Assessing Gharats of the Kamand Valley

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Abstract

This project assessed the challenges facing traditional Himalayan watermills known as gharats. We conducted site assessments at 21 gharats and interviewed both mill owners and local grain farmers to explore the social, technical, economic, and environmental reasons for mill abandonment. Additionally, we examined the factors causing diminishing demand for gharats’ services. We developed recommendations for watermill owners, and initiated a pilot renovation on an abandoned mill to test innovations that can maintain the gharat’s tradition.
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EXECUTIVE SUMMARY: ASSESSING GHARATS OF THE KAMAND VALLEY

The Decline of Gharats in the Himalayan Region

The District of Mandi resides in the northwestern Indian state of Himachal Pradesh. A predominantly rural state, Himachal is home to just under seven million people (Census of India, 2011). The region’s high mountains and narrow roads discourage the import of goods, resulting in a need for locally produced food. Consequently, agriculture dominates the state’s economy, contributing about 30% to the state’s gross domestic product and providing employment for nearly 71% of the population (Himachal Pradesh Department of Agriculture, 2015). Since the region’s primary crops are wheat and corn, the need has always existed for a method to process these foods. Small, individual watermills, known in Hindi as “gharats”, were developed to fulfill this purpose (see Figure 1). Harnessing energy from the many streams and rivers that cut through the mountains, gharats have been in operation for centuries, processing grains into flour using a large grindstone connected to a turbine that spins with the flow of water.

Figure 1. Himachali gharats (Paredes, 2015).
This simple technology harnesses natural resources into energy and income for families, and is thought to produce a higher quality of flour than modern alternatives (Abhik Ghosh, 2008). Unfortunately, fewer of these water mills are in operation every year. Many factors are contributing to the gharats’ decline, ranging from environmental changes to lack of technological innovation (Vashisht, 2012). The goal of this project was to build an understanding of indigenous milling methods in Mandi District and to create recommendations that can improve the industry’s longevity. To accomplish this, our team set three objectives: conducting baseline site assessments, interviewing stakeholders, and collaborating with stakeholders to create innovative mill improvement strategies.
Indian Gharats: Operation and Challenges

Before completing our on-site fieldwork, we conducted preliminary research to gain both a historical and a technical understanding of gharats, as well as to identify the broad challenges that they face.

Operation

The Himachali gharat (Figure 2) has remained technically unchanged for centuries, using an ancient technique developed around 100 B.C.E. to grind wheat into flour (Hellmans, 2004). Water is first diverted from a nearby river or stream into stone or earthen canals. These canals guide the flow toward a chute, which is placed above the gharat in order for the water to gain momentum as it falls toward the turbine. Debris is removed from the flow through the use of makeshift wooden filters. The gharat’s turbine and chute have classically been constructed of wood, but recent years have seen a trend to replace these components with metal counterparts (Vashisht, 2012).

Figure 2. Basic structure and mechanism of a gharat (Gurudev, 2015).

A funnel with a slow release mechanism is located on top of the grindstone, gradually depositing grain into the stone’s center. Centrifugal force pushes the grain outwards, crushing it into flour. The flour is released through the edges of the grindstone where it can be collected by the gharati.
**Contemporary Challenges to Gharats**

Thousands of gharats in Himachal are still functional and used on a regular basis. However, given the unique location requirements and remote nature of some gharats, there are numerous factors that contribute to the abandonment of the mills (Vashisht, 2012). To address these topics more completely, we evaluated the mechanical, environmental, and social challenges that determine a gharat’s success.

**Mechanical Factors**

Rainwater picks up rocks and dirt as it flows down the steep mountainsides that flank the rivers of Himachal Pradesh, saturating them with small particles. Crude water filtering techniques (see Figure 3) are inefficient in removing most of the debris, resulting in significant erosion damage to the mill mechanism. Wooden turbines and blades are the most affected, and must be frequently repaired or replaced.

![Common canal filter comprised of vertical sticks](image)

**Figure 3. Common canal filter comprised of vertical sticks (Lentz, 2015).**

In addition to wear on the turbine, friction generated during the milling process slowly smooths the surface or the grindstone. It must be frequently roughened in order to maintain its milling efficiency (Ghosh, 2008).

**Human and Environmental Challenges**

The gharat’s location also poses unique challenges. Although the rivers that power the gharats are fed by snowmelt and glacial runoff, rainfall is the driving factor behind their flow rate. In monsoon season, 70% of the average annual rainfall in Himachal falls during
the months of July, August, and September, with just a small amount of precipitation in the winter months (Meoweather, 2014). This uneven rainfall causes the water level of rivers and streams to vary wildly over the year, creating unreliable conditions for the water diversions necessary to power the mills (see Figure 4).

Figure 4. Water diversion from river (Paredes, 2015).

In addition, alterations in the flow of water sources upstream from the mill may render it inoperable, and can occur due to floods, landslides, and human interventions. Increased absorption of water into the ground due to extensive deforestation in the region is also a factor, and can result in a reduction in the flow of mountain streams (Agarwal, 2009).

**Challenges in Supply and Demand: Tradition vs. Technology**

Finally, the introduction of modern alternative milling techniques in rural communities has greatly reduced demand for the gharat’s services. Some local farmers have turned to more convenient processing methods, such as installing diesel-fueled or electric mills in their homes rather than transporting up to 30 kg of grain to and from the gharats (Ghosh, 2008). This shift towards electric milling is thought to carry a negative health effect. When subjected to the high temperatures produced by electric mills, fat inside grain becomes rancid and many of the vitamins are destroyed (Aubert, 1989). The low
grinding rates found in gharats distribute nutrients much more efficiently, and also increase levels of vitamin B₁ (Moritz and Jones, 1950).

In order to research more into the challenges facing gharats, we conducted on site fieldwork and interviewed millers near IIT Mandi’s Kamand Campus.
Methodology

The goal of this project was to build an understanding of indigenous milling methods in Mandi district and to create recommendations that could improve the industry’s longevity. In order to meet this goal, our group established three objectives:

1. Gather basic site information, including the location, operations, and quality of mills.
2. Obtain stakeholder knowledge about mill operations, usage, and challenges to the industry.
3. Collaborate with local millers to develop strategic improvement scenarios.

The methodological approach that our team used is summarized in Figure 5.

![Methods Overview](image-url)

**Objective 1: Site Evaluation**

In order to conduct effective site evaluations, we identified gharats on the basis of local recommendations and recorded their GPS locations. We developed a site assessment checklist that aided us in documenting key technological and geographical traits of the gharats. Information points of interest included whether the gharat was operational, its proximity to the road, the character of the terrain between the gharat and the road, the mill’s turbine design, and the current water flow conditions. Since our team was limited in terms of time, the scope of our assessment was restricted to mills within a 30 km radius of the IIT Kamand South Campus.
**Objective 2: Interviewing the Stakeholders**

In order gain firsthand information into mill operations, usage, and challenges to the industry, we conducted two separate kinds of interviews: one with the local villagers and another with the gharatis. We first interviewed villagers who use the gharats to grind their grain and those who use alternative methods, utilizing snowball sampling to contact respondents (Figure 6) (Biernacki, 1981). The customers we met at the gharats were our initial sample, and with their help we identified other residents who used alternative milling methods. Villager interviews focused on the reasoning behind each stakeholder’s milling practices. To encourage friendly dialogue, we recorded stakeholder responses immediately after the conclusion of the interviews.

![Interviewing gharat #1 owner (Paredes, 2015).](image)

Upon the completion of each mill’s site assessment, we conducted a loosely structured, open-ended interview with each mill owner. Open-ended interviews allowed the data to emerge naturally through discussion (Berg, 2011). We designed questions to yield specific data on general challenges to gharats, parts that frequently break down and whether attempts to upgrade or adapt the gharat had been made in the past.
**Objective 3 - Development of Recommendations**

Our final objective was to collaborate with the gharatis to develop potential recommendation scenarios. Our team accomplished this task in two steps. First, we developed a set of mill improvement scenarios based upon our findings from site assessments and stakeholder interviews, taking care to craft these scenarios around specific issues of interest to the gharatis (Berg, 2011). Second, we identified policies and business innovations that could be favorable to the gharats. We delivered the outcomes of this work to the stakeholders for further input.

**Data Management**

Data containing gharati and villager names was stored on a password-protected laptop. Only numbers and not actual names were used in our publications. Interviews first were obtained orally in Hindi and then translated by IIT team members. This information was relayed to WPI team members and recorded.
Results and Discussion

In this section, we present results obtained while completing our three objectives.

**Objective 1. Site Evaluation**

We identified and assessed 21 gharats (Figure 7) by recording essential information from our checklist.

![Location of gharats (near Kamand area)](Image)

**Figure 7. Gharats we assessed (Adapted from Google Maps).**

Of these 21, eleven were functional, but only three were the gharati’s sole source of income. Gharats were found in clusters, usually next or close to a village. The bigger the village, the more gharats we found. Most of the gharats we found divert water from a river using stones; those located alongside larger rivers find it easier to obtain the flow rate they need. Gharats #1, #2 and #3 were each located next to a strongly flowing river, near the
north campus of IIT Mandi. They are all functional, with a noticeably fast-spinning grindstone. Gharats #5 - #10 are located in a village called Neri. Three of them are functional, but are located next to a smaller river. With the exception of gharat #8, which has a highly efficient turbine and nozzle to direct the water, these mills spin at a slower rate than #1, #2 and #3. Gharat #11 is in disrepair, and according to the gharat, it is because the turbine had broken a few years back. They could not afford to replace it, but we saw that the flow of water they were using came from a groundwater stream that was very weak, and we wondered how it could ever be functional without a holding tank to increase potential fluid head. The last cluster we found consisted of gharats #12, #13, #14, #15, #16, #17, #18, #19, #20 and #21 near a village called Mathaneul. Five are functional, and they all use water from a very strong groundwater stream.

The water flow that the gharats received ranged from almost none, as was the case with gharats #11 and #21 (both in disrepair), to enormous quantities of channeled water, as was the case with gharat #20. Figure 8 shows the assessed gharats’ operational condition, as well as the percentage of abandoned gharats with no flow.

**Status of gharat**

- Operating: 52%
- Abandoned: 43%
- No flow: 78%
- Flow present: 22%

**Flow condition of abandoned gharats**

Figure 8. Status of gharats and flow conditions of abandoned gharats (Paredes, 2015).
Reasons for low water flow vary. Anecdotal responses noted that road construction brings mud and silt to streams. This can make the stream “disappear into the mud” (as described by one gharati) and become harder to harvest. This was the case with gharat #11. Gharat #20, however, had diverted so much water upstream from #21 that it no longer had sufficient flow.

A gharat’s flour output per hour is directly dependent upon the amount of water that it receives, the turbine’s efficiency, and how well the water is directed towards the turbine’s blades. One of the most successful gharats (#20) was exceptional. It had undergone an extensive, costly renovation a few years ago, and utilized five grinders simultaneously. The gharat’s owner claimed to produce 170kg of flour every hour. However, this gharat proved to be an outlier. Figure 9 shows that most gharats process between 10kg to 20kg of grain per hour.

![Grinding rate per hour of operating gharats](image)

**Figure 9. Reported grinding rate (kg per hour) at operating gharats.**
Only two mills (both provided a single source of income) were accessible by road. Farmers who wish to mill their grain at other gharats must travel between 20 to 400 meters on foot with grain on their backs, and then the same distance back. Paths to the gharats were steep and rocky, and proved difficult for our team to use (Figure 10).

In terms of equipment, we found at least eight different types of turbines. We were surprised to find that the majority of operational gharats had upgraded to metal turbines. Out of the 11 operational gharats, seven used metal turbines, and only four still utilized wooden ones. Reported costs of renovation varied from 5,000 to 10,000 rupees. The design of the metal turbines varied from gharat to gharat. Some were constructed by the gharati, while others were built by area welders. Figure 11 shows a renovated turbine.

Figure 10. Path from road to gharat (Paredes, 2015).
Objective 2. Stakeholder Perceptions

Our interviews revealed more details into lives of gharatis. Most gharatis were very committed to their occupations. Of the ten gharatis interviewed, only one was not planning for his children to inherit the gharat. Among the owners of gharats with metal turbines, maintenance was not seen as a large issue. All turbine renovations had occurred between 5 and 10 years ago, and since then no repairs had been required. Owners of gharats with wooden turbines (Figure 12) told a different story. Turbines lasted around 10 years, after which they had to be replaced at a cost of around 5,000 rupees. These turbines’ wooden blades also frequently broke, and were fashioned and replaced by the gharati himself. Regardless of turbine type, mill grindstones must be maintained and replaced at the same rate. Every month or so the gharati has to remove the stone and flip it to re-carve grooves into the surface, a process which costs around 1,000 rupees. After approximately 10 years, the stone must be completely replaced. While some gharatis cut the stones themselves and others buy them, replacement did not seem to be a hardship.

Figure 11. Gharat #3’s metal turbine (Paredes, 2015).
Lack of lighting inside gharats was unanimously cited by gharatis as a limiting factor on output. The mills are very dark inside, and the milling process requires that the gharati is able to see the mechanism. Running electrical wires to the mills is beyond the economic means of most gharatis, so gharats are reliant upon natural lighting. Consequently, as one gharati explained, mill operation is limited to around 8 hours per day.

Charges for milling varied from gharat to gharat. Eight of surveyed gharatis employ a barter system, keeping 10% of the output in exchange for milling a farmer's grain. Two gharatis grew and milled their own grain, selling it in local markets for 20 rupees per kg. The owner of gharat #20 had a contract in which the government dropped off grain off en masse at his gharat and paid him .6 rupees/kg to grind it.

Competition from electric mills has greatly decreased the demand for gharats' use. According to one gharati, demand for his mill had fallen around 50% in the past 5 years due to two electric mills which had been purchased by local farmers. When we interviewed villagers near this gharat, those who used the electric mills stated that although they were aware that the taste of flour grinded in the electric mills was inferior to that of gharat-grinded flour, the added inconvenience of carrying their grain to the gharat outweighed the taste benefits of milling their grain there.

Interviews with villagers in Manyana provided a clear example of the negative consequences gharat closure. Road construction 5 years ago had greatly reduced the flow
of a mountain stream which powered the gharat that serviced the village. Its grinding rate was cut to below 5 kg per hour, dramatically slashing the income of the gharati. When the mill’s turbine broke two years ago, he did not have enough income to replace it, and the gharat fell into disrepair (Figure 13). Now, villagers must walk almost 4km to use the nearest electric mill. Besides reducing the quality of the flour villagers receive, this mill also charges either 3 rupees per kg of flour or keeps 15% of the output, a higher rate than that of the gharat. We found this rate increase to be consistent among other electric mills in our sample area.

Figure 13. Gharat in disrepair in Manyana (Paredes, 2015).

**Objective 3. Development of Recommendations**

After analyzing data obtained through our first and second objective, we developed ideas for improving mill operation and increasing their demand. When we took these recommendations back to the gharatis, we discovered that some of these suggestions were not desirable from their perspective. For example, although we thought a brochure or flier advertising gharat locations might be distributed in area, they indicated that their presence was already well known. However, they agreed that raising awareness about the nutritional benefits of stone ground flour would be useful. Other recommendations the gharatis did see as feasible were developed further and appear in our Project Outcomes.
Discussion

We identified three key factors that tend to lead to mill abandonment. First is lack of water flow, which can have a devastating effect. The abandoned mills in Neri village, for example, were all located on the same side of the river. The millers told us that they were abandoned when the flow of the river changed direction slightly and left them with a very small flow rate. This problem is complex and hard to address, leaving gharatis at the mercy of the frequently occurring landslides of Himachal Pradesh. Second, we found that every operational mill was within five minutes of the nearest road. Farmers near mills that are far from roads found it inconvenient to carry their grain to and from the gharats, and chose to use electric mills instead. Third, we found that occasionally, as with gharat #11, the owner cannot afford to replace parts that have broken down.

Turbine material directly affects mill output. Gharats with wooden turbines routinely produced a lower grinding rate than metal gharats diverting water from the same stream. Gharatis who had upgraded their mills reported that the investment had paid off in around three years. This easy replacement is clearly worth the effort.

Although most villagers interviewed attested that flour ground in a gharat tastes better than flour ground in an electric mill, few were aware of the nutritional benefits of gharat flour. Over the long term, consuming only electrically milled flour has potentially devastating health effects. A German study in 1970 fed varying types of flour to groups of rats. Flour constituted 50% of the rats’ diet. After four generations, only the rats that had been fed fresh, stone ground flour maintained their fertility (Bernasek, 1970).
Project Outcomes

Recommendations

Our data from site assessments and interviews led to three recommendations that can support and maintain the gharat’s tradition in the future:

1. Improve gharat access and visibility.

2. Support commercial and cooperative contracts for local gharats.

3. Implement technological upgrades to gharat parts.

First, we suggest two small changes to the gharat business operation. Roadside signs (see Figure 14) can identify the easiest path to the gharat. In some cases where access is difficult, we suggested creating roadside booths at which customers might drop off grain and pick up flour. This would reduce the effort farmers need to exert carrying grain and flour over rough terrain, the biggest inconvenience of using the gharats cited in farmer interviews. Although one gharati felt this would require another worker to staff the booth, we suggest implementing a mailbox-like structure where grain can be dropped in but only the gharati can later remove it and carry it down to the gharat.

Figure 14. Possible roadsign of a gharat (Paredes, 2015).

To raise awareness about the advantages of using gharats, we recommend the circulation of an informational flyer distributed to local villages (see Figure 15). This flyer would stress the beneficial health effects of stone ground flour and the lower milling cost of
the gharats. Although we initially thought to include a map showing the locations of nearby gharats on the back side, some gharatis thought this was unnecessary as locals know their location. However, this information could be distributed to villages farther away, specifically those solely reliant upon electric milling. We plan to present these flyers to the leaders of the local villagers near the gharats we visited, so that they can distribute the fliers to their neighbors and educate them about the benefits of consuming gharat flour.

![Why should you mill your grain in a gharat?](image)

**Figure 15. Front side of informational flyer (English translation).**

Our second recommendation is to boost commercial and cooperative contracts for local gharatis. To take the first step, we proposed policy to the IIT recommending that they purchase grain wholesale and grind it at local gharats. Beside the health benefits, IIT Mandi would stand to financially gain from this action. Grinding grain at gharats costs around 10 rupees per kilogram less than grinding it at an electric mill. As IIT dining facilities currently purchase 450 kg of flour each day, milling at gharats could save the school as much as 1,000,000 rupees per year. Response to this recommendation was enthusiastic, both from gharatis and from an IIT administrator.

Our third recommendation concerns basic technological upgrades. Expecting an increase in demand due to our previous recommendations, we recommend that mills still using wooden turbines and blades should convert to metal components due to their increased efficiency and low maintenance costs. Renovations to the gharats' water
diversions were also proposed to gharatis where necessary, as some gharats’ channels were leaking significant amounts of water.

Finally, we recommended to the IIT that they consider further study of gharats as either an IIT design practicum or as a future IQP/ITSP project. We believe the development of mill-powered interior lighting could greatly benefit gharatis. While our team was able to design a prototype, we realized that dedicating the time required to fully refine, test, and implement this device would prevent us from reaching our original objectives. The prototype we designed would slot into the top of the mills grindstone, spinning along with it. A gear attached to the top would be connected by a bike chain to a small generator in order to power a 60 watt light-bulb (see Figure 16). Follow up interviews with gharatis indicated a high level of interest in this prototype.

Figure 16. Electrical generator prototype (Lentz, 2015).
The impact of implementing such a device would be significant, as this device has the potential to triple a gharat’s potential output. However, it must be as low tech as possible so the gharati may maintain it himself (Ghosh, 2008). Additionally, we recommend the establishment of a local cooperative which supplies grain to IIT dining facilities. IIT mess halls’ flour consumption will continue to rise as construction of IIT Mandi’s Kamand Campus progresses. If the IIT were able to cut out the middleman (their current flour supplier), the university could further cut food expenses while providing a boost to the local economy.

**Pilot Renovation: Manyana**

In addition to our three principal recommendations, our project also facilitated the renovation of a gharat near Manyana, a small town 5km from Mandi in order to showcase possible outcomes from implementing our recommendations. After the end of our project, a new metal turbine will be installed by IIT students; along with designs for an improved chute and water storage tank. Villagers near the gharat are currently forced to walk nearly 4 km to reach the nearest electric mill. To alert them of the renovated mill and encourage their business, the above mentioned flyer will be distributed in the area.
Conclusion

The gharat is part of the heritage and identity of Himachal Pradesh. Our study revealed a long tradition of mill culture that is integral to the lifestyle of local villagers. Gharats are a low cost, sustainable, and healthy means of grain processing in the region. With some minor upgrades and adaptations to their business model, the gharats of Himachal can be preserved, providing millers with locally important and financially viable businesses. The gharatis and their mills represent a perfect snapshot of Himachal: the old seamlessly mixing with the new to meet the unique needs of people in this region.
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Supplemental Materials: Background

Watermills Background

The earliest evidence of water powering a rotating wheel was in 300 B.C.E at Perachora, Greece (Lewis, 1997). Philo of Byzantium was the inventor of this machine and it’s considered one of the first mills powered by water. However, in 1965 Joseph Needham placed the origin of the first watermills around 350 B.C.E in India. Ancient Indian texts referenced a cakkavattaka (turning wheel) described as an arahatta-ghati-yanta (machine with pots attached). Because Needham’s reference never mentioned water, Philo’s invention is believed to be the first watermill in history. It was powered by a large chain of pots to raise water (Reynolds, 2002). This came to be known as a vertical wheel watermill. The mechanism was developed by many cultures and throughout time the design underwent changes and improvements. There are 4 types of vertical wheels. The undershot, overshot, pitchback and breastshot. Figure 17 shows each type of vertical wheel and how water runs through them.

![Figure 17. Types of vertical wheel.](Short, 2012, 2007 -a, 2007 -b, 30 2009)

The overshot water wheel mechanism was a big step to increase efficiency of the wheel, given that the weight of the water helped to increase the torque generated by the wheel. Nevertheless this kind of mechanism was more expensive to build given the
water canal had to be above the mill. It was first developed by the Romans between the 1st and 2nd century (Hellmans, 2004).

A change in technology brought the horizontal water wheel; created either in Thessaloniki, Greece or Sidon, Lebanon between 200-100 B.C.E. The design of this type of water wheel has not changed much since its creation as well (Hellmans, 2004). Figure 18 and Figure 19 illustrate the design shift.

![Figure 18. How a horizontal water mill operates (top-alternative-energy-source, 2011)](image)

![Figure 19. How a horizontal wheel operates (support@siyavula.org.za, 2009)](image)

Figure 19 further shows how the flow of water pushes the paddles in a horizontal manner, therefore its name. Although the designs of the wheel and the position of the water race changes from mill to mill, the idea has always remained the same. Regardless of its efficiency, according to our investigation this kind of water mill has been adopted around the world. Construction materials used are mainly wood and stone, two primary materials found anywhere; this keeps the cost of production and maintenance low.
Suplemental Case Study #1: Revitalizing Himalayan Mills Through Technological Innovation

A 2012 study conducted by Ajay Kumar Vashisht, a Professor in the Department of Soil and Water Engineering at the Central Agricultural University in Ranipool, India, thoroughly examined the issues causing the closure of watermills and their capacity to be improved. Mills under study were located in remote parts of Nainital, Almora, and Dehradun districts of Uttarakhand State. The first step Vashisht took was to identify the current structure of the watermills and the many problems causing their demise. The first thing that jumped out at Vashisht was the high frequency of part breakdowns. Sand and rock particles suspended in the stream acted like sandpaper upon the mill shaft and blades, requiring the owners to perform routine maintenance and inspections. The traditional mill design uses a wooden shaft with blades individually slotted into its outer surface. Since part maintenance can be addressed on a case by case basis and components are constructed of local materials, breakdowns can be repaired by the owners or local artisans in two to three hours. Previously suggested upgrades to the watermills replaced the wooden mill components with conjoined metal parts. Although greatly increasing mill efficiency, replacing worn out parts would now require the owners to make a trip to a local service center, a journey lasting up to 5 hours one way. This increase in repair difficulty was universally voiced by mill owners when asked why they had previously resisted technological upgrade.

Vashisht measured the grinding output the mills, finding the total to be much below that of newly developed electric and diesel powered grinders. Interviews conducted with local farmers and mill workers shed more light onto the problem. Near many of the closed mills, farmers had simply stopped growing grains, either in preference of more lucrative crops or because the soil had been depleted so much it would no longer support agriculture. Finally, Vashisht found that unreliability in water flow was the reason most frequently cited for mill closure. A number of environmental factors combine to cause this. The intense rains of the Southeast Asian Monsoon season brings a disproportional amount of rainfall to the Himalayas, causing the discharge rate of the streams feeding the mills to wildly vary over the year.
Deforestation and overgrazing has also greatly increased the rate at which water is absorbed by the ground, reducing runoff and total volume of the streams.

Coupling this information with a complex mathematical analysis of the flow conditions and mill designs, Vashisht made four main recommendations. To combat the uneven rainfall patterns, water should be tapped from a higher elevation in the stream. This increases the hydraulic head of the water; meaning less total volume is required for the same amount of power. Secondly, he stresses that in order for a new technology to be successfully implemented in the mills either repair services be easily accessible or the owner can complete the repairs himself. For the purposes of the rural Himalayan mills, this means that any upgrade must not drastically change the structure of the mills. Third, Vashisht believes the millers should capitalize on the greater nutritional value of flour produced in the gharats. Finally, he provides a small engineering tweak to the design of the mill blades, making them curves as opposed to flat. Through his analysis, this would increase efficiency by about 10%.

**Suplemental Case Study #2: Re-energizing watermills for multipurpose use and improved rural livelihoods**

A 2006 study by Sunil K. Agarwal, a scientist working in the Department of Science and Technology in New Delhi looked into ways to adapt pre-existing watermills in the Himalayas to new uses. Watermills are still prevalent in the Indian Himalayas; the Indian government estimates there are as many as 200,000 in the northwestern states of India. Their design is relatively similar, being based upon centuries old knowledge. Agarwal claims that their output of 5-10 Kg of flour per hour is no longer enough for owners to make sufficient profit. This has prompted many mills to fall into disuse in recent years. Since the communities these mills serve are so rural, technology upgrades that would have allowed the mills to perform tasks other than grinding locally produced crops have never been implemented. Agarwal and his team set out to assess the benefits of upgrading the mills and adapting them for multi-purpose use.

Mills in the study were modified in many ways. First, the turbine was replaced. Based on an upgraded version of the existing design, the wooden turbine shaft was
replaced with a steel shaft, and the flat fins connected to the turbine were curved in order to maximize force exerted by the water. Secondly, a metal ball bearing replaced the axle on which the wheel rotates. This had a tremendous effect, increasing output by 70%. Coupled with the improvements in turbine and blade design, Agarwal’s team was able to produce twice as much flour as per day.

The capacity to produce electricity was an outcome that greatly intrigued Agarwal. Since mill operation ceases in the night, some of the upgraded mills were outfitted with a power generation system. The water wheel could be switched to the power system when the owners were done milling for the day, creating up to 2-3kWh of electricity during the night. Agarwal believed that if mills could coordinate, they have the capacity to provide rural communities with nighttime power and/or other machines that can use the power of the mill, such as a rice-huller. This way millers use the energy of the mill more effectively.
## Supplemental Materials: Methodology

### Gharat Assessment Sheet

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<thead>
<tr>
<th>Field</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mill #</td>
<td>Date: Owner:</td>
</tr>
<tr>
<td>1. Route to mill?</td>
<td></td>
</tr>
<tr>
<td>2. GPS Location:</td>
<td></td>
</tr>
<tr>
<td>3. Length (time) of route? (From nearest road)</td>
<td></td>
</tr>
<tr>
<td>4. Is it operating?</td>
<td></td>
</tr>
<tr>
<td>5. Mill internal structure. How many people work in the mill?</td>
<td></td>
</tr>
<tr>
<td>6. Grinding rate (video recording) (rpm)</td>
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</tr>
<tr>
<td>7. Is there debris in the flow? (Soil, rock, grains)</td>
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</tr>
</tbody>
</table>
8. Is the gharati willing to be interviewed later?  
☐ yes  ☐ no

9. Rate the gharat’s ability to be renovated:

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<th>6</th>
<th>7</th>
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<th>9</th>
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10. Rate your interactions with the Gharatis:

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</thead>
</table>

Gharat Score:
Gharatis Questionnaire

Mill #     Date:     Owner:

1. How long have you worked in this mill? How many work there

2. Who built this mill?

3. Who taught you how to operate the mill?

4. Who owns the mill?

5. Who worked here before you?

6. Do you have children? Young? Older? If older, where are they?

7. Do you expect them to take over your work someday?

8. How often do gharat parts wear down?
9. How do you perform repairs—how long does it take and how complicated is it? (For problematic parts)

10. What is the biggest challenge you face?

11. What do you do when the mill is not operating?

12. Have there been any attempts to improve mill design or adapt its function?

13. Are you interested in adapting the mill to generate electricity or for other purposes than milling grain?
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<td>Distance + Time</td>
<td>People Working inside</td>
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<td>Across gorge</td>
<td>N/a</td>
<td>N/a</td>
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<td>N/a</td>
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<td>Across gorge</td>
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<td>Across gorge</td>
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<td>N/a</td>
<td>N/a</td>
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<td>Not accessible</td>
<td>Across gorge</td>
<td>N/a</td>
<td>N/a</td>
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<td>Across gorge</td>
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<td>N/a</td>
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<tr>
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<td>400 m, 12 min</td>
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<td>No-flow</td>
<td>0</td>
<td>No</td>
<td>Not accessible</td>
<td>Across gorge</td>
<td>N/a</td>
<td>N/a</td>
<td>0</td>
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<tr>
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<td>No-flow</td>
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<td>No</td>
<td>Not accessible</td>
<td>Across gorge</td>
<td>N/a</td>
<td>N/a</td>
<td>0</td>
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<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>40</td>
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<td>400 m, 12 min</td>
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<td>No-flow</td>
<td>0</td>
<td>No</td>
<td>Not accessible</td>
<td>Across gorge</td>
<td>N/a</td>
<td>N/a</td>
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Site assessment data collection for non-working gharats.
### Gharati Interview Data

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<tr>
<th></th>
<th>1,2</th>
<th>3</th>
<th>5</th>
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</thead>
<tbody>
<tr>
<td>Mill Age</td>
<td>20</td>
<td>40-50yrs</td>
<td>as long as gharatis can remember</td>
</tr>
<tr>
<td># of workers</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>who built the mill</td>
<td>Inlaws of the gharati's wife</td>
<td>bought land, gharat came with it</td>
<td>ancestors</td>
</tr>
<tr>
<td>who taught you?</td>
<td>Inlaws of the gharati's wife</td>
<td>previous landowners</td>
<td>ancestors</td>
</tr>
<tr>
<td>mill owner</td>
<td>womens husband + brother in law</td>
<td>interviewee</td>
<td>interviewee</td>
</tr>
<tr>
<td>who work before you?</td>
<td>Inlaws</td>
<td>previous landowners</td>
<td>ancestors</td>
</tr>
<tr>
<td>children?</td>
<td>yes + assist in mill operation</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>taking over?</td>
<td>yes, mill will not be sold</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>Part Maintainance</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>details</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grindstone:</td>
<td>sharpen every 2 months, 500Rs. Replaced after 5 years for 8000Rs</td>
<td>sharpened twice every month, 6000Rs per yr. Replaced every 10-15 yrs for 11,000Rs</td>
<td>sharpened every month for 1000Rs. replaced every 10 yrs for 4000 - 5000Rs</td>
</tr>
<tr>
<td>Turbine:</td>
<td>Metal, not replaced since renovation 10 yrs ago</td>
<td>not replaced since renovation 10 yrs ago</td>
<td>wooden replaced with metal 5 yrs ago</td>
</tr>
<tr>
<td>Blades:</td>
<td>metal, break freq during rainy season, can ind. replaced</td>
<td>metal, never replaced</td>
<td>2 years since metal blades were replaced</td>
</tr>
<tr>
<td>Canal / Diversion</td>
<td>diversion must be repaired after monsoon season</td>
<td>must be repaired after monsoon season</td>
<td>destroyed during monsoon season</td>
</tr>
<tr>
<td>challenges?</td>
<td>lack of flow during early summer</td>
<td>none stated</td>
<td>destruction of diversion, lack of light, on route to gharat, water flow</td>
</tr>
<tr>
<td>what happens when isnt operating?</td>
<td>water is diverted to auxiliary chute</td>
<td>water diverted to axu</td>
<td>water diverted</td>
</tr>
<tr>
<td>previous renovations?</td>
<td>metal turbine installed 10 yrs ago by husband</td>
<td>by owner</td>
<td>turbine 5 yrs ago</td>
</tr>
<tr>
<td>interested in adaptations?</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>Output</td>
<td>output 10 kg per hour, only 30 with summer flow</td>
<td>output 10 kg per hour, only 5kg with summer flow</td>
<td>4.5 Kg per hour</td>
</tr>
<tr>
<td>Payment method(s)</td>
<td>barter system, 1/10th kept</td>
<td>barter system, 1/10th kept</td>
<td>barter system, 1/10th kept</td>
</tr>
<tr>
<td>other notes</td>
<td>gharat is legal property, people dont want to carry heavy grain to gharats so they are installing electric mills in thier homes. Demand has fallen about 50% due to these other mills.</td>
<td>wants to build shelter for people who comes to use the gharat.</td>
<td>2nd mill across river not operating due to weak flow and stolen to irrigate crops. Mill runs every 2 days when someone comes to use it, and all day long during harvesting season. Must use flashlights at night to reach gharat.</td>
</tr>
<tr>
<td>Gharati</td>
<td>8</td>
<td>10</td>
<td>11</td>
</tr>
<tr>
<td>---------</td>
<td>---</td>
<td>----</td>
<td>----</td>
</tr>
<tr>
<td><strong>Mill Age</strong></td>
<td>One year old</td>
<td>40-50 years old</td>
<td>more than 100 years old</td>
</tr>
<tr>
<td># of workers</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td><strong>who built the mill</strong></td>
<td>Owner</td>
<td>Owner's family</td>
<td>Gharati(70 yrs old)'s grandfather</td>
</tr>
<tr>
<td><strong>who taught you?</strong></td>
<td>extended family</td>
<td>ancestors</td>
<td>ancestors</td>
</tr>
<tr>
<td><strong>mill owner</strong></td>
<td>interviewee</td>
<td>interviewee</td>
<td>interviewee</td>
</tr>
<tr>
<td><strong>who work before you?</strong></td>
<td>n/a</td>
<td>ancestors</td>
<td>ancestors</td>
</tr>
<tr>
<td><strong>children?</strong></td>
<td>plans to give gharat and land to his children</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td><strong>taking over?</strong></td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Part Maintenance details</th>
<th><strong>Grindstone:</strong></th>
<th>same as mill 5</th>
<th>same as mill 5</th>
<th>mill not operational</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Turbine:</strong></td>
<td>metal, has not been replaced</td>
<td>wooden turbine, lasts 8-10 years before replacement, constructs replacement turbine himself, unsure of cost</td>
<td>broken, replacement costs 5000Rs and they do not have the money</td>
<td></td>
</tr>
<tr>
<td><strong>Blades:</strong></td>
<td>metal bowls, have not needed maintenance</td>
<td>wooden, replaced when needed, fashioned by owner</td>
<td>see above</td>
<td></td>
</tr>
<tr>
<td><strong>Canal / Diversion</strong></td>
<td>diversion damaged during rainy season</td>
<td>diversion damaged by rainy season</td>
<td>chute is damaged and would need to be repaired</td>
<td></td>
</tr>
<tr>
<td><strong>challenges?</strong></td>
<td>no other challenges stated</td>
<td>no other challenges stated</td>
<td>water flow is miniscule, road construction 2 years ago filled stream with mud</td>
<td></td>
</tr>
<tr>
<td><strong>what happens when isn't operating?</strong></td>
<td>water diverted back to river</td>
<td>water diverted back to river</td>
<td>n/a</td>
<td></td>
</tr>
<tr>
<td><strong>previous renovations?</strong></td>
<td>none after mill construction</td>
<td>none</td>
<td>none</td>
<td></td>
</tr>
<tr>
<td><strong>interested in adaptations?</strong></td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td></td>
</tr>
<tr>
<td><strong>Output</strong></td>
<td>20 kg peak</td>
<td>10kg/hr</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td><strong>Payment method(s)</strong></td>
<td>Sells flour in market for 20Rs/kg</td>
<td>sells flour in market</td>
<td>n/a</td>
<td></td>
</tr>
</tbody>
</table>

- **other notes**
  - Very interested in electricity to light mill at night. Flour is tastier when milled in gharats. Land has been in has family for 40-50 years
  - Broken wooden blades in chute. While at the mill, observes a farmer hopping over stones to cross the river carrying a huge bag of grain to be milled.
  - Electric mill 2 km away has taken the business from this gharat. Cited road construction as reason for reduction in flow. Tiny flow rate not large enough for gharat by our estimations; the family would have to build a storage tank to build up the necessary fluid head to run the mill for a few hours. Path to the gharat was the worst of any we had been to: steep and muddy, with plants that irritate your skin if touched littering the sides. Interview with electric mill owner: mill costs 13 Rs/hr to run. Electricity costs 4.5 Rs / hr. charges 3Rs/kg to use mill, or keeps 15% of output.
<table>
<thead>
<tr>
<th>Gharati</th>
<th>13</th>
<th>20</th>
<th>21</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mill Age</td>
<td>At least 150 years</td>
<td>Old gharat had been on land for 100 years. Gharat-zilla began construction in 2008</td>
<td>More than 200 years old</td>
</tr>
<tr>
<td># of workers</td>
<td>1</td>
<td>3 - 8</td>
<td>2</td>
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<tr>
<td>who built the mill</td>
<td>Ancestors</td>
<td>owner contracted engineers to build mill for 70 Lakh 6 years ago</td>
<td>Ancestors</td>
</tr>
<tr>
<td>who taught you?</td>
<td>Ancestors</td>
<td>engineers</td>
<td>ancestors</td>
</tr>
<tr>
<td>mill owner</td>
<td>interviewee</td>
<td>interviewee</td>
<td>interviewee</td>
</tr>
<tr>
<td>who work before you?</td>
<td>ancestors</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>children?</td>
<td>will gift mill to children</td>
<td>will gift mill to children (grown man)</td>
<td>yes</td>
</tr>
<tr>
<td>taking over?</td>
<td>yes</td>
<td>yes</td>
<td>does not want children to work in the mill. Is sending them to college in Mandi</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Part Maintenance details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grindstone:</td>
</tr>
<tr>
<td>Turbine:</td>
</tr>
<tr>
<td>Blades:</td>
</tr>
<tr>
<td>Canal / Diversion</td>
</tr>
</tbody>
</table>

| challenges? | none stated | none stated | no slow release mechanism, road construction 5 years ago reduced flow greatly |
| what happens when isn't operating? | water diverted to auxiliary chute | water jet pipe valve closed | water diverted back to river |
| previous renovations? | turbine 2 years ago | construction of gharat-zilla from gharat 6 years ago | metal turbine installed 2 years ago. |
| interested in adaptations? | yes | no | yes |
| Output | 20 kg/hr consistently | 170 kg/hr, plans to increase to 400 kg/hr | 16kg/hr |
| Payment method(s) | keeps 10% | Govt provides grain, man mill it for 0.6Rs / kg | keeps 10% of output |
| other notes | implemented 5 KW electricity generation device for 1.5 Lakh, but it broke after 6 months of use and he has not replaced it. Government extracts salt from the water. | Sells his own flour for 20Rs / kg in market, says he sells 20,000 Kg/month. Bought gharats upstream so all the water would be used for his gharat. Built bridge across river (6m) to allow easy road access. | Chute renovations could greatly improve the amount of water going to the mill, the chute leaks a lot |
Supplemental Materials: Project Outcomes

Proposed Flyer

Why should you mill your grain in a gharat?

- **Gharat flour is tastier!** Electric mills leave flour with a burnt taste.
- **Gharat flour is healthier!** It has a higher fiber content than electric-milled flour and its better for your digestion.
- **Gharat flour is cleaner!** Electric mills spin so fast that pieces of stone can get chipped off and end up in your flour.
- **Gharat flour is cheaper!** Gharats keep 10% of output, less than electric mills.

For more information contact your local Gharati
Name:
Tel: +91-XXX-XXXX

Why should you mill your grain in a gharat?

यह एक का उपयोग करने के लिए थोड़ा असुविधाजनक लग रहे हो सकता है, जबकि घराट चक्की की बाजी या डीजल चक्की से एक धीमी दर पर अनाज गर्ने, यहाँ कुछ कारणों से है तुम क्यों चाहिए:

- **Gharat आटा स्वादिष्ट है !** इलेक्ट्रिक मिल्स में एक तीतर स्वाद के साथ आटा छोड़ देते हैं।
- **फाइबर सामग्री में अधिक है, फाइबर घोलने के पाचन के लिए सबसे अच्छा है।**
- **इलेक्ट्रिक मिल्स में तेजी से टंगने से दूर, उत्तराधिकारी के साथ आटा छोड़ देते हैं।**
- **एक gharat का उपयोग करना सस्ता है!** घराट विज्ञानी मिल्स की तुलना में कम उत्पाद का 10% रहते हैं।

For more information contact your local Gharati
Name:
Tel: +91-XXX-XXXX
Location of gharats (near Kamand area)

- Red: Non operating
- Blue: Operating
- Orange: Indian Institute of Technology

Location of Gharats – nearest villages

Back face flyer
Supplemental Materials: Photos

Outside Gharat Photos

Figure 20. Gharat #2

Figure 21. Gharat #4
Figure 22. Gharat #5.

Figure 23. Water canal of Gharat #15.
Figure 24. Gharat #15.

Figure 25. Gharat #14.
Figure 26. Gharat #21 water diversion system

Figure 27. Gharat #21.
Figure 28. Gharat #3 water chute.

Figure 29. Gharat #8 metal water turbine.
Figure 30. Gharat #10 wooden water turbine.

Figure 31. Gharat #3 metal water turbine.
Inside Gharat Photos

Figure 32. Utensiles used to collect milled grain.

Figure 33. Slot bottom of grindstone.
Figure 34. Gharat #20 water wheel powering 4 mills at a time.

Figure 35. Gharat #3 Grindstone opening and slow release mechanism.
Figure 36. Inside gharat #3.
Gharatis

Figure 37. Gharati #11.
Figure 38. Gharati #5.

Figure 39. Gharati #20.
Figure 40. Gharati #10.

Figure 41. Gharati #21.
Farmers

Figure 42. Farmer #2.

Figure 43. Farmer #3.
Figure 44. Farmer #1.