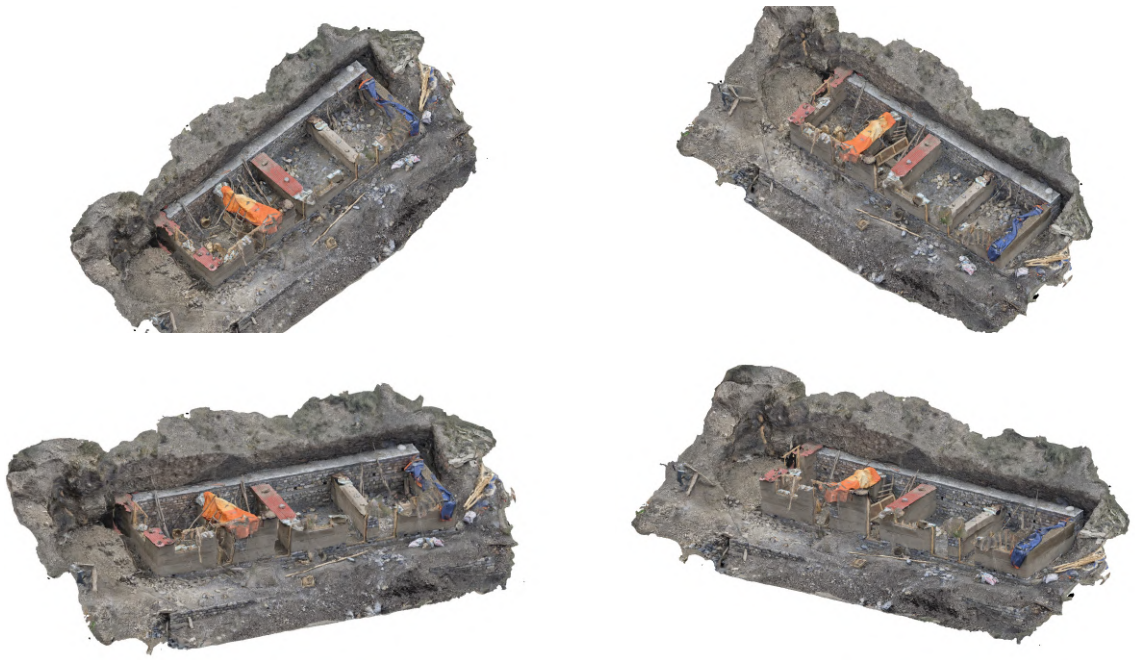

Figure 27: Yungdrung La's Home: An angled perspective from the two front corners of the 3D digital model representing Yungdrung La's home.

Figure 28: Yungdrung La's Home: An angled perspective from the back corners of the 3D digital model representing Yungdrung La's home.

# Appendix B: Post-ISP Work

## B.1 Return to Lubra

Even after several hospital visits, I chose to return to Lubra every time. After the program, I independently returned to Lubra to continue scanning what I missed the previous site visits. Because of my dedication and persistence, I developed two more models from data I collected, along with a third model from older drone footage that my collaborator and I found online. The models consist of a highly-detailed scan of the main village (see figures 32-43), a scan of the riverbed (see figures 44-51), and then a scan of the main village structures from 2016 (see figures 52-55). To view these models, please refer to Appendix C.

## B.2 Engineers For Exploration Research Group

After my ISP, I proposed my project to the Engineers For Exploration Research Group at the University of California, San Diego. The directors of the organization accepted my project, and here I work as the project founder and lead engineer of this project. When I returned to Lurba, I built a project webpage for the project to exist for all to access (see figure 29). As the lead engineer, I present tri-weekly with other lead engineers, manage a team of undergraduate engineers, and actively collaborate on how to improve each others' projects further. Please visit `https://e4e.ucsd.edu/floods-of-lubra` to read more about it.

## B.3 Jan Serie Fellowship

Over Summer 2022, I earned the Jan Serie research fellowship through my school. This fellowship provided funds that allowed me to work on my research full time. During this time, I created more figures (see figure 30), published my work in the Nepali Times, and obtained approval and access to high-quality satellite imagery from Planet, a leading satellite imagery company. These datasets and satellite imagery are critical in developing digital elevation models of the Lubra area.

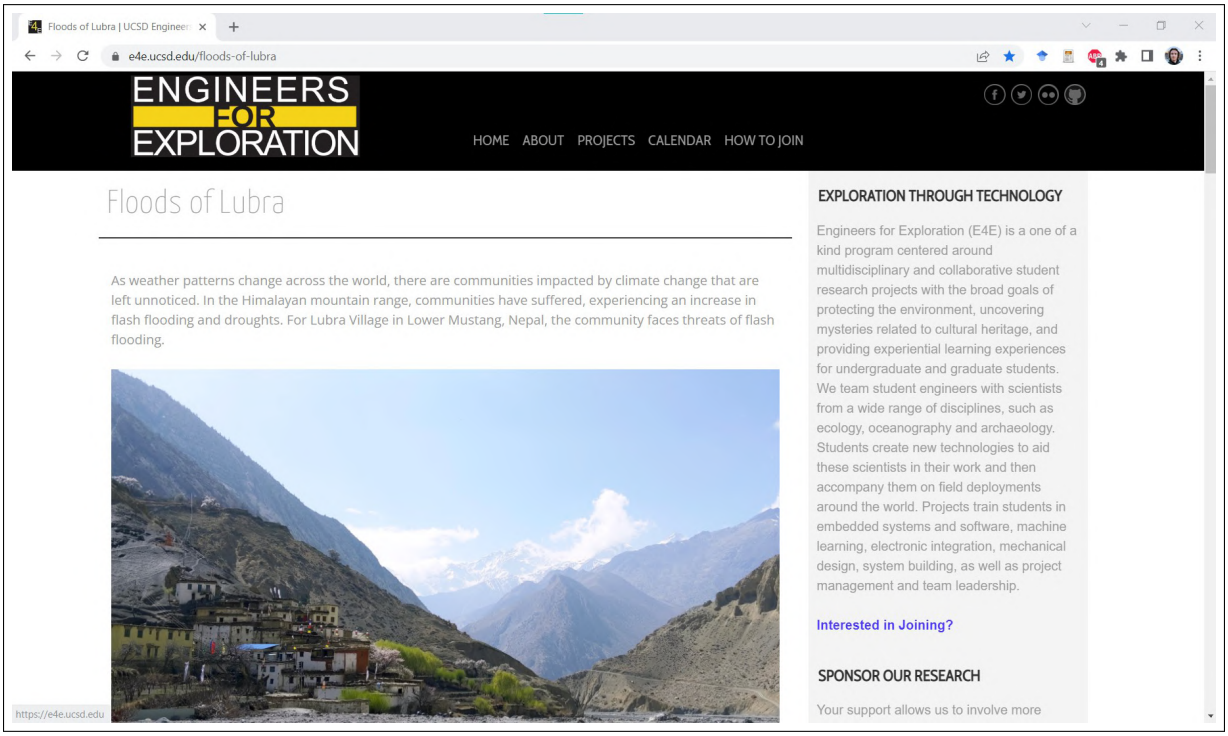


Figure 29: Floods of Lubra project webpage on the E4E website.


Figure 30: Land change comparison between 2016 (left) and 2022 (right) showing how the elevation of the river bed is rising..

## B.4 Nepali Times Publication

In order to share the story of Lubra village, I chose to work with Mr. Kunda Dixit of the Nepali Times to publish my team's report. Over Summer 2022, I synthesized my work into a succinct article that Nepali Times approved and published. To read the article, please visit `https://www.nepalitimes.com/banner/mustang-forced-to-adapt-to-climate-crisis/`. (See figure 31).


Figure 31: Nepali Times Publication: "Mustang Forced to Adapt to Climate Crisis".

## B.5 Fulbright Application

Through communal discussions and presentations, I have been encouraged to continue documenting salient stories using this expressive methodology, and I would like to expand my research further through the Fulbright Open Study/Research Award.

**Project title: "Using Remote Sensing Technology in Understanding and Visualizing Himalayan Climate Change"**

### B.5.1 Abstract

As weather patterns change across the world, Himalayan communities struggle to adapt in the face of climate change. Many communities have suffered, experiencing an increase of flash flooding and droughts. For my project, I will build off of my previous work in Nepal by utilizing remote sensing technologies such as drone and satellite imagery to create unique, highly-detailed 3D visualizations as a way to document climate-related impacts in Lubra village and other Himalayan communities. In tandem, I will conduct oral interviews with members of these communities to understand how flooding and droughts are affecting their ways of life. I will then couple the digital models with writing about cultural nuances derived from oral interviews to contextualize these visualizations. Pairing visualized data with personal accounts, I hope to provide an informative story that depicts Himalayan climate change on a local level, and demonstrate these impacts to both the Nepalese and global audience. This type of writing takes advantage of global accessibility through online platforms, and creates a space that is safe for even the most non-technical readers. To complete this work, I will collaborate closely with my co-researcher, Yungdrung Tsewang Gurung, and his research team. Additionally, I will work closely with one of my mentors, Dr. Isabelle Onians of SIT, and utilize her knowledge in navigating Nepal, and her extensive network to connect me with other experts relevant to my project. Through nine months of work, I aim to publish my results in a scientific journal and emphasize full credit to all parties involved. Through these publications, I hope to bring understanding between communities as we address contemporary climate issues.

## STATEMENT OF GRANT PURPOSE

Ronan Wallace, Nepal, Computer Science and Environmental Studies

Using Remote Sensing Technology in Understanding and Visualizing Himalayan Climate Change

As we walked, I could feel the sun glare down on my cap, unable to reach my already peeling face. The further we trekked from Muktinath in Mustang, the more my co-researcher Yungdrung Tsewang Gurung expressed concern and worry for his village, Lubra. Considered to be one of the few fully Bön practicing villages in Nepal, Lubra village sits at the edge of Lubra river in the Annapurna Conservation Area, nurturing over 800 years of cultural and ancestral significance.

Every year between June and September, however, Lubra valley faces flash flooding disasters. What is normally the three to five meter wide Lubra River turns into a creeping 150 meter wide flood. During these monsoon seasons, water flows through the valley to meet with the Kali Gandaki River, carrying all types of sediment and stone with it. The increase of water turns this valley into a concrete mixer, as the sediment-stone-water mixture turns into a type of viscous sludge. As this sludge collects high in the valley, water may not be able to find passage, causing this muddy water to build. Eventually, the sludge gives way, bringing down a rush of aqueous concrete. These flood bursts repeat without fail over two months, spanning the entire riverbed and swallowing any obstacle in its path.

In the 2021 monsoon, homes were damaged, leaving two families to take shelter in a guesthouse for three months. Jzikmey Angyal, 25, saw the flood rush into the lowermost room of his home. Having lived his entire life in Lubra, he felt the loss, but said: "It is what it is. If the next monsoon is like the last one, the rest of my house will be gone." The next two monsoon seasons could leave several families without homes. "In next ten years, the entire village could be gone," Jzikmey says.

For Lubra, the loss is devastating and irreparable. Decades of culturally significant land is slowly disappearing, and many families fear that their ancestral heritage will go with it. Due to its remote location, not many outsiders experience the damage in person. Lubra often goes unnoticed or disregarded, where many diminish or refuse that such an issue exists. Because of this, the Lubra community struggles to acquire proper funding to implement effective solutions.

As weather patterns change across the world, Himalayan communities struggle to adapt in the face of climate change. Like Lubra, many communities have suffered, experiencing an increase of flash flooding and droughts. For my project, I will build off of my previous work in Nepal by utilizing remote sensing technologies such as drone and satellite imagery to create unique, highly-detailed 3D visualizations as a way to document climate-related impacts in Lubra and other Himalayan communities. In tandem, I will conduct oral interviews with members of these communities to understand how flooding and droughts are affecting their ways of life. I will then couple the digital models with writing about cultural nuances derived from oral interviews to contextualize these visualizations. Pairing visualized data with personal accounts, I hope to provide an informative story that depicts Himalayan climate change on a local level, and demonstrate

these impacts to both the Nepalese and global audience. I aim to publish my results in a scientific journal and emphasize full credit to all parties involved. Our previous work involved two of my drones, so I am familiar with obtaining the proper drone permits to conduct the work. Other platforms for sharing may include news outlets like the Nepali Times.

Having lived in Lubra for several weeks, I explored extensively how I could utilize my strengths and skills that best addresses the needs of the community. As a student of Computer, Data, and Cognitive Science at Macalester College, I spent over four years investigating remote sensing technology and its potential in environmental conservation and cultural preservation. Through formative research experiences, I found that pushing the voices of climate victims at the forefront of my research paired with readable data visualizations provides the most authentic and genuine way of relating the problem to any audience. Having worked with the Lubra community for several months, I have been able to test this methodology by creating 3D digital models depicting flood damages, and synthesizing them with oral interviews into a publishable format for the Nepali Times (search "Nepali Times Mustang Forced to Adapt to Climate Crisis"). This type of writing takes advantage of global accessibility through online platforms, and creates a space that is safe for even the most non-technical readers.

Through communal discussions and presentations, I have been encouraged to continue documenting salient stories using this expressive methodology, and I would like to expand my research further through the Fulbright Open Study/Research Award. When residing in Nepal, I developed a strong professional network in both Kathmandu and Mustang. To conduct this work, I will continue to work closely with my co-researcher, Yungdrung Tsewang Gurung, who is not only from Lubra, but has also collaborated extensively with the National Trust for Nature Conservation (NTNC) in the Annapurna Conservation Area Project (ACAP). I will also work with his team, Sonam Lama and Dane Carlson. Sonam Lama is a Tsum valley native, research associate at Washington University in St. Louis, and recent Humphrey Fellow at MIT; and Dane Carlson is an environmental design strategist at UNOPS Nepal, and holds a Master of Landscape Architecture II from Harvard University. Both have played a critical role in relating land-based knowledge to struggles against the climate crisis, and have guided me thoughtfully through my research. Along with Yungdrung and his research team, I will work with Dr. Isabelle Onians of the School for International Training Nepal, and utilize their knowledge and network to connect with other experts in my field. I will be mainly based in Pokhara, with visits to Lubra village, SIT in Kathmandu, and any other mountainous sites of interest.

My project will take place for nine months between mid-July 2023, and mid-April 2024. When I arrive, I will take a month to reacquaint myself with my peers, colleagues, and previous host families. Through this month, I will spend time in Kathmandu with Dr. Onians, then settle in Pokhara with my host community. Finally, I will arrive in Lubra where I will reconnect with Yungdrung and the team. For the following three months, I will live with Yungdrung and his family in Mustang, where we will conduct additional interviews with Lubra and the surrounding communities to further our understanding of their position as victims of climate change, and how

they are being forced to adapt. In parallel, we will collect aerial imagery of Lubra and other communities that pertain to the information we learn from interviews, which is critical for 3D visualizations, data analysis, and culture preservation through thorough documentation. In the final five months, I will work with both Yungdrung and Dr. Onians to explore and connect with other Himalayan communities, explore how climate change is affecting them, and develop relationships that facilitate conversations of cultural exchange and communal understanding. At the end of my Fulbright, I hope to have visited at least three other Himalayan communities across Nepal, and document their stories using the methodology used in Lubra.

Not only will this work inspire further research, but will also enrich my personal growth as I develop deeper connections with my team and mentors in Nepal. These connections will only radiate into the communities as relationships develop through sharing and experience. Being able to understand one another as humans is critical in empathetic collaboration, and I hope to bring this to life both in Nepal and back home in my community.

## PERSONAL STATEMENT

Ronan Wallace, Nepal, Computer Science and Environmental Studies

Sitting in a circle at the healing center in Pharping, Nepal, we offered our names, birthplaces, and majors as we introduced ourselves. Anthropologists, political scientists, and spiritualists circulated their excitement for our research program. As the circle concluded at me, shock and confusion ensued as I shared my passions in computer science. The first question came with no surprise: "Why are you here?"

During my time at Macalester College, my curiosities have evolved from translating brain functionality into software and hardware, to utilizing sensor technologies to understand and conserve the earth we live on. I've found that the interactions between computer science, neuroscience, environmentalism, and ethnography have a tremendous amount of potential in helping and understanding one another. By the start of the Fulbright program, I will have studied six years in computer science with an emphasis on data science and cognitive science. I believe that understanding human decision-making on both a cognitive and neurological level is fundamental in creating artificial intelligence that can effectively perceive and safely interact with the world we share. Using this understanding, I've made large strides to develop more effective and ethical technologies in environmental conservation and cultural preservation. Through a variety of professional research and academic experiences, I've established a foothold in a niche field that I know I am meant to be in without reservation.

I am an explorer and leader at heart, carrying an innate sense of care and empathy towards others. My career would be meaningless and nonsensical if it didn't support and help others. In order to create community-centered, culturally-conscious technologies, I realized that I would need to immerse myself in other cultures, and bring collaborators together from across the world to address contemporary climate issues. Having traveled to over twenty countries, I sought to diversify my perspective and values through meaningful conversations and sharing experiences. From these relationships and exposures, I've come accustomed to the magnitude of complexities and differences between cultures, and the multitude of cultural nuances that exist even in the smallest communities. What's fascinating to me is how these experiences have drastically shifted my understanding of culture and ancestral heritage, something I deeply respect and reflect on as I conduct research. What led me to work in Nepal specifically is not only my technical ability to help in Himalayan climate issues, but how developing relationships with Himalayan communities will facilitate a space of cultural exchange and mutual understanding, both critical qualities in collaboration and communication.

As I sat with my peers in Pharping, I had only one answer: "Empathy." With the knowledge and skills I have accrued, I want to direct my career towards something meaningful and fulfilling, something that positively influences and impacts the lives of others. Applying my studies to environmental conservation and cultural preservation, I am able to grow into a more empathetic engineer, and give back to communities that have taught me so much. I believe conducting this

work will provide me the best experience I need to propel my career deeper into the field of conservation technology. I cannot stress how imperative it is to develop technologies that will help us navigate and mitigate environmental and ecological issues of today with cultural awareness, and I hope to lead and influence those around me to join. After the Fulbright program, I intend to earn my Ph.D. in conservation technology with the end goal of founding my own research organization. The Fulbright Open Research grant exists at the intersection of my interests, will allow me the time, space, and funds to carry out successful and meaningful research, and bring others together to develop technologies to heal our planet.

# Appendix C: Post-ISP 3D Models

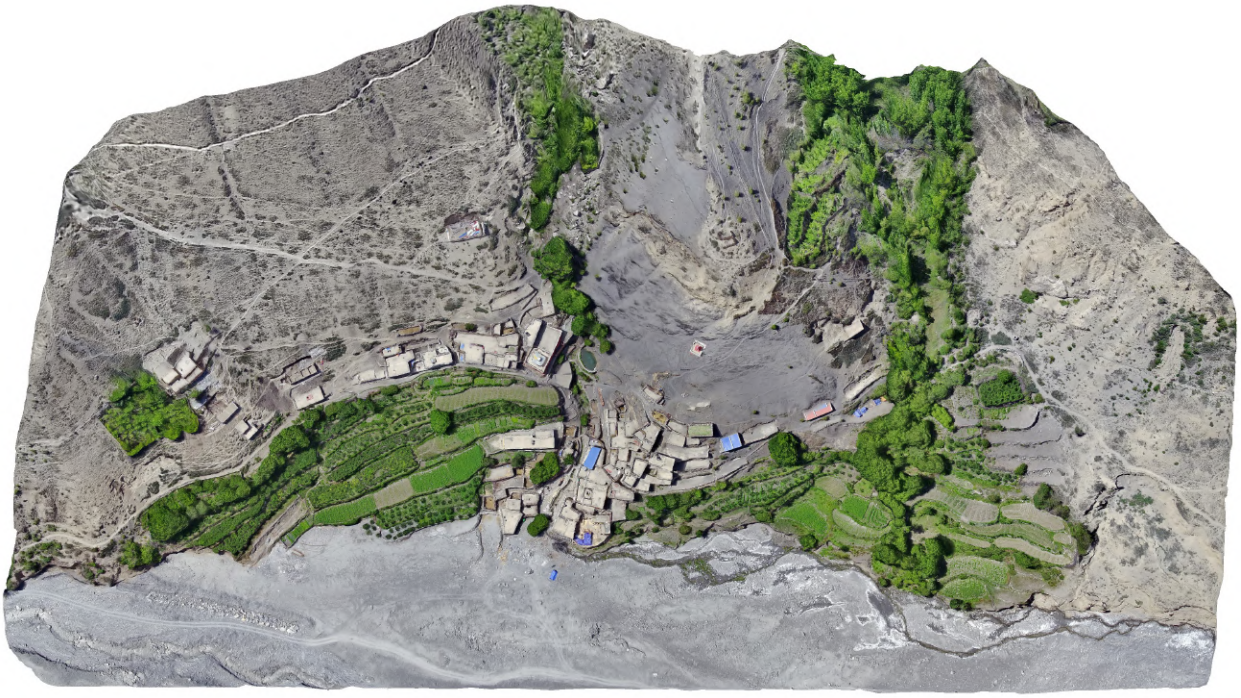

Figure 32: New model of Lubra village - aerial view.

Figure 33: New model of Lubra village - frontal view.

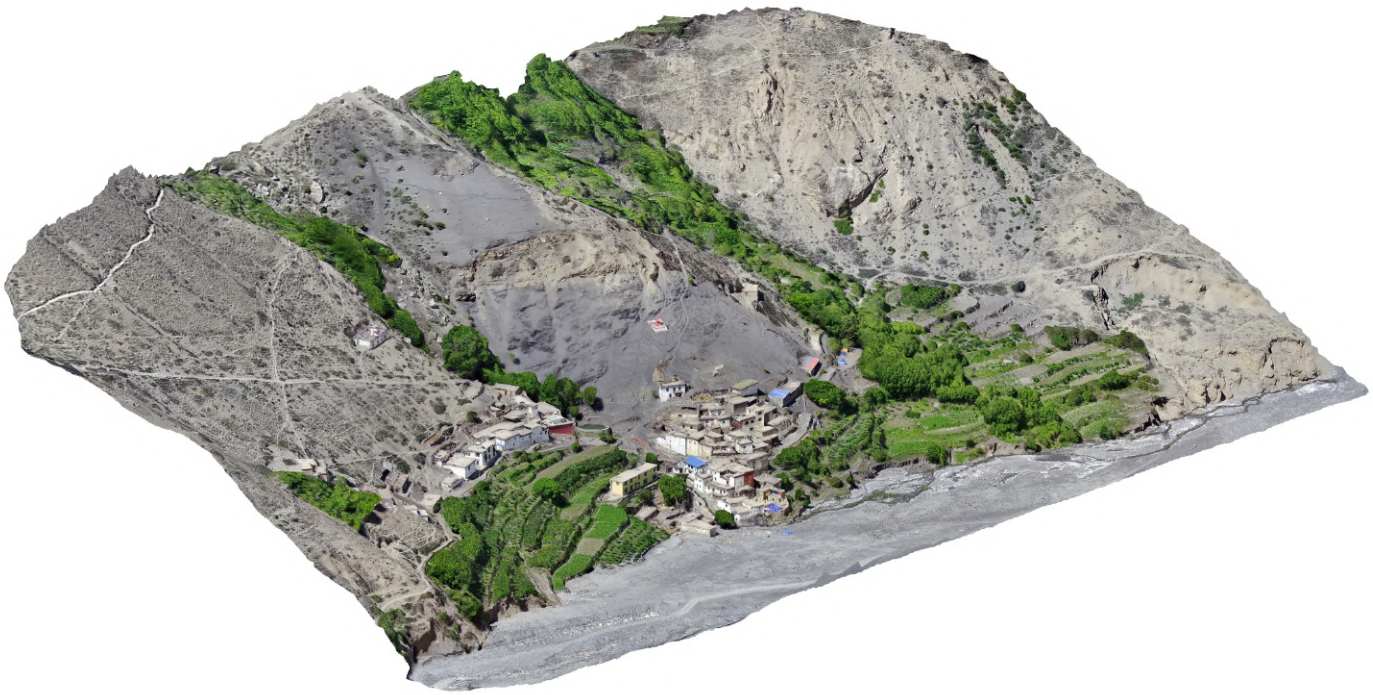

Figure 34: New model of Lubra village - left frontal view.

Figure 35: New model of Lubra village - left frontal view, zoomed-in.

Figure 36: New model of Lubra village - right frontal view.

Figure 37: New model of Lubra village - right frontal view, zoomed-in.

Figure 38: New model of Lubra village - second frontal view.

Figure 39: New model of Lubra village - frontal view, zoomed-in.

Figure 40: New model of Lubra village - left aerial view, zoomed-in.

Figure 41: New model of Lubra village - right aerial view, zoomed-in.

Figure 42: New model of Lubra village - side view.

Figure 43: New model of Lubra village - left and right views from behind.

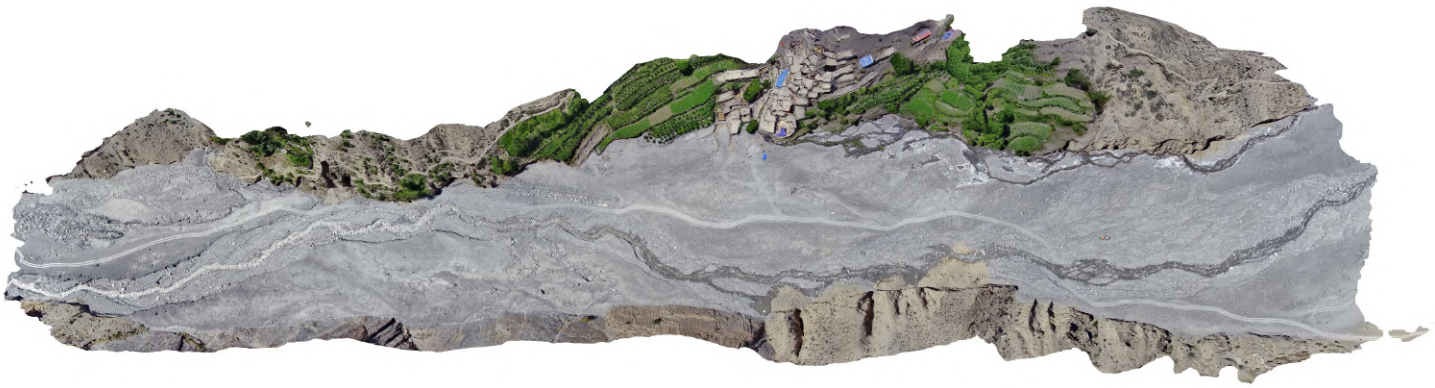

Figure 44: Riverbed model - aerial view.

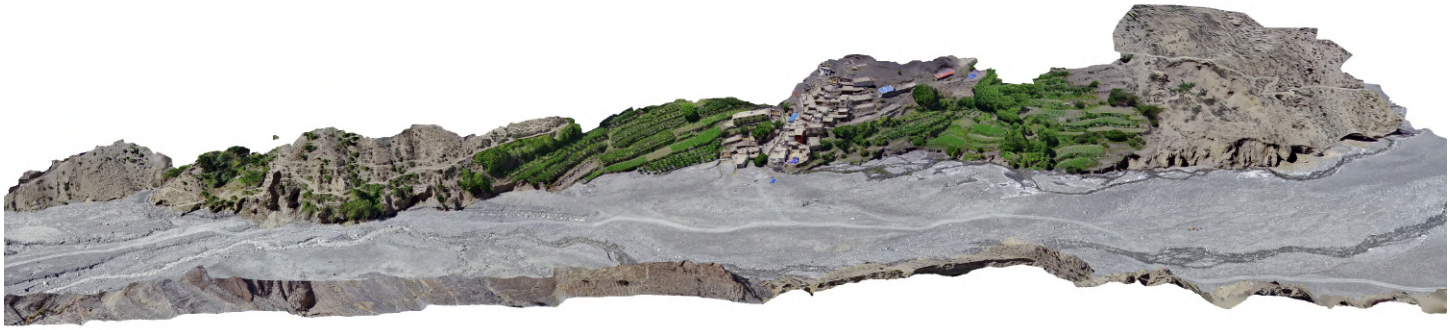

Figure 45: Riverbed model - frontal view.

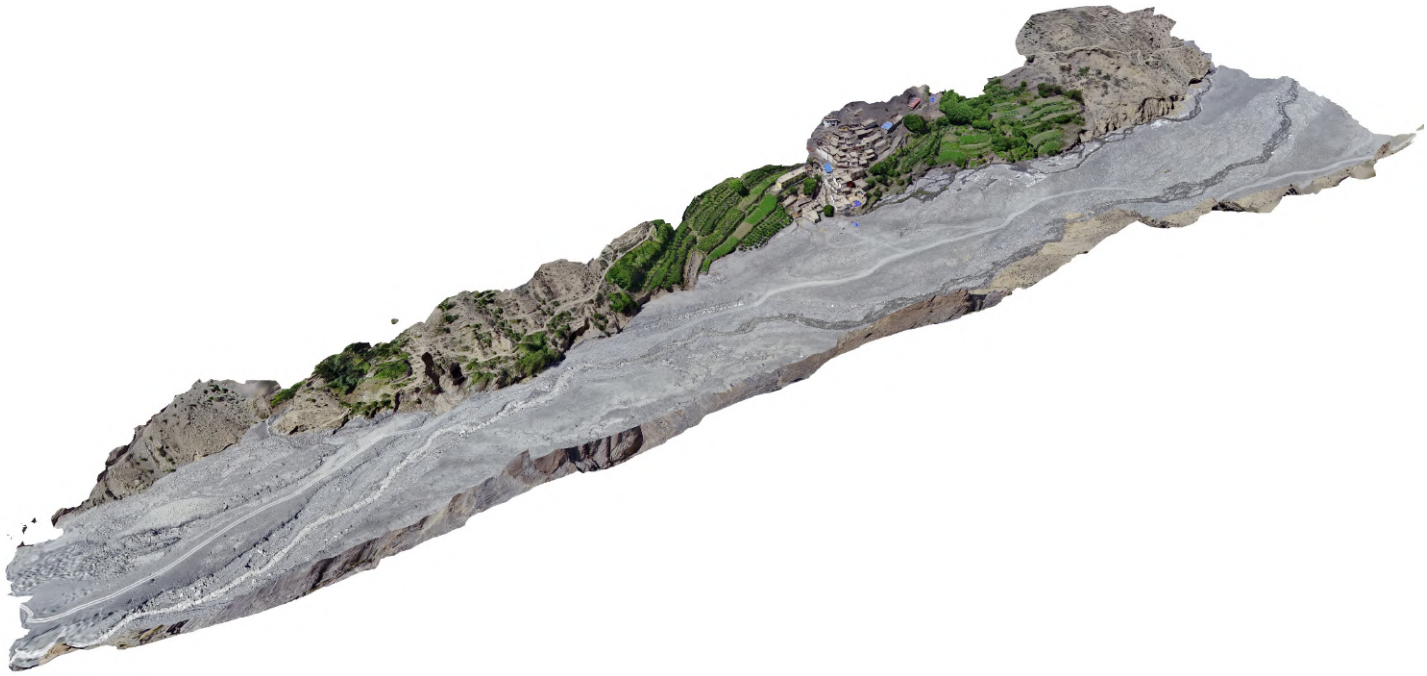

Figure 46: Riverbed model - left aerial view.

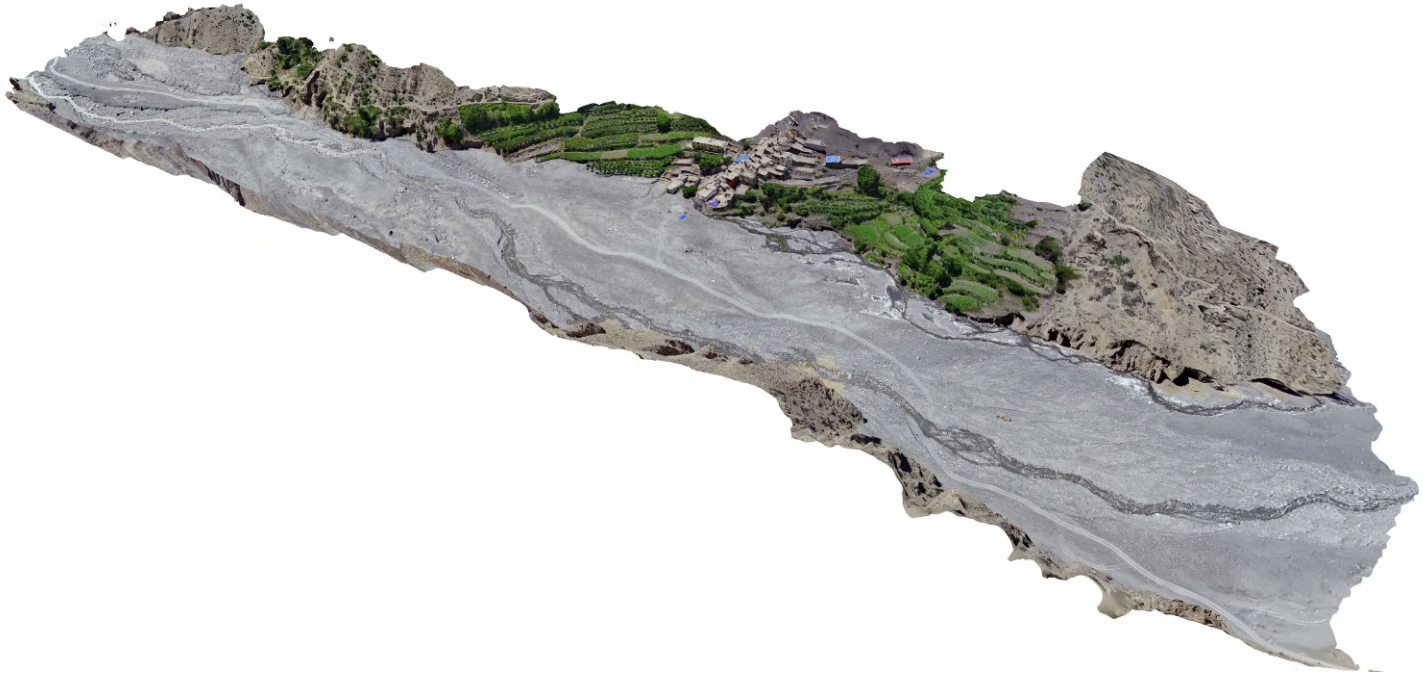

Figure 47: Riverbed model - right aerial view.

Figure 48: Riverbed model - left side view.

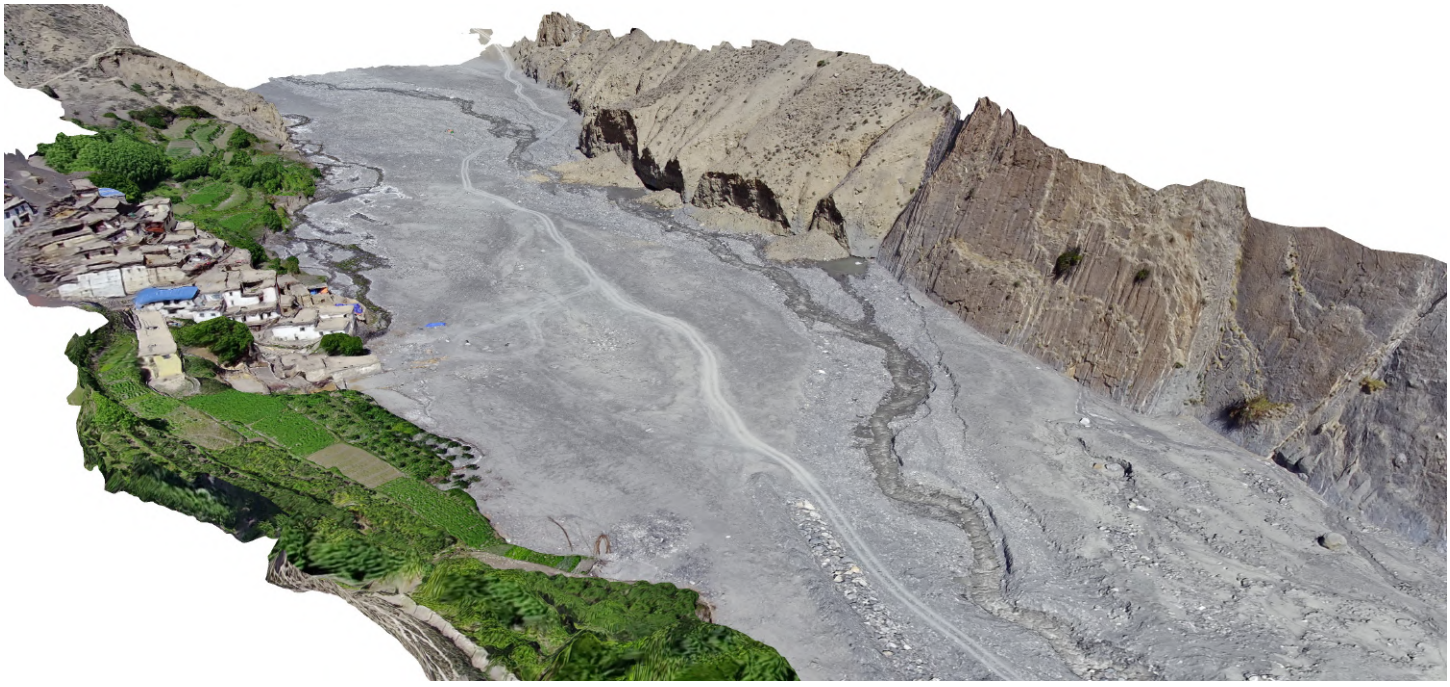

Figure 49: Riverbed model - left angled side view.

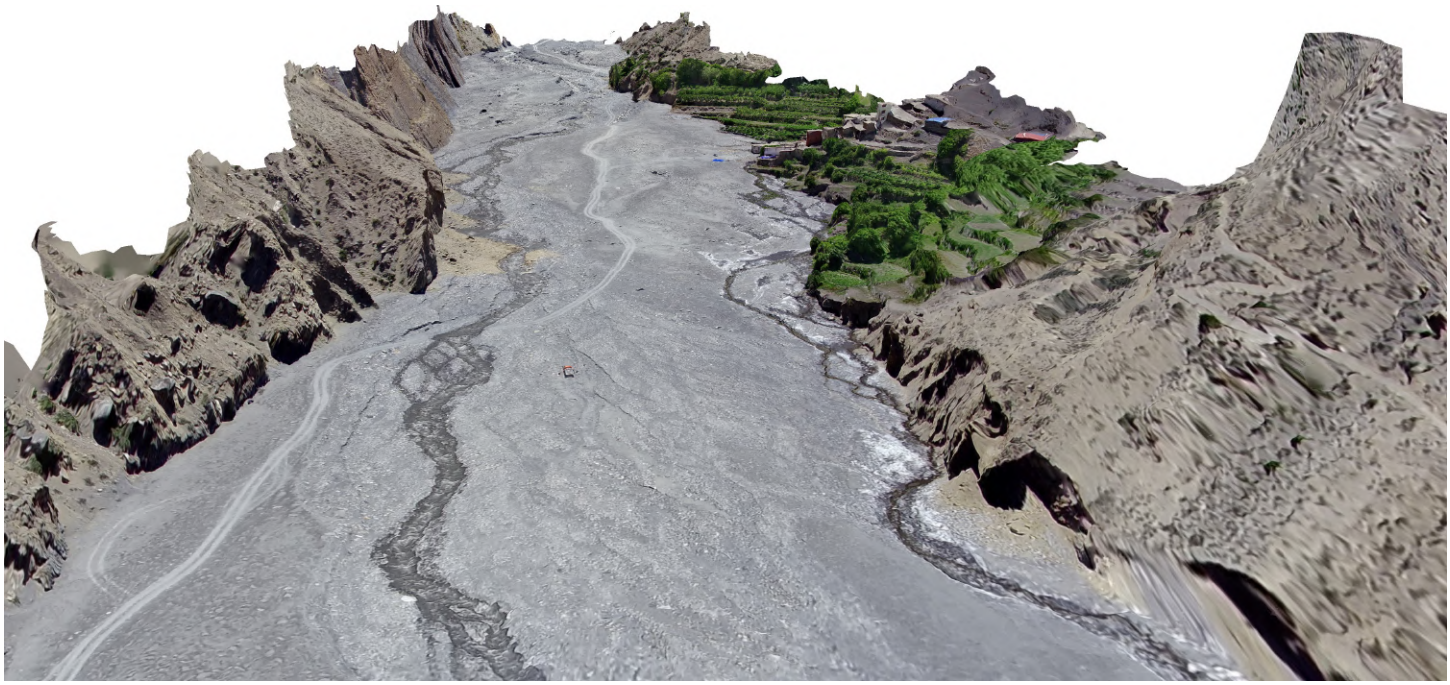

Figure 50: Riverbed model - right side view.

Figure 51: Riverbed model - right angled side view.

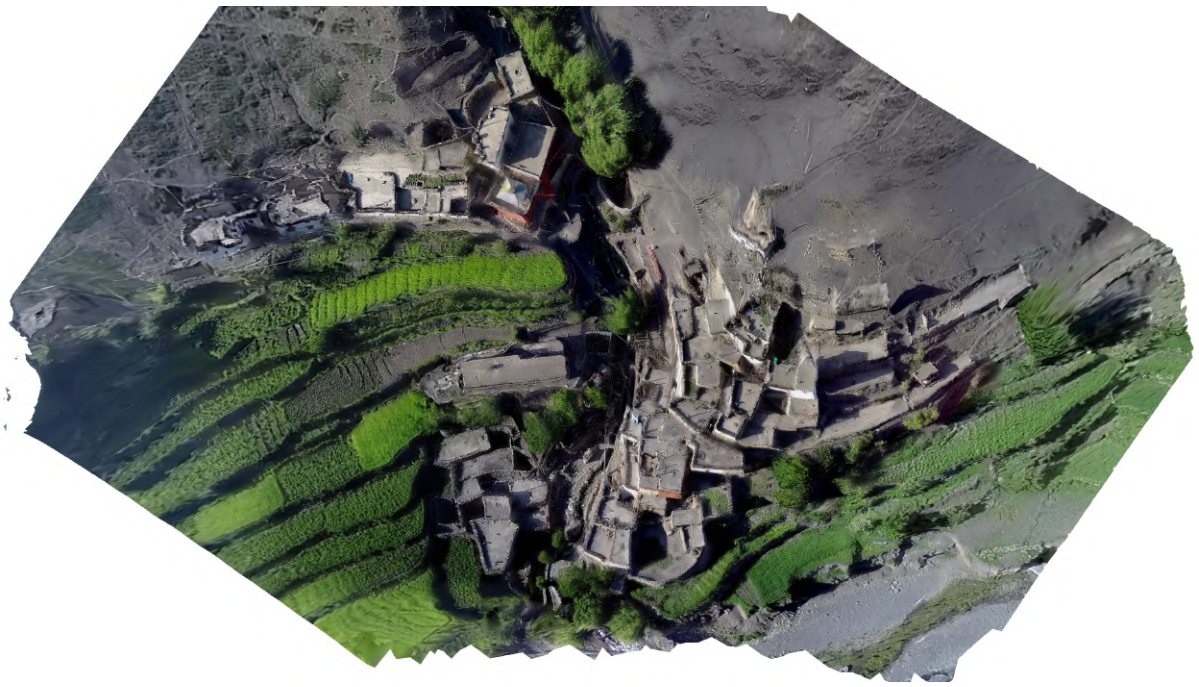

Figure 52: Model of Lubra village in 2016 - aerial view.

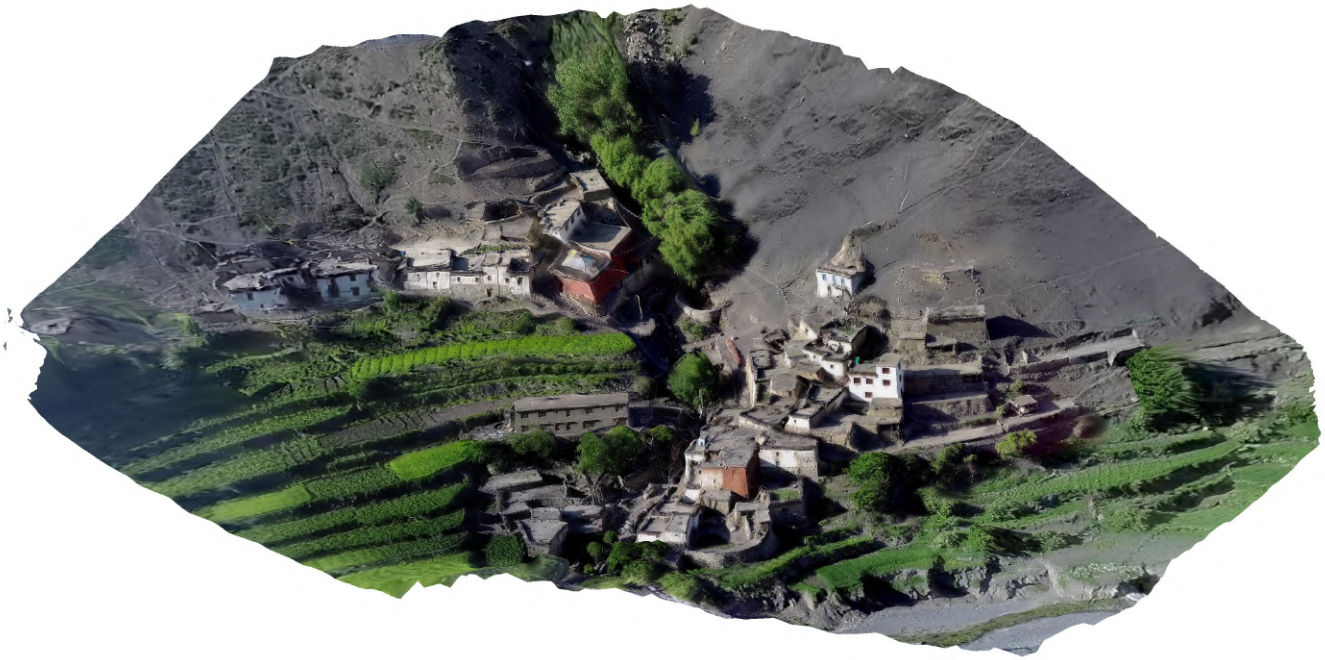

Figure 53: Model of Lubra village in 2016 - frontal view.

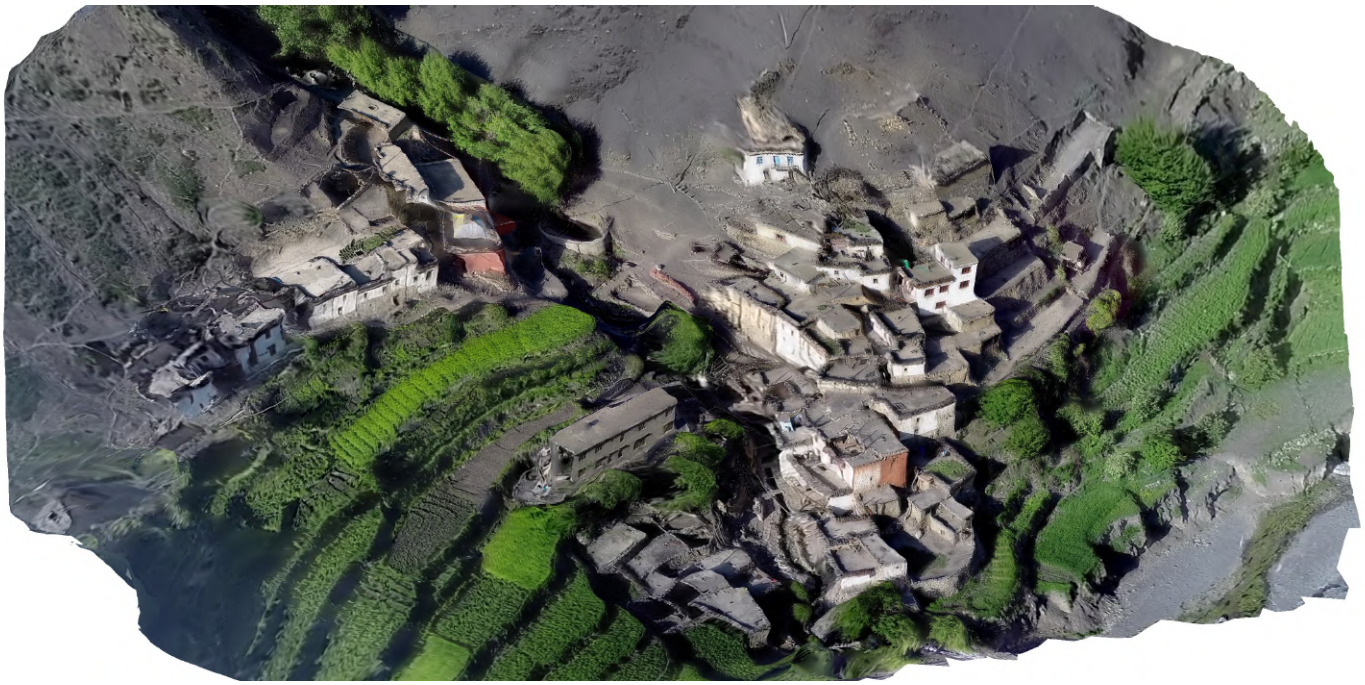

Figure 54: Model of Lubra village in 2016 - left side view.

Figure 55: Model of Lubra village in 2016 - right side view.


Figure 56: My co-researcher Yungdrung La and I hiking from Muktinath to Lubra Village.

Figure 57: Conducting interviews in Lubra Village.

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