Freshwater Ecosystem Services in the Face of Climate Change:

Local Perceptions and Government Policies

Freshwater Ecosystem Services in the Face of Climate Change

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Report Submitted to:

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Abstract

Climate change is dramatically changing the Himalayan Third Pole region and is causing a decrease in the availability of freshwater. The goal of this project was to investigate the perceptions of the impact of climate change on freshwater ecosystem services in the Mandi District of Himachal Pradesh. Our team conducted interviews with a diverse range of stakeholders from distinct geographical locations. We discovered that the disconnect between the community's needs and the actions of the local government must be bridged.

Acknowledgments

We would like to thank the following people for their contributions to the success of this project:

- Professor Vivek Gupta for his mentorship and fieldwork participation and support.
- Professors Uma Kumar and Ingrid Shockey for their advice, mentorship, and friendship throughout this project.
- Dr. Rinki for her mentorship and fieldwork participation.
- Professor Ashutosh Sharma of IIT Roorkee for surveying advice
- APN for funding the REFRESH project.
- All interview participants that made this project possible.

Authorship

It is impossible to designate a chapter or even a given section to a single author. Within each section, different members of our WPI members have combined their efforts to complete a preliminary draft. Next, the entire WPI team would sit down together to edit the draft from top to bottom. After receiving critics and feedback, the team repeatedly sits as a whole to edit the draft into its final product. No author can be given to any one particular section of this work, but rather, all members of the team have contributed equally to the report. We would like to give credit to our IIT Mandi team members for translational and fieldwork contributions.

This work is original to the project's authors and study participants and was not generated or assisted using ChatGPT or AI tools.

Meet the Team

Matthew McMahon (WPI)

Hello, my name is Matthew McMahon, and I am from Pepperell Massachusetts. I am pursuing a Bachelor's and Master's degree in Aerospace Engineering at WPI. My trip to India has been an eye-opening experience and I have loved learning about and being a part of the Himalayan culture. I am grateful for the lifelong memories and friendships that I have gained from this project. I am very excited to see the results of the REFRESH project throughout the Himalayas.

Violet Smiarowski (WPI)

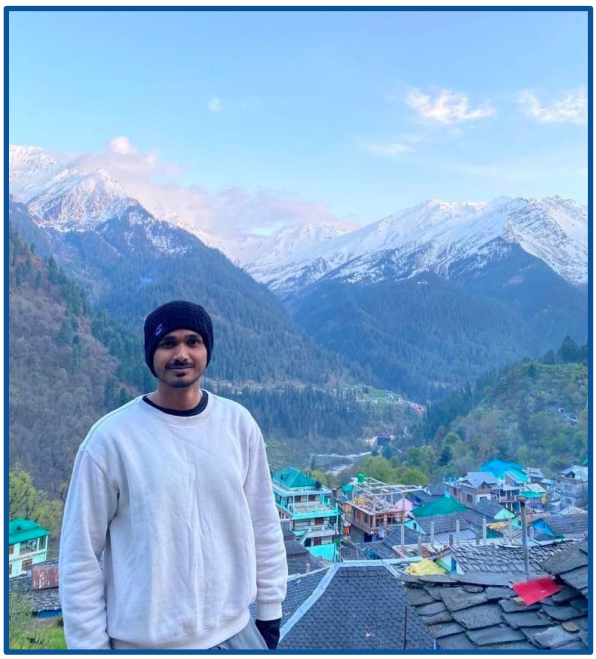
Hello, my name is Violet Smiarowski and I am from Branford Connecticut. I am pursuing my Bachelor's and Master's degrees in Chemical Engineering with a biological focus at WPI. I am so grateful to have had the opportunity to travel to India and be a part of this team. My favorite part about this trip has been hiking, exploring the towns around campus, and trying different kinds of food.

Achilles Gikas (WPI)

Hello everyone, my name is Achilles Gikas. I am from Peabody, Massachusetts and planning on graduating WPI with a double major in Biomedical Engineering, and Mechanical & Materials Engineering. This journey to India and across the Himachal Pradesh Himalayan region gave me an opportunity to meet people with an upbringing and lifestyle completely different to my own. Getting to listen to these stories and their villages' relation to the local freshwater environments gave my friends and teammates ample information to provide information to this report and to the grander REFRESH project that supervises our own.

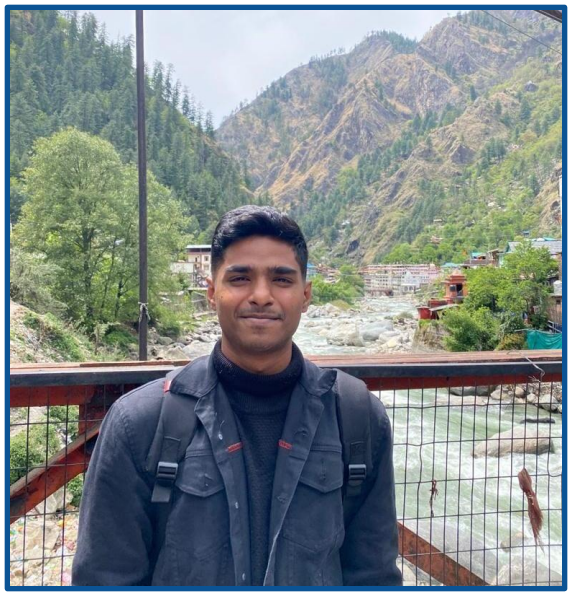
Rohan Bharti (IIT)

Hi there! My name is Rohan Bharti and I hail from Gaya, Bihar. Currently, I am pursuing a Bachelor's degree in Computer Science Engineering from IIT Mandi. During the course of the project, I went on a field trip in the beautiful Parvati Valley of Himachal Pradesh for the project and learned about how climate change impacts freshwater ecosystems and local communities' daily lives. Working with amazing people made the trip unforgettable. We discovered environmental features that disturb locals' lives and how climate change worsens these issues, deepening my understanding of the planet's challenges.



Atharva Vidulkar (IIT)

Hello, my name is Atharva Vidulkar, I'm from Nanded, Maharashtra. I am pursuing my bachelor's in Mechanical engineering at IIT Mandi. I enjoyed my time during the project, exploring the Himalayas. I got to know a lot about the freshwater ecosystem in Himachal Pradesh as well. Overall it was an enriching experience.



Manav Sharma (IIT)

Hello, my name is Manav Sharma and I am from Hapur, Uttar Pradesh. I am pursuing my Bachelor's of Technology in Mechanical Engineering at IIT Mandi. I am so grateful to have had the opportunity and be a part of this team. My favorite part about this project has been exploring the Himalayas, getting to know the various things about locals, and the fun with this team.

Rajat Dawra (IIT)

Hello, my name is Rajat Dawra and I am from Rajasthan. I am pursuing my Bachelor's of Technology in Computer Science Engineering at IIT Mandi. It was a pleasure to be a part of this project and the wonderful team. My favorite part of the project was obviously the Field trip where we got to explore and learn a lot about the Himalayas and the ecosystem and also had a lot of fun.

Executive Summary

Background

The state of Himachal Pradesh is located in northern India in the foothills of the western Himalayas. The region is deeply affected by climate change impacts, with indicators including both the drying of the rivers and springs and extreme weather events such as cloudbursts and flash floods (Kajal, 2021). The freshwater ecosystem services (FES) are a vital commodity to the local communities for critical needs like irrigation, drinking, and essential economic resources, as well as for recreational uses and cultural traditions. Climate change has the potential to strain or even devastate local livelihoods tied to freshwater services (The Third Pole, n.d.). Families living in villages within Himachal Pradesh have started moving to more urban areas as a result of the difficulties in envisioning and building a future where water and consequently agricultural opportunities have become so scarce (Kajal, 2021).

Approach

The method our team used to utilize to accomplish the objectives and overarching goal of our project can be seen in the figure below.

Figure 2. Objectives and methods utilized

We conducted a broad set of site assessments to understand better which freshwater ecosystem services were utilized in the region. Our team visited critical locations throughout the district of Mandi. We also mapped the past and existing freshwater infrastructure in each location. Our team utilized convenience sampling to engage with local residents and individuals working in freshwater ecosystem services occupations. The second objective complemented our empirical data with personal accounts of the effects of climate change on the local population. To diminish unconscious bias, we examined a wide range of locations in our site assessments such as villages in the mountains, on the river, and in urban areas. Finally, to document and quantify

the vulnerability of freshwater ecosystem services in the studied communities, our team completed an informal vulnerability assessment. The vulnerability assessment identified areas of critical concern to highlight the interrelationships between climate change and community vulnerability.

Results

We conducted site visits and engaged with residents from a variety of villages ranging in altitude from the river valley basin area to higher in the mountains. We found that the main freshwater ecosystem services were sources for drinking water, water needed for household and spiritual activities, irrigation, and water for animals. Most of the drinking water was sourced directly from springs and distributed using informal or government-supplied waterlines. Residents used rainwater or water collected indirectly from runoff not suitable for drinking and available in larger quantities for livestock and irrigation.

In recent years villagers throughout this region reported experiencing fewer and less consistent precipitation events. This scenario is accompanied by lower flow in the rivers, and rising temperatures all of which factor into the more frequent and severe droughts. The rainfall received is reported to be too intense, not allowing for the natural restoration of the underground water supply creating additional strain on local communities.

The impacts from climate change have forced adaptation measures to be taken by individuals whether it be by driving out of town to collect water, or by fetching water from a nearby river to meet the demand. Local residents also reported having to change to more resistant crop varieties or having to stop growing produce altogether as a livelihood.

This area's water infrastructure is vulnerable to the changes brought by climate change. Respondents feel that the government is not doing enough in terms of maintaining the resources or providing support when needed. In some cases, water is supplemented but not in great enough quantities. At other times residents feel there is enough water, but not the proper distribution scheme. Finally, communities reported a disconnect between the residents and the government where solutions provided are not addressing the true needs.

Recommendations

Recommendation 1. Community Liaison: Due to the common grievance of the disconnection between village residents and authorities in charge of designing and implementing the government schemes, we recommend the introduction of a village liaison. The ideal role of this position would be to continue our team's role as interviewers, recorders, and monitors of needed freshwater schemes and vulnerabilities in rural villages. The liaison can interact with and assess as an independent agent, as other local government bodies have proven ineffective at providing reliable freshwater ecosystem schemes.

Recommendation 2. Survey Adjustments: Our second recommendation is directed to readjust our interview process. During the interview process, our team noticed a rigidness in the questions that prevented a natural flow of dialogue with our respondents. In order to accomplish what is intended in these interviews, listening to the personal account and narrative of the resident's relation with the freshwater services, more open-form questions must be introduced

into the survey. Along with this, questions regarding the ranking of available freshwater services could be removed and replaced with questions asking about the quality of the services instead.

Conclusion

Climate change is dramatically affecting the freshwater ecosystem services of the Mandi district. The last decade has shown a decline in rainfall and snowfall, with an increase in extreme weather events such as monsoons, cloudbursts, and landslides. Although there has been government intervention in the design and creation of various ecosystem service schemes, there has been poor execution and a lack of follow-through. Without proper intervention, climate change will continue to reduce the number of freshwater resources in the Mandi district to a breaking point. This project is relevant to two of the United Nations' Sustainable Development goals of Clean Water & Sanitation and Climate Action.

Figure 12. The United Nations, n.d. (https://sdgs.un.org)

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Introduction

Climate change is causing dramatic changes in the Himalayas and making the region a keystone variable in the local and global ecosystems. Most recently the Himalayan region has been designated as the “Third Pole" among climate scientists for its critical glacial ecosystem and for the part it plays in changing the natural hydrological cycle in the surrounding areas. After the north and south poles, the Himalayas have the greatest stores of glaciers leading to this region being disproportionately affected by climate change (Kulkarni et. al., 2021). The Himalayas are the source for each of the 10 major river systems which provide freshwater ecosystem services such as irrigation, drinking, and power to over 1.9 billion people (The Third Pole n.d.).

The state of Himachal Pradesh is located in northern India in the foothills of the western Himalayas. The region is deeply affected by climate change impacts, with indicators including both the drying of the rivers and springs and extreme weather events such as cloudbursts and flash floods (Kajal, 2021). These events subsequently aggravate landslides, and drought conditions, and hinder traditional agricultural practices that have had devastating outcomes for communities. The freshwater ecosystem services are a vital commodity to the local communities for critical needs like irrigation, drinking, and essential economic resources, as well as for recreational uses and cultural traditions. Climate change has the potential to strain or even devastate local livelihoods tied to freshwater services (The Third Pole, n.d.). Families living in villages within Himachal Pradesh have started moving to more urban areas as a result of the difficulties in envisioning and building a future where water and consequently agricultural opportunities have become so scarce (Kajal, 2021). The distress climate change is causing communities around the “Third Pole” Himalayan regions has the potential to bring forth a migration crisis if the problem is not promptly addressed (The Third Pole, n.d.).

The goal of this project was to investigate freshwater ecosystem services in the Mandi District in the face of climate change. To meet this goal, we identified 3 objectives. First, we identified the range and scope of the existing services in the region. Second, we gauged the local and expert perceptions of freshwater ecosystem services in a time of climate change. This objective considered the perspectives of local policymakers, community members, and experts in the field of climate and ecosystem services. Third, we developed a vulnerability assessment to highlight areas of greatest concern.

We hope our assessment provided insight into future policy recommendations that can be used by our collaborators as part of the Asia-Pacific Network for Global Change Research working on the **RE**gional cooperation for **FR**eshwater **E**cosystem **S**ervices in the **H**imalayas (REFRESH) project. The goal of the REFRESH project is to advocate for the protection and restoration of freshwater ecosystem services through increased research on climate change-related topics and ultimately policy recommendations.

Background

Mapping Climate Impacts in the Himalayas

The Himalayan arc ranges from the northeastern tip of India through Nepal and onward to the eastern edge of Bhutan. This mountain ecosystem is home to massive glacier fields, primary rivers, and the backbone of agricultural livelihoods across Asia. The mountains are also a hotspot for climate change monitoring under the eye of the previously mentioned Third Pole climate change designation. Climate change can create vulnerability to extreme weather events

due to its influence on the natural hydrological cycle. A summarization of these connections can start with greenhouse gasses such as CO_2, CH_4, N_2O, and H_2O that when emitted from a gaseous layer within the earth's atmosphere traps heat leading to an unequal energy transfer in and out of the atmosphere. This uneven transfer is what causes the increase in temperatures allowing for a greater water-holding capacity in the atmosphere and increased evaporation leading to an overall greater moisture content in the air. These compounding factors are what cause elevated precipitation rates, latent heating, and storm intensity. All of the precipitating systems feed on the additional moisture content creating a positive feedback loop (Mall et al., 2006; UCAR, 2023).

Himachal Pradesh is experiencing the many effects of climate change and glacial recession from the activity in the Himalayas and in the state itself. Glaciers in Himachal Pradesh have decreased at a rate of 67.84 km^2 per year from 4020.6 km^2 in 1994 to 2198.5 km^2 in 2021 (Rajat, 2021).

> *Almost half of the glaciated area in Himachal Pradesh has disappeared in only 27 years (Rajat, 2021)*

This is illustrative of the severity of the glacier loss. The resulting water produced from the receding glaciers is then available to participate in hydrology, worsening the occurrences of extreme weather events.

Predicted Outlook

One of the first ways the melting glaciers impact the land nearby is through movement downstream. Rivers such as the Beas, which flows directly through Mandi, are glacier-fed and the river's flow is heavily dependent on patterns of glacial melt. The change in the volumetric flow is predicted to increase the prevalence of droughts and floods by inducing faster movements of water. Integrated models have been made to predict the future glacial recession and the resulting impacts on the Beas River Basin from the glacial melt. Temperatures and precipitation in the Beas River Basins are expected to increase respectively by 1.8°C to 2.8°C and 9.8% to 33.3% by 2046-2065, and 2.8°C to 5.4°C and 17.7% to 39.7% by 2080-2099 (Li et al., 2015). The anticipated changes will have a dramatic impact on the local climate and the frequency of extreme weather events. The temperature and precipitation rates induced by climate change will lead to increased extreme rainfall events such as cloudbursts. Cloudbursts in north India appear as sudden and heavy rainfall over a short period and area and many times lead to flash flooding. These events occur most commonly in valleys from elevations from 1000m to 2500m due to the orographic nature of these events (Dimri et al., 2017). The escalation in the frequency of extreme rainfall events is linked to floods and landslides that cause damage and loss to cropland, infrastructure, animals, and people in the affected area Additionally, the rain from cloudbursts moves too rapidly across the land for the water to saturate and restore the underground aquifers. Almost 90% of extreme rainfall events are observed during the monsoon season from July to September when climate change is now creating more exaggerated and dynamic seasons. Although the hotspot for these events is within the northwestern region of Himachal Pradesh, research indicates that almost 40% of the state now experiences heavy rainfall throughout the year (Gouda et al., 2022).

The consequences of extreme weather events brought on by climate change are felt strongly in Himachal Pradesh. In the past, consistent rainfall allowed for a continuous supply of water. Climate change is shifting the natural cycle and transitioning to less frequent rain, snowfall, and extreme weather events. This brings flooding and the unpredictable movement of the water downstream. Rapid runoff can exacerbate the effects of droughts and the drying of natural springs that are no longer able to recharge as they used to (Kajal, 2021). For example, the majority of farmers in the Kullu District report not having enough water to irrigate their crops. Damage to the cropland from hailstorms and flooding, on top of the lack of a stable supply of water, is making it hard for rural communities to produce crops sustainably. Almost 90% of the residents in Himachal Pradesh rely on agriculture and because of climate change, it is becoming almost impossible for communities to stay (Agrawal et al., 2019). Villagers have started migrating to cities where freshwater services are more reliable (Kajal, 2021).

Hidden Impacts

Reliance on freshwater ecosystem services extends across many domains to include fishers, farmers, shepherds, and the gharat owners who run local water-milling services. These economies rely on water ecosystems to sustain their occupation and livelihood. Fishers depend on freshwater streams and ponds to provide a habitat for fish, farmers depend on freshwater ecosystems to irrigate their crops, and shepherds need water tanks for buffalo, sheep, and goats that provide most importantly manure but also ghee, milk, and other important milk and wool products to the community. The accurate recording of impacts is not well understood, and it is important to recognize disconnected and marginalized communities who are often left out of the conversation and not given a platform to express their voice and experiences regarding how they are being affected by climate change.

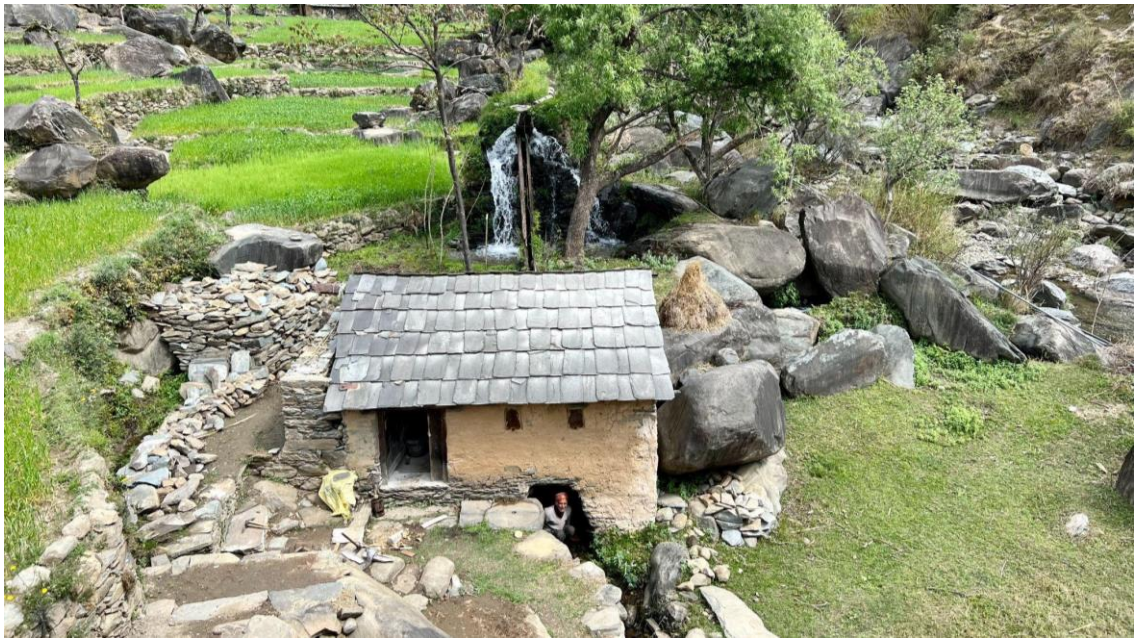

Figure 1. Gharat is used for grinding flour in Kataula, HP. The water is diverted into the gharat by a gul (the channel of water seen at the top of the image) where the downward gravitational force of the water is used to spin a turbine (Photo Credit: Violet Smiarowski). This energy can also be used for producing lumber, textile, or shaping metal (Bhatt et al., 2021)

The perspectives of local policymakers and experts in the field of climate change and ecosystem services are important in identifying what is being regulated. These local policymakers include government officials and Ministers in departments that control public works, fisheries, agriculture, energy, and environmental science & technology. They have the power to create, change, and implement policies and legislation.

Adapting to Climate Change

While this project's primary concern was Himachal Pradesh, other Himalayan regions, both inside and outside of India, are being affected as well and have been the subject of similar reports. The state of Jammu and Kashmir, located in the northwestern Himalayas, faces similar circumstances as Himachal Pradesh. A report published in May of 2022 led by S. Sherz Mahdi looked at similar critical freshwater issues that this area and the Beas River Basin face. In their report, Mahdi's group confirmed ongoing and recent changes in the local climate via weather reports and geographic mapping of receding lakes and riverbeds around the Kashmir Valley. Along with this, testimonials from farmers who needed to change an aspect of their farming techniques due to a lack of available freshwater were reported. In terms of the first point, the report links the growing lack of freshwater for local farmers to the decrease in precipitation across the state, losing about 5 mm of rainfall per year since 1980 (Mahdi, 2022). This report also records the increase in temperature maximums and minimums across the summer and winter seasons of the year. To the second point, the testimonials the group recorded gave insight into how impactful losing major sources of freshwater is on a local scale both economically and geographically. While the graphs do not greatly reflect declining freshwaters in the Kashmir Valley, the three testimonials do reflect major farming changes such as loss of chilling hours for fruit treatment, a period for fruit trees between 32°F and 45°F needed to break dormancy, conversion of paddy farms into orchards for a reduced need of water, or a complete reduction of farming yield for some (Mahdi, 2022). Overall, the report gives a comparable look at climate change impacts and the secondary implications for freshwater sources.

While the issue of melting glaciers has been ongoing, government intervention through either scheme or policy has been lacking, especially in the Himalayan regions of India. While the Indian government has recognized the potential threat climate change is to the Himalayan region, having created the National Action Plan on Climate Change (NAPCC) in 2009, its implementation is far from wholly effective (Azhoni et al., 2017). The NAPCC's purpose is to delegate the national missions established in itself to related ministries and state-level departments and directorates. While on paper, having this system to delegate the implementations at a local level, in practice, NAPCC has been inefficient on the local level, with the Mandi Zone becoming a keystone location (Azhoni et al., 2017). Since its initial launch, people both inside and outside the NAPCC range commented on specific barriers and issues seen. These comments were collected by Adani Azhoni and recorded. While these reports were taken in 2017, the issues are still relevant and necessary to look at to view the issues of governmental climate-related policies. Out of all the other keystone issues, the most prevalent is the lack of accountability in the program. A majority of comments made to Azhoni concern "ghost structures" where dams would appear designated on paper as constructed, with supply orders and work permits filled, but would have no physical body (Azhoni et al., 2017). Other major issues include a lack of communication between government bodies, a lack of information on ongoing schemes to the public, and reservation of higher-level agents going on-site visits. Currently, several barriers are preventing adaptation in the face of changes in water availability

inflicted by climate change. Although there is a growing awareness of climate change there exist challenges in overcoming socio-economic and institutional factors. In 2016 when local residents were asked what they felt the barriers were to proper adaptation many people believed that it would be difficult to understand the future impacts of climate change and identify solutions, and furthermore that there was a lack of climate change experts. Another common response was that many of the existing policies had been poorly implemented. To properly adapt to the changes some solutions could include first properly identifying the magnitude of the problem, local government agencies taking charge, increased collaboration between agencies, and agency accountability (Azhoni et al., 2017).

Approach to Data Collection

The methodology our team used to utilize to accomplish the objectives and overarching goal of our project can be seen in the figure below (Figure 2).

Figure 2. Objective and methods utilized

We conducted a broad set of site assessments to understand better which freshwater ecosystem services were utilized in the region. Our team visited critical locations throughout the district of Mandi. Basic observations were recorded with photographs and notes to document essential features and characteristics. We also mapped the past and existing freshwater infrastructure in each location. Our team utilized convenience sampling to engage with local residents and individuals working in freshwater ecosystem services occupations. This sampling strategy enabled our team to grasp the freshwater ecosystem services that were most important in the local communities in the region. To diminish unconscious bias, we examined a wide range of locations in our site assessments such as villages in the mountains, on the river, and in urban areas to accumulate a diverse set of perspectives among the local community members.

The second objective complemented our empirical data with personal accounts of the effects of climate change on the local population. We conducted interviews with local community members from a diverse range of geographic and economic backgrounds. These interviews contributed data to a map of the freshwater resources in the village, the history of government intervention to improve the freshwater supply, and the changes required to adapt to

climate change. A portion of the interviews was also recorded for the purpose of making a short video documentary.

Finally, to document and quantify the vulnerability of freshwater ecosystem services in the studied communities, our team completed a vulnerability assessment. The assessment identified areas of critical concern to highlight the interrelationships between climate change and community vulnerability.

Results and Discussion

After conducting the surveys and interviews across a variety of villages in the region, our team collected enough information to record and interpret into a series of collective insights and notable data. This section presents our findings, sorted by our team's initial objectives.

Objective 1. Identifying and Assessing Existing Freshwater Ecosystem Services

Our team conducted site visits to a sample of locations ranging from lower to higher altitude points in the Beas River Basin. Key data from each location included concerns and site-specific conditions for the freshwater ecosystem services. The map seen below highlights the three communities studied in this report.

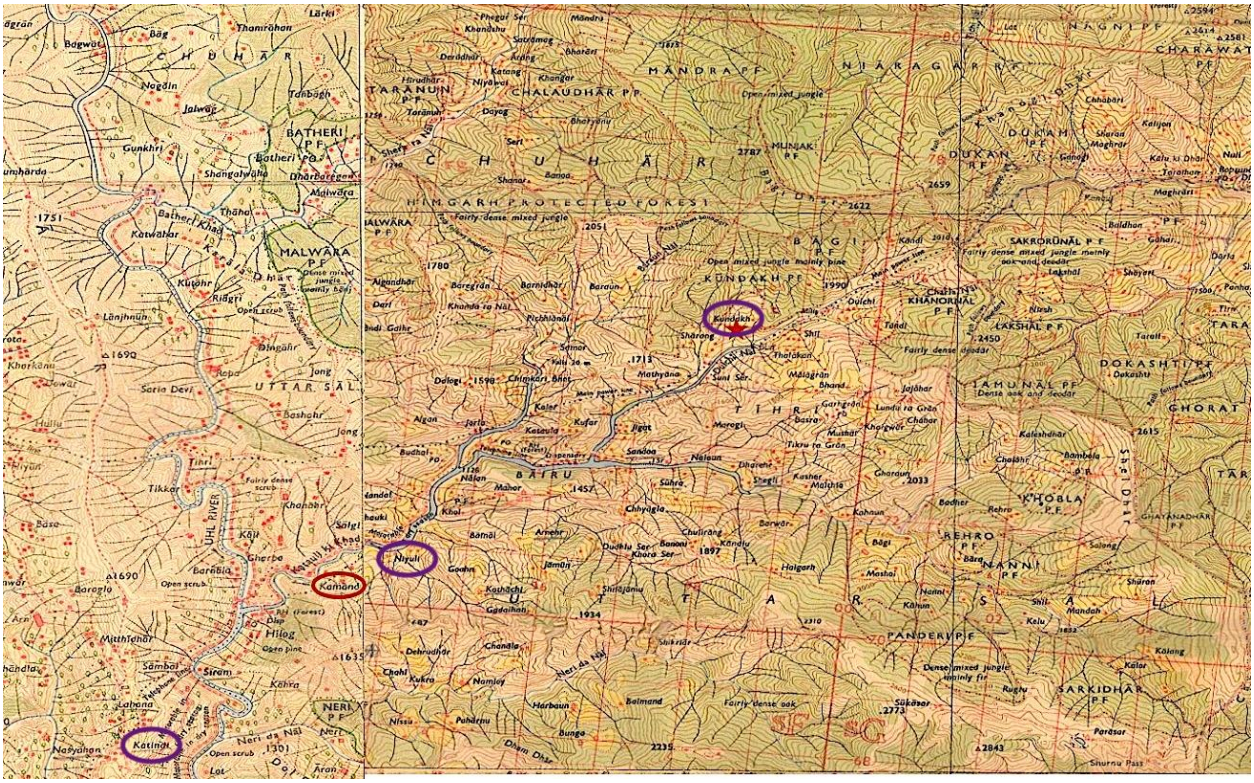

Figure 3. Topographic map showing the proximity of Katindi, Niyuli, and Kundak to Kamand where IIT Mandi is located

Rural Mountain Village of Kundakh

Among the rural villages we visited, Kundakh, can be found in the higher elevations of Mandi District at 2000m. This village is considerably populated with approximately 564 residents (2011 Census) and obtains its freshwater from two primary sources. Local residents

described their water infrastructure challenges and capacities to our team and led a tour of their infrastructure. In this community, water for irrigation and animals is collected and diverted from rivers and streams. The accessibility of this water is dependent on the season where between May and June this resource is fed by glacial melt and between July and August by the monsoon. Their drinking water, however, is collected through a newly constructed water lift built in 2017 (Interview 1, Kundakh, 2023). Water is stored using government-built enclosed storage tanks and dispersed to the community by pipelines. Examples of their infrastructure can be seen in Figure 4. Before the water tanks and water lines, residents relied on a set of wells. In these cases, the water had to be carried by hand to wherever it needed to go. Maps of the Kundakh site and its freshwater ecosystem service infrastructure changes over time can be seen in Appendix A.

Figure 4. Water tank and open pipeline in Kundakh (Photo Credit: Manav Sharma)

One of the critical water usages emphasized was the water required for farm animals. Within the community, cattle provide many vital resources. One of the most important in agricultural villages is manure for farming. Additionally, cows provide food products such as ghee, milk, and other valuable milk products. An image of their cattle pond can be seen below (Figure 5). At the time of the visit in March, the water level in the pond was low with water only reaching one side of the pond.

Figure 5. Cattle pond in Kundakh (Photo Credit: Manav Sharma)

Riverside Village of Niyuli

Set along the bank of a tributary to the Uhl river and at an elevation of 1100m. The villagers of Niyuli get their water from two main sources. The water used for drinking is piped in directly from a nearby spring/bouri. This water is considered clean enough to drink unlike the water used for irrigation and livestock that is collected from the Nalla runoff water. The water from the Nalla flows in larger volumes and although comes from springs the water is indirect and flows openly leading to more contaminants. The water from the Nalla is also distributed by pipe for irrigation for farmers.

To increase access to water, in recent years the government installed a pipe system hooked up to a tank in the mountains. Due to a lack of maintenance, the tank is never filled and the pipes are not operational. This is causing villagers to have to rely on their own means of water collection and fetch water from the river by hand when the springs dry up (Interview 2, Niyuli, 2023).

Figure 6. The landscape of Niyuli. This village is located in a valley surrounded by mountains and next to a river. Crop fields can be seen next to the river in the center of the image (Photo Credit: Violet Smiarowski)

Sub-Urban Mountain Village of Katindi

Located in the mountainous outskirts of Mandi at an elevation of 1300m, Katindi is a small community that holds a population of 210 people and 45 households (2011 Census). Residents here primarily receive their water from mountain springs. The spring water is distributed using government-provided pipelines across the village and is used for cooking, drinking, and washing. Some of this water is stored in tanks on the roofs of houses for household use. Irrigation, on the other hand, is needed in larger quantities with less strict quality requirements, a separate source is used. Instead, cyclic rainfall is the only supplier of water for farming. There is no government irrigation scheme for the area. This had not been an issue for

residents of Katandi, because of the past reliability of the rain patterns but with changing rain patterns and droughts in recent years there has been a greater strain on the current freshwater ecosystem services. In addition to no irrigation scheme, residents who own livestock have no governmental support for providing water for those animals (Interview 6, Katinidi, 2023).

Figure 7. Crop fields in Katindi (Photo Credit: Violet Smiarowski)

Shared Regional Services

Along the primary roads running from Mandi Town through the smaller villages at higher elevations, government wells have been provided in evenly distributed locations to supply residents with potable water within walking distance of the road. These bore wells provide water via a manual crank pump and are photographed below (Figure 8.) In some cases, these wells can be accessed by communities accessible by footpath only that reside above the roads. In other cases, residents can walk or drive to fill water canisters for personal use.

Figure 8. Manual hand pump seen on the side of the road around villages (Photo Credit: Matt McMahon and Violet Smiarowski)

Another shared service includes the traditionally designated sacred springs that can be found periodically alongside the roads. These springs, usually constructed by the local villages, are sourced from water basins inside the mountains. Primary uses for this water supply include consumption and religious services. These religious services include days and festivals where people go to resources and worship. Locals will also collect the holy water to bring home and shower with to cleanse one's body of disease. (Interview 1, Kasol, 2023). An example of these springs is provided below (Figure 9).

Figure 9. Naturally replenishing protected spring located below the village of Kundakh (Photo Credit: Matt McMahon)

Objective 2. Gauging Local Perceptions of Freshwater Services

Our second objective focused on the responses to changes and scarcities in the region. We noted a trend in responses, in which residents cited water quality as well as climate disruption to water as their primary concerns.

Availability and Quality of Freshwater

The first topic investigated was the locals' thoughts on the current availability of freshwater in the community and if there had been any changes in the quality of freshwater over time they remember. We were not surprised by the responses recorded in these interactions. We

found that the availability of water in all the villages studied was reported to have decreased in recent years. In Niyuli, interviewees noticed a decline in the amount of water. Their recollection was that 20 years ago there was enough water to meet all their needs and the rivers flowed high, whereas during our fieldwork the river has very little flow, as seen in Figure 10 (Interview 4, Niyuli, 2023)

Figure 10. Tributary to the Uhl river with very little flow (Photo Credit: Violet Smiarowski)

Additionally, local residents attributed improper waste management as being a major factor in the reduction of freshwater quality. According to these interviews, residents noted that due to a lack of proper governmental waste management in rural areas, basic trash such as plastic wrappings and food packaging waste is being thrown into local streams or burnt in makeshift landfills. River disposal of waste dramatically increases during the monsoon season, when the intense rainfall and river volume gives the perception of the waste being completely removed from the area if disposed of into the raging water. The reality of doing this leaves the basins of these rivers dramatically polluted and potentially unable to provide quality freshwater for irrigation or consumption further exasperating local FES in the area.

Figure 11. River from Niyuli with littered with plastic trash (Photo Credit: Violet Smiarowski)

Impact of Climate Change on Freshwater Ecosystem Services

Understanding the community's perception of the impact of climate change and compound extremes on the local freshwater ecosystems in the community and the risk of water scarcity or water stress in the community was a large part of the project. In interviews with community members of all villages, a decrease in the availability of water was reported. They attributed the strain on available water to a combination of climate change, deforestation, and in some communities an increase in population. Although not all interviews specifically mention climate change, examples of climate change-related effects such as reduced water quality, less snowfall, less water volume, and intense rainfall were included.

An example of this can be seen in Katindi where it was reported that since 1994, there has been no significant snowfall in the region whereas prior the region received 1.5-2 ft of snowfall during the winter season (Interview 1, Katindi, 2023). The decline in snowfall results in less flowing water in the spring as the frozen water reserves melt. All of the communities we visited experienced changes in precipitation throughout their lifetimes. Particularly in Katindi, climate change has begun to shift and decrease the amount of rainfall, leading to a shortage of crop yield and quality and putting their growing seasons at risk for crop failure. This is damaging to the local economy and forces people to outsource a greater portion of their diets

> *"Earlier we used to sow rice in the region during Monsoon [Season] which is not the case today. Crop production is so low that even the cost of seeds is not compensated by the output itself."* *(Interview 5, Katindi, 2023)*

since they can no longer be grown where they live. The crops that are able to be grown also have to adapt where they used to be apples grown in Katindi, from a combination of more extreme temperatures, and reduced precipitation apple production is now minimal (Interview 6, Katindi, 2023). Meanwhile, in Katindi inconsistent rainfall has caused various crops to become obsolete and villagers have had to change staple crops such as wheat seed varieties to adapt to changes (Interview 10, Katindi, 2023).

Adaptation Measures

Climate change-related disasters are increasingly experienced in these communities, and include landslides, cloudbursts, and droughts. The droughts are especially detrimental since the water available is often not enough forcing adaptation measures to survive. During these periods of drought villagers from Niyuli and Katindi reported needing to personally source water either by collecting it from rivers by hand (Interview 2, Niyuli, 2023), taking their cattle to near river areas for their drinking water needs, or other places such as "Magrudhaar" (Interview 10, Katindi, 2023).

> *"Droughts are the major issue in the region. In peak summer water supply is not adequate to meet the water demand of cattle. So locals have to bring water from nearby water sources like river and springs in vehicles."* (Interview 1, Katindi 2023)

Another way the people in these communities have to adapt is by finding their own means of distributing water. In most cases the government is only able to provide limited amounts of drinking water at centralized locations, additional efforts have to be done at a personal level. Water distribution was identified as one of the most lacking governmental initiatives. One of the interviewees expressed concern regarding the distribution of water for irrigation (Interview 2, Niyuli, 2023). While some farmers are able to afford pipes to irritate the fields, that is not the case for all. Some can rely on traditional systems such as diversion channels and kuhls, but this is only an option for those within gravity feed range of the river or another body of water.

Governmental Efforts

In each community, residents had opinions about the role and responsibility of the government in water management. The communities spoke to the government's efforts for adaptation to climate change impacts on freshwater resources and problems with the current water infrastructure. While government aid is noted to be available to support these water-vulnerable villages, our interviews suggested that this form of intervention is lacking in certain measures. In Kundakh, interviewees noted that the government supplied tanks of water sporadically to supplement the shortages. Unfortunately, the delivered amounts were only able to provide families with drinking water, leaving none for irrigation or cattle (Interview 1, Kundakh, 2023).

In Niyuli some residents reported recent efforts made by the government to increase the forested areas in the surrounding areas that would improve the current water quality and volume, but not everyone in the community was in agreement about if that was true. As mentioned previously, the government had also installed a water tank and pipe

> *"It's the duty of the government to take care of these resources."* (Interview 6, Katindi, 2023)

system that due to improper maintenance and communication are not operational. Interviewees expressed that the agriculture department made no effort to talk to community members or farmers about the installed tank system leading to poor tank placement (Interview 4, Niyuli, 2023).

In Katandi, the general consensus was that the governmental distribution efforts were not enough to meet the needs of the town. Some individuals want a greater localized water lifting scheme, but a majority of interviewees felt that an irrigation scheme would be largely beneficial to addressing the upcoming problem of crop failure. When asked what community members were willing to pay, although many were willing to pitch in 50-150 rupees/month, a couple of people did not feel it was right to pay since it was the government's responsibility to maintain the ecosystems (Interview 2 and 6, Katinidi, 2023).

Objective 3. Assess and Highlight Vulnerability

Our final objective was to sort and record growing trends that exhibit a decline in the overall ecological health and thus harm freshwater access. These trends span across all regions covered during the interviewing portion of this study and on average contribute to the harm of freshwater quality in every area.

The Decline in Average Precipitation Rates

The most prevalent issue shared across all villages was the decrease in local precipitation. Outside and within monsoon seasons, interviewees stated that the rate of rainfall has declined substantially in recent years, while intense cloudbursts and thunderstorms have become more frequent (Interview 1, Kundakh, 2023). These extreme weather events are not sustainable or reliable and unable to provide freshwater to local villages. The intense speed and volume of rainfall during cloudbursts can be destructive and dangerous to the residents and their property while the water discharged is many times unable to replenish natural groundwater supplies. Meanwhile, the decline in the overall average precipitation and rainfall patterns puts a strain on the ability of locals to reliably collect water.

The Unreliability of Current Irrigation Methods

The inability to properly irrigate local farm space was a recurring issue across the villages. Aided by the decrease in rainfall, this inadequate water supply leads to the possibility of drought conditions and crop reductions (Interview 3, Katindi, 2023). While methods such as water adaptation to crop reduction could solve the issue of loss of rainfall, some villages such as Katindi suffer intensely from this lack of irrigation. According to interviews in this village, the primary source of irrigation comes from their unique cyclic rainfall across the year. For the past few decades, this rainfall was able to properly supply local farms in Katindi. However, due to the growing threat of climate change, this rainfall has dramatically shifted in timing and intensity, causing farming patterns to break apart. While drinking water is supplied with water tanks Katindi’s condition in the past, the area has nothing to supplement the lack of rain in the present (Interview 2, Katindi, 2023). This oversight acts as a major risk to the sustainability of Katindi and other villages like it.

Discussion

Taken together, our data show that climate change is putting a heavy strain on the freshwater ecosystem services in the Mandi district. However, it is worsened by a variety of factors. In the village of Kundakh, the effects of climate change are further amplified by an increasing local population, stretching the available freshwater resources thin. There is a lack of government accountability in the completion of ongoing ecosystem service schemes. The village of Niyuli was given false hope for climate adaptation measures when the government installed a water tank to collect spring water and added piping into the village. This tank was built with no plan for additional service or maintenance, leaving the village to find alternative sources of freshwater. Finally, in Katinidi, the absence of an irrigation scheme is putting a strain on the ability of this community to grow their food. This story is all too common in the Mandi District, as governmental schemes are often reported to be left mismanaged and not maintained, which disproportionately affects marginalized communities and the least fortunate. Oftentimes, this lack of accountability leaves local residents no choice but to take self-action. This includes being forced to obtain freshwater for their own use or risk reducing their consumption in relation to irrigation. However, self-action is not a reliable or impactful option for many of the many critical issues impacting freshwater ecosystems, such as the rising rates of contamination, deforestation, and landslides.

From conservation in Kasol, a small town in the Kullu district situated directly next to the Mandi district, one solution that a local saw was the introduction of a leader within the community. The role of this leader would be to organize and implement the needs of the community because they are at the ground level whereas the ministries are disconnected. He felt that as long as people in the community were well-informed and had someone to take charge, progress would be made (Interview 1, Kasol, 2023).

We were struck by the inability of community members to answer our question to identify which freshwater ecosystem services are most important to their daily lives. Their response was not due to a lack of knowledge or an abundance of freshwater services, but rather that the villagers are unable to say that any given service is more important than another since to them they are all necessary essentials. For example, the water used for irrigation is no more important than the cow’s drinking water or the water that the locals use for drinking and washing. All of these freshwater ecosystem services are of vital importance to their livelihood, and livelihoods are their future.

Recommendations

After reviewing our interview transcripts, field notes, and overall results, we determined that there are important conversations that need to be facilitated between the rural communities of the Mandi District and the local government in order to make decisions about the mitigation of climate change and freshwater scarcity. These recommendations are designed to address the gap between government policy and funding, and the needs of local communities. Our recommendations are as follows:

1. Recommendation to Connect Government and Community
2. Recommendation to REFRESH Project & Survey

Recommendation #1: Connect Government and Community

Government intervention was a major topic of conversation in each of our interviews. Each village that our team visited had some level of a government-funded freshwater scheme. However, these government schemes are often left incomplete or unmanaged to the extent that they are unable to provide the local community members with the basic necessity of freshwater. There is a disconnect between the needs of the community and the efforts of the government.

The institution of a liaison is crucial to bridge the gap between the community's needs and the government's actions. The role of this liaison is to meet with local community members and members of the government to determine the needs of the community and how the government is able to assist these people. This person should conduct interviews just as our team has done to collect the perspectives of the local community members, and report their findings to the governmental body. The current administrative system in which a Gram Pachayat is elected to adhere to the needs of the community has proven to be ineffective at providing reliable freshwater ecosystem schemes.

An example of this can be seen where in Katinidi many people expressed the need for the government to create a better water distribution scheme that would allow for more efficient farming, and care for livestock. Similar to the way drinking water is distributed, this new scheme would provide a reliable and convenient way to support these villages' livelihoods. If the people of Katindi had a proper outlet to express these changes and effectively work with the government their needs could be satisfactorily met.

Bridging the gap between the community's needs and the government's actions will be beneficial for both parties. The local communities will be given a voice to express their needs and desires. The people will be informed about the actions taken or not taken by the government, and they will be able to contact the liaison with any questions or concerns. Currently, all of the time, money, and person-power that is used to create these neglected and half-finished schemes goes to waste. This addition can be used to greatly reduce this waste and money of the government by ensuring that all schemes are properly finished and maintained.

Recommendation #2: REFRESH Project & Survey

After conducting the interview portion of this project, it became clear after reviewing our team's information and feedback from participants that the survey and the information taken from it could be improved. Out of many post-interview comments, the most common response was that certain questions given throughout the interview were too rigid. Many of the questions' placement also interrupted natural conversation that grew from previous questions. While our original survey still was successful in obtaining useful information, its efficiency and the engagement experience could be vastly improved.

Improvements from the survey could come from giving interviewees more open-form questions and the opportunity to further explain. Adding these questions would allow a better narrative to come from the interview, where personal experiences can be taken and recorded rather than simply quantifiable data. These questions should replace questions regarding the quantitative ranking of existing freshwater services around the village. According to post-interview comments, freshwater consumption and availability is an issue in all forms of collection, from water tanks to spring water collection. Instead of this line of questioning, the interview could focus on opinions of the freshwater sources. This bypasses the task of prompting an objective ranking since respondents in this project reported that all of these sources are important.

From these changes and gaining a personal narrative with inquiries on the available freshwater services, the hope is that the survey will include a story-based form of data collection. Changing the structure of the survey can also provide a more comfortable experience for the interviewees being questioned. We further hope that meaningful conversations can be generated from this dynamic, perhaps leading to partnerships or connections. Relating these interviews back to the greater REFRESH project, these narratives can more easily go into further insight into the necessary actions and policies the local government can utilize.

Conclusion

Climate change is rapidly affecting the freshwater ecosystem services of the Mandi District. The last decade has shown a decline in rainfall and snowfall, with an increase in extreme weather events such as monsoons, cloudbursts, and landslides, and the Himalayan Third Pole has experienced an unprecedented glacial recession. Although there has been government intervention in the design and creation of various ecosystem service schemes, there has been poor execution and a lack of follow-through. The combination of climate change and a lack of action has left the local communities of the Mandi District with a growing problem. Without proper intervention, climate change will continue to reduce the number of freshwater resources in the Mandi District to a breaking point. As the impacts of climate change continue to strain the freshwater ecosystem services of the communities within and surrounding the Third Pole, it is critical to investigate the adaptation measures taken to support communities in mitigating long-term impacts.

We are honored to have been part of the REFRESH project and given the opportunity to contribute to its critically important efforts. This project contributes to two of the United Nations' Sustainable Development Goals of Clean Water & Sanitation and Climate Action.

Figure 12. The United Nations, n.d. (https://sdgs.un.org)

Globally, climate change has disproportionate impacts on freshwater ecosystems and the people that rely on them. We believe that the Himalayan Third Pole will continue to suffer from these effects of climate change without proper intervention.

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Appendix

Appendix A: hand-drawn map from Kundakh describing existing and previous freshwater ecosystem services

Appendix B: The full survey that our team used in the field to interview local community members.

Ecosystem Services Identification- Household Survey Questionnaire

Conducted by

School of Civil and Environmental Engineering,

Indian Institute of Technology, Mandi

In collaboration with

Indian Institute of Technology Roorkee

under the project

"REgional cooperation for FReshwater Ecosystem Services in Himalayas (REFRESH): Understanding the influences of monsoon variability and compound extremes" sponsored by Asia Pacific Network (APN)

The information, opinion, and knowledge you provide will be helpful for us to come up with a detailed assessment of ecosystem services in this community. The survey might take around half an hour. Your response will remain completely anonymous and is solely for our study.

Survey code		**Village/Area**		**Date**	
Latitude		**Longitude**		**Altitude**	

Section 1: Demographic information of the participant

Age		**Gender (M/F)**		**Marital Status**	
No. of family members		**No. of Earning members**		**Education level**	
Occupation			**How long have you lived here?**		

Section 2: General awareness on Ecosystem Services

1. **Are you aware of what ecosystem services(benefits we get from nature) are? If yes, list them.**

Yes	
No	

2. **In your opinion, which ecosystem provides you more services/benefits?**

Forest Ecosystem	**Freshwater Ecosystem**	**Others:**

3. What are the most important services that you get from this ecosystem?

Section 3: Provisioning services

4. Which of the following sources do you use for your water needs? Please rate their importance to you on a scale 1-10.

Sources of water	Yes/No	Rate its Importance on a scale 1 (least important) – 10 (extremely important).
Piped water (Govt supply)		
Stream/river		
Spring		
Borehole/well (Groundwater)		
Pond/reservoir/lake		
Wetland		
Other (specify)		

5. Which of the following services do you get from the freshwater sources nearby?

Services provided by freshwater	Yes/No	Rate their importance on a scale of 1 (least important) – 10 (extremely important).
Water for drinking		
Water for non-drinking (domestic) use		
Water for irrigation		
Fish		
Others (please specify if so)		

6. What are the major sources of drinking water in your area, how much volume do you collect/use per day and rate the quality of the water of these sources?

Sources of water	Yes/No	Local unit/litres	Rate the quality (1-10)
Piped water (Govt supply)			
Stream/river			
Spring			
Borehole/well (Groundwater)			
Pond/reservoir/lake			
Wetland			
Other (specify)			

7. Do you pay for drinking water? If yes, how much do you pay? (per-month basis)

8. **What are your major sources for water for domestic use in your area, how much volume do you collect/use per day and rate the quality of the water of these sources?**

Sources of water	Yes/No	Local unit/litres	Rate the quality (1-10)
Piped water (Govt supply)			
Stream/river			
Spring			
Borehole/well (Groundwater)			
Pond/reservoir/lake			
Wetland			
Other (specify)			

9. **Has the quality of freshwater changed in the past ten years? If yes, rate its previous and current water quality.**

Change in quality of water	Yes / No	
Source	Rate the previous quality (1-10)	Rate the current quality (1-10)

10. **How often does the community need to use alternative sources of water due to shortage of water?**

Period	Yes/No	Alternate source
Once a week		
Once a month		
Once a quarter		
Once in six months		
Rarely		

11. **Do you pay for water supply? If yes, how much do you pay? (per-month basis)**

12. **Do you own any agricultural land?**

Yes	Area =

No	

13. Which crops/plantations do you grow? Are they irrigated or rainfed and if irrigated, which water sources do? *(Sources: Piped water (Govt supply), Stream/river, Spring, Borehole/well (Groundwater), Pond/reservoir/lake, Wetland, Other.)*

Crops	Irrigated	Rainfed	Source of water

14. What plant-based/ Forest-based resources do you rely on?

Plant-based sources as services	Yes/no	Comment/rate their importance (1-5)
Timber		
Fuelwood		
Fodder		
Cereals		
Thatch		
Vegetables		
Fruits		
Medicinal plants		
Ornamental plants		
Essential oil		
Dye		
Others (please specify if so)		

15. Do you own a livestock/poultry farm? If you do, how much do you earn from these animal-based products?

Do you have livestock?	**Yes/ No**	
Animal-based services	**Products**	**Income obtained through them**
Dairy products	**Milk** **Ghee** **Butter** **Curd** **Meat** **Other**	
Poultry products	**Egg** **Meat** **Other**	

Section 4: Regulating Services

16.Which of the following benefits do you get from nature?

Regulating Services	Yes/No	Comment/ rate their importance (1-5)
Erosion control		
Water regulation/Flood control		
Climate regulation		
Habitat maintenance		
Pollination		
Pest or Disease Control		
Soil retention/ fertility		
Dilution by water/air		

Section 5: Cultural Services

17.Do you feel that nature also benefits you with religious, cultural, recreational, tourism aspects? If yes, what are those benefits?

Yes	
No	

18.Are there any places of spiritual, religious or aesthetic attraction in your area? If yes, please specify.

Yes	
No	

19.Have you seen tourists visit your area? (Yes/No)

20. If Yes, what is/are the reasons for tourist attraction here?

Cultural services	Yes/No	Comments/rate its importance (1-5)
Recreation		
Aesthetic beauty		
Tourism		
Education and Research		
Religious/ nature worships		
Spiritual		

21. Are there any particular season or time when tourism is famous here? If yes, please specify.

22. Is tourism beneficial or non-beneficial to you? List the specific reasons for your answer.

Beneficial				
Non-beneficial				

Section 6: Climate change and human impacts on Ecosystem Services

23. Have you noticed any changes in the climate of your area during your time here?

24. Is the area prone to any natural disasters? List them –

25. If so, how does the community manage the consequences and prepare?

26. Have measures been taken to ensure continued freshwater availability during natural disasters? If yes, specify them.

Yes	
No	

27. Has climate change affected ecosystems in any manner?

Major ecosystems	Change (0- No change, 1- increase, 2- decrease)	Reasons for change
Forest		
Agriculture land		

Freshwater		

28. Have you noticed any changes in the availability of specific ecosystem services in recent years?If yes, please specify the service as well as the reason for the change.

Service	Change (0- No change, 1- increase, 2- decrease)	Reasons for change

Section 7: Payment of Ecosystem Services

29. If you are asked to contribute and pay for maintaining the ecosystem, are you willing to pay and how much?

Yes	
No	

30. If you do or do not want to pay, what is/are the reason/(s)?

31. Who do you think should manage the fund generated for managing a healthy ecosystem?

Bodies	Yes/No	What you expect from them
Local community		
Government		
The village administration		
Others (specify)		

Section 8: Management of Ecosystem Services

32. Is there anyone who is responsible for managing the ecosystem services in your community?

33. Are there any ecosystem management-related activities carried out to support livelihood enhancement in your areas?

Yes	
No	

34. Are there any initiatives underway to improve the management of ecosystem services in your community?

Yes	
No	

35. Do you feel that the government is considering the perspectives and needs of the local community while making decisions related to freshwater resources and climate change?

Yes	
No	

36. Do you think there is a scope for improvement (any additional comments or suggestions regarding the ecosystem services in your community)?

Yes	
No	