Indian Institute of Technology Mandi

# Incorporating Traditional Methods of Irrigation with Water Management in Mandi, India


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Date:
October 18, 2013


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## Abstract

Access to water is a significant factor for the survival of north Indian farmers in villages that are situated particularly in hilly areas. These villages often have inadequate surface water sources so they rely on rainwater. Our project's goal was to evaluate traditional irrigation practices in Mandi District in Himachal Pradesh and to design a model to provide farmers at higher altitudes with a sustainable, self-sufficient and cost-effective water management system. Through site assessments and interviews with local farmers, we learned that there is a greater need for drinking water than irrigation water. Therefore, our design utilizes water-harvesting techniques to gather rainwater in a tank that can be used for irrigation or routed through a water-purification system for drinking purposes.

# Executive Summary

## Introduction and Background

Local irrigation systems have been handed down through generations becoming a tradition in India, with regional farmers designing processes that were invented to adapt to the landscape. The people of Sikkim, for example, have combined water-harvesting systems with land management systems in order to become more efficient. Rice and cardamom fields are irrigated in bench terraces, which can be watered without the need for distribution channels. In Arunachal Pradesh, two important traditional methods of irrigation show the range of low-tech engineering. Bamboo pipes irrigate rice fields along with a series of earthen dams and conduit channels that can be used to flood or drain fields as necessary for the harvest and planting seasons.

In the northern state of Himachal Pradesh, traditional irrigation methods such as canals (*kuhls*) have been built by local residents to draw water from the small streams that originate from hill springs. The springs are the only reliable sources of water in a number of locales. As elsewhere, though, new technologies have been implemented to improve the traditional styles of irrigation (see Figure 1, below). Under the Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA), the government of Himachal Pradesh has helped to make permanent kuhls and tanks, solidifying in place the simple and locally adapted irrigation for self-sufficient farms that provided for individual families (Department of Rural Development, 2005; Government Official of Department of Agriculture, 2013).

**Figure 1: Opening of *Kuhl* Irrigation**

## Methodology

Our goal was to evaluate traditional methods of irrigation and to design a model to provide farmers on higher altitudes with a sustainable, self-sufficient, and cost-effective water management system. The goal was accomplished through four objectives:

- We identified and evaluated factors that influence a design for irrigation.
- We assessed the government policies and public responses to these policies and irrigation issues.
- We evaluated villages situated on different altitude levels and assessed their irrigation techniques.
- We designed a model of water harvesting and made recommendations that can support farmers.

To complete our objectives, we identified three main characteristics that influence irrigation design. These characteristics included the topography of the area, the available water sources and monsoon patterns and the types of crops with corresponding water requirements. We found this data through archival and online research, site assessments, and informal interviews using a sample of convenience.

We studied water related acts passed by the government by conducting archival research at the library and through online research. We evaluated current minor irrigation projects that are implemented to improve agriculture. By visiting and interviewing the District Agriculture Officer of Mandi, we were able to learn about the current policies and ongoing projects. We also visited the Irrigation and Public Health Department to inquire about various water programs provided to local farmers and villagers.

Finally, we visited local villages according to their respective elevations. Farms with varying access to a steady supply of water, such as the river, were assessed in comparison to villages that were located higher in the hills. During our site visits to local farms, we also interviewed and gathered feedback from the farmers about the existing government policies and schemes, how useful they are, and the improvements that could be made. Moreover, we asked about their water needs regarding irrigation or drinking water. With the help of our IIT teammates, we managed the differences in language. Indian students translated the interview questions between English and Hindi to local farmers and government officials. We learned local participants provide better responses to our questions in Hindi.

The last objective was to design a model that is suitable to the hilly terrains of Himachal Pradesh. Our model is inspired by some techniques of irrigation being used in this area as well as the others. We also evaluated the different sources for water that were available and designed a plan that farmers can use for their farms. Finally a scale CAD model using SolidWorks was created to demonstrate the proposed idea's effectiveness.

## Findings

Using Google Maps, our team found a topographical map specifying altitude levels of different villages. The map indicates the steep terrain, access to water, and the distribution of small villages throughout the district. Rainwater, especially during monsoon season, covers about 70% of total rainfall per year. At the Central Library in Mandi town, we found sources about agriculture in Himachal Pradesh and the types of crops with corresponding water requirements. The main crops produced in the state include maize, rice, wheat, vegetables, fruits, and fodder crops.

To learn about the government policies and irrigation schemes for our project, we interviewed local government officials representing branches of agricultural planning such as the Agriculture Department and Irrigation and Public Health Department. Most were in agreement that the need for irrigation was high, but noted that cost and terrain as key reasons for inaccessibility. The most surprising finding was that agency officials use a cost-benefit analysis to determine action. They focus on helping villages that could provide better income. There are several government schemes and projects implemented throughout the district to improve irrigation on fields. The MGNREGA scheme has helped farmers by constructing the *kuhls* or diversion channels using concrete for more permanent structures. Modern techniques such as the micro-irrigation system and poly-houses were also introduced to produce better quality crops by subsidizing 80% of the total cost. Farmers living on hilly mountains received minimal help as they are remote areas and have a lower percentage of population.

**Figure 2: Conducting Interview in Mandi Agriculture Department**

We evaluated and assessed the fields of seven villages in and around Kamand including Kataula, Kamand, Kathindi, Hadbon, Neri, Khani and Sundernagar. In each, we identified irrigation methods farmers used, ongoing government projects (if applicable), local crops produced, and the water and irrigation issues farmers were facing. When we visited the local villages, we discovered that there were many commonalities between them.

In the villages located near plentiful water sources there was, in every case that we encountered, an occurrence of *kuhls*. The farmers would divert water from the river through their farms and back to the river. These *kuhls* are used, in addition to irrigation purposes, in the operation of mills. In only one scenario did we find that the *kuhls* were government subsidized, everywhere else they were hand dug by the farmers who operated the farms.

At the higher elevations we found that the farmers were much more self-reliant; they use smaller fields to grow crops for self-consumption. As the crops being grown are not being used for profit, they are not putting active efforts towards improving the irrigational methods and rainwater is reportedly sufficient for the time being.

We found through interviews and site assessments that water is unsafe; there have been reports of people getting severe stomach illnesses. Due to increasing demand, government is focusing more on drinking water than irrigation. This has led the government to build storage tanks for local villagers. We discovered two cost-effective and easily accessible methods such as the solar water disinfection (SODIS), which exposes water to sunlight for a period of time, and the sari cloth filter, where old women's cloth is folded four to eight times to strain away bacteria that is usually present in the water. After assessing irrigation methods and water needs of villages in Mandi district, we determined that a rainwater harvesting technique would be applicable, especially since these areas receive abundant rainfall during monsoon season.

## Analysis

Based from the information we gathered through research, site assessments and interviews, three common themes emerged in our findings: the altitude, access to irrigation systems, and cost. Over the course of our investigation, we have found that government help is provided to the farmers but there does not appear to be many participants. Reasons that very few farmers are taking advantage of these opportunities include indications of mistrust of the government, lack of awareness, and lack of reliable water sources.

Villages situated on lower levels of the mountain have nearby springs and rivers that local farmers can access, while villages situated on higher altitudes have limited access to these springs and thus lack a source of consistent water. In villages, such as the ones we visited, information travels slowly, if at all, especially between villages that are very remote or with no road access. Information about the irrigation schemes and new modern irrigation techniques rarely gets spread according to government officials in Mandi Agriculture Department. Even after knowing about the government initiatives for irrigation such as the 80% subsidy, the common people are unable to afford the cost that they are supposed to put in. Only those with enough money are able to utilize the scheme.

Farmers were self-sufficient by using *kuhls* and tanks for generations in Himachal Pradesh but as the standard of living and the population increased, so did the water demand. Since there is no real change in irrigation practices, farmers are facing water crisis. Some farmers have inadequate water to drink, let alone to irrigate the fields.

After we realized that there is insufficient drinking water, we had to re-evaluate our project parameters. We started to research efficient water collection and purification systems. One purification system that we discovered uses solar water disinfection (SODIS), which lets the water sit in sunlight for at least six hours. This allows the UV rays to penetrate and kill all the microorganisms in the water thus purifying it. The water purification strategy was incorporated into our final design due to the ease of implementation as well as its cost-effectiveness.

## Recommendations

Our findings revealed that villages are facing drinking water issues rather than irrigation issues, so we have proposed a sustainable design that will alleviate water scarcities. Rainwater is collected using a roof water harvesting technique that involves gutters of houses, which then channels water through pipes into a storage tank. The tank is made of block or concrete and has a circulation system that can be added to aerate water, which helps remove iron and carbon dioxide. Attached to the system is a water purifier, which uses the concept of solar water disinfection (SODIS) for drinking purposes. Pathogens are killed by exposing it to sunlight using the concept of solar water disinfection (SODIS). Another outlet is attached for irrigation if required. This design includes the following sections as shown in Figure 3.

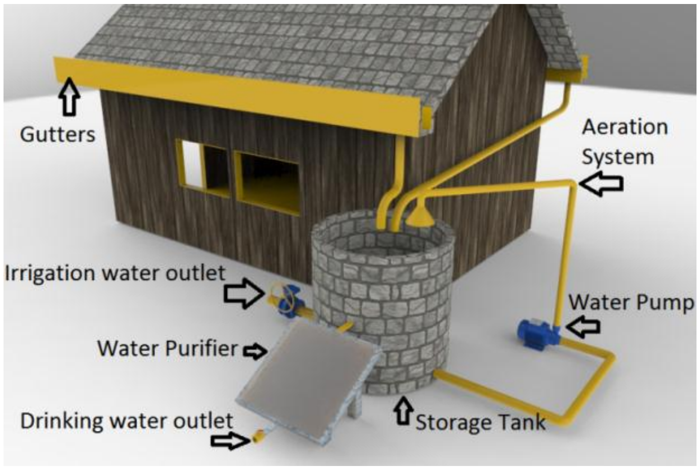


**Figure 3: Recommended Water Management System Model**

## Conclusion

This project revealed an important water issue that villagers are facing besides irrigation for fields. In 2007, a drought destroyed the local harvest of subsistence farmers. Due to the drought, farmers did not even have drinking water for days and the government failed to provide any form of assistance. A system like this could alleviate the impacts of unanticipated natural disasters, and increase the overall resilience of the community. The ability to recover for these calamities can be a struggle for communities living at higher elevations. This model can augment water supply to these hilly areas especially in times of drought. Since most of the farmers utilize rainwater for irrigation, the design also captures rainwater through roof gutters and stores it in a tank.

Our project sought to improve the lives of farmers particularly those situated in vulnerable locations at higher altitudes by creating a model of water management system that is easily accessible and maintained. We realize that this scheme may not be suitable for constant use but it does provide a certain level of safety and assurance that even during extreme weather the livelihood of the farmers will be preserved. This solution can help villagers and farmers on hilly areas around Himachal Pradesh and other states that have limited access to surface water but have abundant source of rainwater.

## Acknowledgements

We would like to thank Dr. Ingrid Shockey for all her help with guidance, editing, and moral support.

Dr. Manu Devadevan for asking the question that led us to this incredible experience and growth of knowledge.

Mr. Sanjaya Thakur for an amazing personal tour of Kataula, which involved the gift of many cucumbers.

All the local farmers that were willing to talk to complete strangers and explain to us how they manage their fields.

The Agriculture Department for their cooperation.

The Irrigation and Public Health Departments in both Mandi and Kataula.

And all the drivers that made it possible to get from one destination to another safely.

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## Chapter 1. Introduction

Local irrigation systems have been handed down through generations becoming a tradition in India, with regional farmers designing processes that were invented to adapt to the landscape. The people of Sikkim, for example, have combined water-harvesting systems with land management systems in order to become more efficient. Rice and cardamom fields are irrigated in bench terraces, which can be watered without the need for distribution channels. In Arunachal Pradesh, two important traditional methods of irrigation show the range of low-tech engineering. Bamboo pipes irrigate rice fields along with a series of earthen dams and conduit channels that can be used to flood or drain fields as necessary for the harvest and planting seasons. Some of the traditional irrigation methods, specifically well irrigation, use water harvesting systems such as the *rahat* (known as Persian wheel). Many of these systems, however, are becoming extinct in north-eastern states due to the modern systems implemented by the government (CE IIT Kharagpur, 2011d; Sengupta, 1985).

In the northern state of Himachal Pradesh, traditional irrigation methods such as canals, (*kuhls)*, have been built by local residents to draw water from the small streams that originate from hill springs. These water sources are called *jhoras.* The springs are the only reliable sources of water in a number of locales. As elsewhere, though, new technologies have been implemented to improve the traditional styles of irrigation. Under the Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA) scheme, the government of Himachal Pradesh has helped to make permanent *kuhls* and tanks, solidifying in place the simple and locally adapted irrigation for self-sufficient farms that provided for individual families (Department of Rural Development, 2005; Government Official of Department of Agriculture, 2013). However, there are drawbacks from these actions the government has provided.

In the 1970s, the government became more involved with regulation of agricultural and water use practices. This has led to a more centralized control of farming that has generated a hierarchy of clerks, engineers, and administrators. The organization of this system may sound effective, but, in fact, because of the hierarchy, the system has been inefficient with many middle-men that the farmers have to navigate. The Himachal Pradesh Water Act says that "the State Government shall have the power to add or amend, vary or rescind the schedule" and that it "may make rules for carrying out the purposes of this act" (Government of Himachal Pradesh

Irrigation and Public Health Department, 1968, p.4). The power is bestowed upon the state and the common farmers have a limited voice in the matter; the rules cannot be modified. The policies standardize everyone even if the farmers have a localized need. Furthermore, there are fees in every department that add up and can be very expensive to the farmers (Government of Himachal Pradesh Irrigation and Public Health Department, 1968).

It can be argued that embracing the traditional practices, especially the irrigation methods, is important for communities in India. Using traditional irrigation practices in agricultural districts can provide communities with more sustainable and cost-efficient irrigation system (Sengupta, 1985). Consequently, the goal of our project was to evaluate traditional methods of irrigation and to design a model to provide the farmers at higher altitudes with a sustainable, self-sufficient, and cost-effective water management system. In order to meet our goals, we identified and evaluated factors that influence a design for irrigation. We assessed the government policies and public responses to these policies and irrigation issues. We evaluated villages situated on different altitude levels and assessed their irrigation techniques. Finally, we designed a model of water harvesting and made recommendations that can support the farmers.

# Chapter 2. Literature Review

This project uncovers and documents regional methods of traditional irrigation for the purpose of preserving and reviving the strategies among local farmers. In order to establish the context for our work, we turned to the literature to better understand the site itself. We identify the common types of regional traditional irrigation methods, consider the environmental and social factors that could affect an irrigation system's design, and examine the context for water and irrigation policies. Finally, we introduce case studies that help to gain more insight on the consequences of incorporating traditional irrigation methods with water management systems.

## 2.1 Site Description

Himachal Pradesh, situated in the northern part of India, has a geographical area of 55,673 square kilometers of which less than ten percent is under cultivation due to the presence of hilly terrains. The farming is done using terrace farming and is rain fed during the monsoon months. Under the current government schemes only a hectare of land is utilized for irrigation (Planning Department Government of Himachal Pradesh, 2006). The state experiences annual rainfall ranging from 350 millimeters to 3800 millimeters. The district-wise monthly average rainfall variation and temperature variation experienced by the state in millimeters is given in Figure 1 below (Ramachandra TV, Gautham Krishnadas and Rishab Jain, 2012; Planning Commission, 2009). These charts show the rainfall in Himachal Pradesh over the course of a year. This is necessary because monsoon season is absolutely vital for survival of the crops and here we see that there really is not lot of other times when these crops can rely on a steady supply of water.

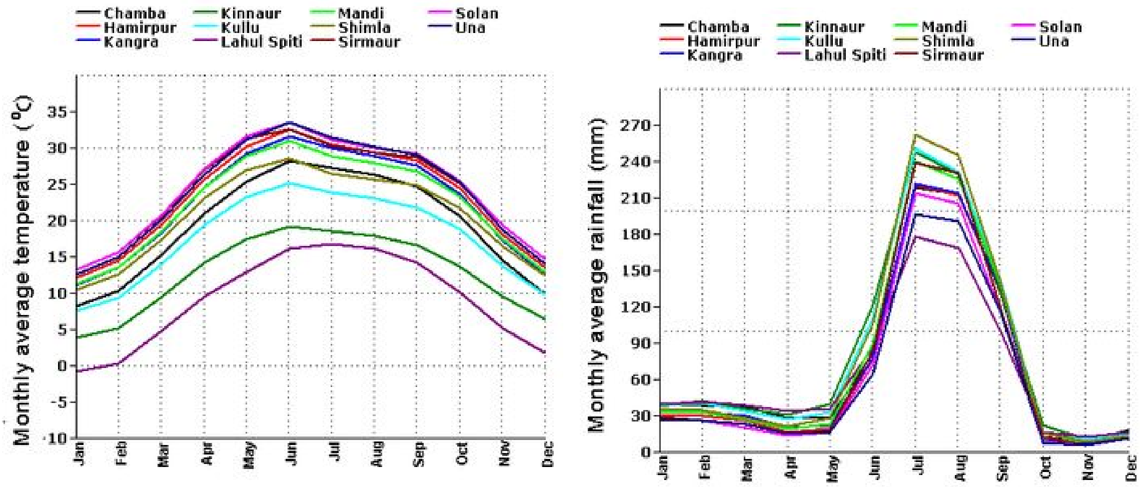


**Figure 1: Temperature Distribution in HP and Rainfall Distributions in HP**

In the center of Himachal Pradesh, Mandi is known as the “Kashi of the Hills”. The community itself is a beautiful city located across the banks of Beas River. The area is a historic place of sacred temples, lakes, and farms. The livelihood of many people in the district comes from agriculture. Consequently, Mandi is an important commercial trade center for crops from different regions across the country. Some of the common crops produced include grains, corn, vegetables, and orchard fruit ("Mandi," 2013).

Local environmental conditions vary widely with mountain ranges that form the foothills of the Himalaya present in the region. The highest regional point has an altitude of 5,486 meters on peaks near the Kullu border, while the elevation of Mandi is at about 1043 meters. Consequently, climate and growing conditions in Mandi vary. In winter, it can be bitter cold in the higher altitudes, while in summer it can be warm especially at lower elevations (Mandi District Administration, n.d.).

Many small villages are set in the region to the north-east of Mandi, near to the river Uhl, a tributary of river Beas. The farmers at higher elevations in the nearby Kamand, Kataula and Kathindi regions depend on rainfall as the source of irrigation. The rest of the year, after the monsoon season, the scarcity of water is such that people barely manage to get drinking water. Nearly seventy percent of the rainfall occurs in monsoon season. Due to seventy percent of the water falling in a period of only five months, a shortage for the rest of the year makes irrigation impractical. Other locations in India have more reliable rain patterns or available sources of water whereas in Mandi District, scarcity of water is a viable concern. Here, adaptation is necessary for survival.


**Figure 2: Section of Mandi District**

## 2.2 Traditional Regional Irrigation Methods

To understand how irrigation works and its importance, we present a brief background about small-scale irrigation and introduce some commonly known traditional irrigation methods and their significance.

Irrigation is a way for farmers to manipulate existing water sources to either store or distribute the resource.  It has been a fundamental need for the survival for farmers because it provides water, the lifeblood of crops, to the growing plants when there is not enough rain. One of the first reported cases of irrigation is among the ancient Egyptians, who built dykes to trap the water that would flood from the Nile River. Irrigation strategies are necessary to all forms of agriculture due to the unpredictability of the weather. It provides a guarantee that there will be water in the case of a drought. It also has the added benefit of keeping the plants at a safe temperature level to mitigate frost during cold spells and to stop them from overheating during times of increased heat. Irrigation is also necessary to promote evaporative cooling by delaying bud formation, and some microorganisms are helped with the added moisture (Jamal & Shinwari, 2013). As one researcher noted, the "objectives of irrigation are: to supply water partially or totally for crop need, to cool both the soil and the plant, to leach excess salts, to improve groundwater storage, to facilitate continuous cropping, and to enhance fertilizer application" (Jamal & Shinwari, 2013, para. 3).

Different methods of irrigation were implemented regionally in India because of the location in which they were situated as well as the availability of nearby resources. Nevertheless, we identified three common formats for irrigation that exist in India. These include diversion channels, surface-drainage tanks, and wells. Across regions and districts in India, these methods usually have a variety of nomenclature, each influenced by the region.

## Diversion Channels

One traditional irrigation method that is common is the diversion channel as seen on Figures 3 and 4 below (called *kuhls* in Himachal Pradesh).

**Figure 3: Hand-dug *Kuhl* in Kamand**

**Figure 4: Permanent *Kuhl* in Kataula**

The traditional *kuhl* is constructed with a dug-out main diversion channel that has structures that can be temporary or permanent. Due to annual floods that might destroy the system, temporary channels, which are built using boulders, rocks, bamboo, and tree branches, are preferred. In recent years, people have also started using concrete. These *kuhls* flow through different distribution points creating a diversion-based system (People's Science Institute, 2003). Moreover, this system can range from hundreds to thousands of kilometers long to allow water (primarily floodwater) to be diverted to farmlands. The canals are aligned to draw water from the hill streams or springs. *Kuhls* also collect rainwater and melted snow running from the slopes above them. In addition, lands that are to be irrigated are usually situated on hill-sides, and are supplied on terraces where water flows due to the gravity that "traverses the contours of a mountain slope" (People's Science Institute, 2003, p.14) (Sengupta, 1985; CE IIT Kharagpur, 2011d). Figure 5 gives an illustration of *kuhl* design (Forestry Department, 1998).

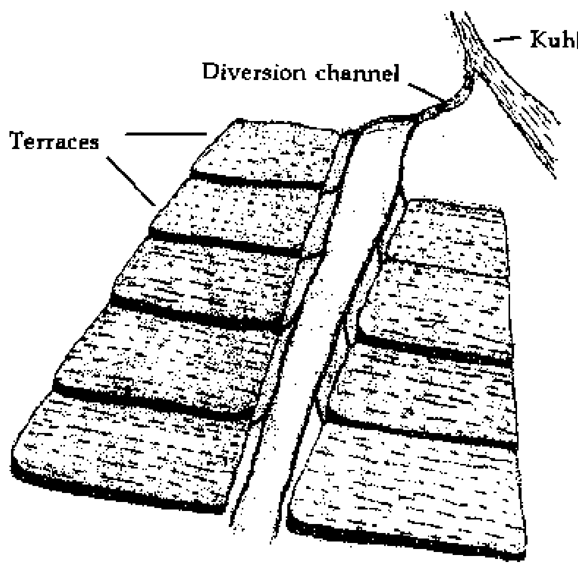


**Figure 5: Water Channel Flow**

A group of these diversion channels often create community-based systems that are used for "sustainable, cost effective and successfully managed by local [governments]" (Bhaduri, 2013, para.1). This system, which dates back to 16$^{th}$ century, is used best post-monsoon when the abundant rainwater runs off through diversion channels. The construction requires a site that has a concrete foundation and has a depth of at least eight inches, where factors like the slope area of land and the available rivers are also considered (Bhaduri, 2013). In the Western Himalayan Region, for example, farmers started irrigation processes that were invented to adapt to these mountainous landscapes. In northern India from Jammu and Kashmir valleys down through Himachal Pradesh and ending in Uttaranchal, farmers have designed *kuhls* that are aligned with land contours to draw water from streams or springs. These canals can range in length from one kilometer to fifteen kilometers. They generally have a trapezoidal cross section and are one to two tenths of a square meter in area (CE IIT Kharagpur, 2011d).

## Tank Irrigation

Another traditional method our group identified is tank irrigation. The nomenclature for this system is rather misleading because tanks are utilized as small reservoirs that are typically in a rectangular prism shape and are used as embankments. This irrigation system is usually constructed in chains to have water flow from tanks upstream to tanks downstream which are important ancient traditions of storing the available water from rainfall, streams or rivers that help improve the cultivation of crops (Chandrasekaran, Devarajulu, & Kuppannan, 2009; Palanisami, 2006; Palanisami, Meinzen-Dick, Giordano, Van Koppen, & Ranganathan, 2011; Vemula, 2010). Tanks can take many forms, as seen in Figure 6 below (Jupiter Informed Ltd., 2010; Kajisa, 2012).

**Figure 6: Tank Irrigation**

Similar to tank irrigation systems, traditional *khatris* are pits, made of rocks, which mainly collect rainwater seeping through these rocks. It is generally built near the foot of the hill with a dug tunnel and steps leading inside through the basin of water. Multiple *khatris* may be constructed, but ideally, the water gets collected in the lower-most *khatri*. These structures do not provide water directly to the fields; the water needs to be carried to the locations. They are usually for drinking purposes as well as washing and taking baths. Being more expensive than *kuhls* (approximately INR 15000 per *khatri*), they are not as popular as *kuhl* (Center for Science and Environment, n.d.; Sharma & Kanwar. 2009). One of the examples of *khatri* can be seen in Figure 7 below (Mohan, 2012).

**Figure 7: *Khatri***

*Baudis* and *nawns* are also tank-style surface water harvesting techniques. Deep pits are built to collect and store the water and they are generally covered with a roof. Both use same techniques, but the difference appears in the final usage of them. *Baudi* generally has a tank-like structure to store the water, in contrast to *nawn,* which is larger and used for numerous purposes such as drinking, washing, and taking showers (Sharma & Kanwar, 2009). One of the examples of a baudi and nawn can be seen in Figures 8 and 9 below.

**Figure 8***: Baudi*

**Figure 9:** ***Nawn***

Tank irrigation systems have components that include the “tank embankment, surplus of escape weir, and outlet channels” (Vemula, 2010, para.1), which are built across the slopes for easy collection and preservation of water. Starting from the tank bank, water flows through the sluices that connect to paddy fields. Tank irrigation is managed by local villagers and mainly used in regions that have dry seasons and irregular monsoons. However, this method has a few disadvantages. The water easily evaporates and the tank occupies a huge area of land, which leads to costly maintenance. Moreover, because the tank is used as water storage, perennial water supply is not guaranteed especially during dry, hot summers (Jupiter Informed Ltd., 2010; Vemula, 2010; Kajisa, 2012).

### Wells

The implementation of the well design requires digging a hole in the ground to provide a perennial "soft water" supply. This "soft water" is more appropriate for irrigation because it sometimes has a lower salt level. Saline water is capable of destroying the quality of crops and has an adverse effect on soil (Abrol, Yadav & Massoud, 1988). To reduce the salinity, wells, which are generally at shallow depths, are dug near the ponds where water is collected on rainy days. Well irrigation is mainly used in alluvial plains due to the softness of the soil. It is also more popular in regions where ground water is plenty and diversion channels are available. This irrigation method is preferable because of the ease of operation, and reduction of danger from water clogging compared to the canal (channel) irrigation during the water flow. Especially when the water level is high, farmers sometimes still utilize water-harvesting systems such as *rahat* (known as the Persian wheel), which was commonly used in India in $9^{th}$ and $10^{th}$ century (Vishwanath, 2009). The r*ahat* is typically operated either by domestic animals such as cows and ox or by people. This expense of energy to push the rod that connects through the wheel to lift the water is also one disadvantage of this system (Verman, 1993; Jupiter Infomedia Ltd., 2010; Sengupta, 1985). An example of well irrigation using the *rahat* is seen on Figure 10 (Acharya & Vishwanath, 2008; Jupiter Infomedia Ltd., 2010).

**Figure 10: Well Irrigation: *Rahat* Operation**

Most traditional systems, such as diversion channels and well irrigation, do not require extensive and complicated maintenance and operation. These systems rely on available natural resources, particularly the water source. Moreover, in India, engagement of the people in the community especially for a community-based system is significant. Traditional systems provide an opportunity for the people to be involved. In addition, operation and maintenance cost of a traditional system is reasonable provided that the system is shared by a number of farms and villagers that use the water (Kout et al., 2012).

## 2.3 Factors that Influence Irrigation Design

These traditional systems are typically in small-scale (meant for a village) where maximum efficiency and sustainability is considered. Customary irrigation methods proved to be resourceful in the use of boulders and tree branches for diversion channels, the storage of rainwater in tanks and the use of wells to collect groundwater. (Jupiter Informed Ltd., 2010). Moreover, they have been in existence for years and able to provide the community good quality of crops (Sengupta, 1985). The implementation of traditional irrigation systems depends on factors such as the environment, economy, and technology.

### 2.3.1 Environment

Among the environmental factors, climate conditions and monsoon patterns, geographical terrain, types of natural water resources, and different types of crops and their corresponding water requirements all play a role. Here we outline factors influencing the choice of irrigation systems in and around Kamand in greater depth (Chaturvedi, 2011; Sengupta, 1985).

#### *Climate*

There are two main seasons in Himachal Pradesh, the summer and the winter. The transition between the two seasons every year is important for the region. The main growing season for Himachal Pradesh is from June to October. This generally falls in line with the rainy/monsoon season. Traditionally, the growing season coincides with the south-western monsoon (CE IIT Kharagpur, 2011d). Because it commences at the same time as the monsoon rains, there is usually plenty of water. However, apart from these two months of monsoon, the farmers have a hard time cultivating due to lack of water.

The majority of usable water at lower elevations comes directly from local rivers. These rivers are fed by glacial melt. Due to climate change, the monsoon season has been unusually dry in recent years. If the trend of global warming continues then the loss of glacial reservoirs is a potential threat. This could prove catastrophic in the event of them disappearing. If the farmers are unprepared for a prolonged drought they could lose the entire crop. A water storage system such as tank irrigation is useful in preserving water for future purposes.

#### *Geographical terrain*

The geographical terrain determines what type of irrigation system is best. Some are suitable for lands situated on hilly mountains and others are more suitable for flat plains. While a drought is a possibility, the soil of the region can help ease the damage. Different types of soil require different amounts of water for irrigation. Soils with high retention capacity require less water whereas soils with low moisture capacity require more water (Finkel, 1981; Toddes, Monahan, Cote, Weininger, & Brattin, 2004). The *terai* soil, for example, comes from the marshlands and tends to have a lot of plant matter. This means that the soil is very moist and is full of nutrients from the decaying plants in the marsh. Another type of soil in Himachal Pradesh is the *submontane* soil. This type of soil forms at the bottom of the Himalayas, providing nutrients and helping to trap moisture from the rainfall. On higher hills, soils range from silt loams to clay loams, which are good for crops such as seeds, vegetables and fruits due to more retention of moisture (Singh, 2010). These characteristics of soils are necessary to ensure the success of the growing season (Chandy, n.d.; CE IIT Kharagpur, 2011a).

#### *Water resources*

Another environmental factor that affects irrigation methods is the source of water. This includes understanding attributes of the existing seasons and yearly climate of a particular region. Developing traditional agricultural methods were primarily based on a consideration of how much water is available in a particular area (Sengupta, 1985). Most traditional irrigation systems used water supply from rainfall, river water, natural springs and ground water, which is accessed through wells. The amount of available rainwater and streams and rivers also help indicate if a diversion channel irrigation method is applicable. Alternative sources of water for irrigation are snow-fed perennial streams, water lifts, and the Uhl and Beas River. In and around Kamand, the main sources of water for irrigation include the river Beas, its tributary Uhl and a few natural springs.

#### *Crops*

Finally, different crops have varying water requirements. Traditional irrigation methods were able to provide the water necessary for crops in India. The types of crops to be grown are determined by the amount of water required. Crop patterns also help to improve the soil quality and subsequent utilization of water. Therefore, the planning of planting has been traditionally based on the principle of maximizing these benefits (Montazar & Gaffari, 2012).

All these factors are significant when designing and implementing irrigation strategies. If any one of these factors are overlooked it can lead to a system that could be potentially harmful to the area as well as to the farmers that it would be designed to help.

### 2.3.2 Economy

Irrigation systems need to take into account the water provisions it can give and its maximum capability when supplying water. Because farmers rely mainly on the rain for their harvests, there is no guarantee that the harvest will be plentiful each year. One example is the low rainfall nationally. There has been a decline of the agriculture’s share of GDP from 19 percent in 2004-2005, to 14 percent in 2011-2012 (“India Economy: Agriculture's Share in GDP to Decline”, 2010).

To offset the strain on farmers, the government offers each farmer subsidies on multiple irrigation projects. These include *kuhls*, tanks, and poly-houses. For some of these plans, the government will pay up to 80% of the total price. Unfortunately most of the farmers cannot even make the 20% of the payment, as their income is less than INR 15,000 as of 2001 (Planning Commission Government of India, 2001).

Although scientific innovation might be prosperous in many cases, other advancements such as genetically modified seeds that the farmers are now being forced to use are not necessarily good for the economy. Genetically modified versions of cash crops have been made available to the farmers of India in recent years. One specific case is a strain of cotton that was supposed to be more efficient and produce more cotton than its non-genetically engineered counterpart. Keshav Kranthi, the director of the Central Institute for Cotton Research (CICR), analyzed the seeds and warned of "the presence of the Monsanto gene in BN-Bt and a 'potential scandal' if the cotton was released commercially" (Jayaraman, 2012, para. 9). Unfortunately this seed underperformed in 2009. This in combination with Keshav Kranthi's warnings led to the stopping of sales and production of the seed (Jayaraman, 2012). In states like Andhra Pradesh and Maharashtra, many farmers have committed suicide because corporations that sell these seeds collect heavy fees where the farmers go in debt and have no freedom except to commit suicide (Shiva, 2013). If all the money that farmers earn goes to international companies, the economy of the state will be greatly affected.

## 2.4 Public Policy Initiatives

Modern India has increasing wealth and power; the consequences of which can be found in agricultural policy initiatives. A good example can be seen with regard to production. India is the second biggest producer of rice and wheat, only after China. To uphold agricultural output, it plans to increase irrigation spending in the next five years 9-fold, to $2.7 billion (Chaudhary & Katakey, 2013). In the state of Madhya Pradesh alone, there are plans to invest INR (Indian Rupees) 7 billion in irrigation projects. The chief minister urged for an approval of 13 proposals of irrigation projects from 2012-2013 and is still pending (DNA, 2013).

Indian governmental control has become more centralized with regard to policy concerns around farming. If farmers want a subsidized scheme for watering their crops, they have to go through hierarchies of clerks, engineers, and administers. The organization may originally have been introduced to make irrigation more effective, but this system relies on every person involved to work efficiently. A single person not doing his job properly can make the process almost impossible to complete. Human nature also plays a role. Abuse of power and bribery can impede the governmental office.  Anecdotally according to an online survey, “the site ipaidabribe.com (IPAB), run by the Bangalore-based Janaagraha Centre for citizenship and democracy, aggregated over 22,490 reports of any kinds of bribes being paid in 493 cities. This registered a total value of INR 833 million (US $15 million) or approximately INR 37,000 (US $670) per bribe” (Sharma, 2013, para.2). This demonstrates flaws across the system. There are too many middlemen that misuse their power over the farmers. Because of the bureaucracy, it has proven to be inefficient. Aside from the poor administration, government has placed policies and initiatives across the state that standardizes everyone.

In Himachal Pradesh, public policy in terms of water usage and irrigation is found in *The Himachal Pradesh Water Act* of 1968. It is a five page act that was amended once in 1978 and again, in 1983. Upon reviewing these acts, it appears that power is mostly bestowed upon the state where the common farmers have limited freedom to voice their opinions. The laws set by the state standardize everyone, even if the farmers have a localized need. The rules set by the state cannot be modified (Government of Himachal Pradesh Irrigation and Public Health Department, 1968).

The trend of centralized agricultural policy is not only a Himachal Pradesh problem. It has become a national issue. One other act, the ‘Gujarat Irrigation and Drainage Act’ of 2013 is one of the most recent and controversial acts (Bhatt, 2013). It is a replacement of the 134 year old ‘Bombay (Gujarat) Irrigation Act’ of 1879.  In the article from Times of India, ‘*Gujarat governor gives ascent to irrigation and drainage bill*’ it is written:

> “One such provision is the 'unbridled' powers to proposed canal officers. These officers will now have powers to detain violators of the Act, which makes it mandatory for farmers to obtain a license from the canal officers for digging a tubewell or a borewell exceeding the prescribed depth, on their land…there was no modernization or innovation in the bill, and … the powers to canal officers were greater than those vested in the police.”  (Bhatt, 2013, para. 4)

This article clearly displays the problem of too much centralization. If an irrigation officer has more power than the police, and the state is the one granting this power, the officers can abuse the power easily and as a result, bribes are common in India. Modernization and westernizing the system seems to be the driving force for all the developing nations in the world but to achieve these goals, centralization of government occurs. It is a global trend today and the ones in the offices will eventually end up taking advantage of the people who rely of them. These officers will take advantage of the local farmers.

To better understand these precedents, we outline here some of the different government policies and acts:

### 2.4.1 Himachal Pradesh Ground Water (Regulation and Control of Development and Management) Act, 2005

The Himachal Pradesh Ground Water Authority was established by a law passed in 2005 under the above-mentioned act. This act was passed for the regulation and control of development and management under the supervision of the State Government. When necessary, the authority can advise the State Government any area, for regulating the extraction of ground water for the benefit of local people, as a notified area. Appropriate measures could be taken to ensure justified exploitation of groundwater resources. Registrations of rig owners' machinery and maintaining databases for the ground water resources are the two main objectives for the regulation of ground water. Moreover, the authority could take steps to ameliorate ground water resources and issue guidelines for the adoption for rain water-harvesting techniques.

### 2.4.2 State Water Policy

The state water policy aims for efficient utilization of drinking and irrigation, thereby promoting its conservation and call forth community participation. The policy elevates participatory approach involving local stakeholders and communities, including women, in management to water resources and its development. Ground water exploitation in a justified manner for domestic use and irrigation can be promoted in a viable manner wherever possible. Non-conventional methods and artificial recharge of the ground water resources is practiced to improve the ground water level. Individual and cost effective irrigation planning from all available sources of water and appropriate irrigation techniques is adopted to maximize the benefits of irrigation and productivity of cultivable lands. Notions of justice and equity are taken care of while allocating water for irrigation. Conjunctive efforts are taken to minimize the gap between irrigation potential and utilization. Scientific water management and farm practices and sprinkler and drip irrigation systems is exercised wherever possible.

### 2.4.3 Irrigation and Public Health Department – Himachal Pradesh

The objective of Irrigation and Public Health Department is to provide safe drinking water and assured irrigation to maximum feasible cultivated area with people's participation. As one of the initiatives taken to promote people participation, WASH (Water Availability Self-Help) Project has been signed between the Government of India and the Federal Republic of Germany for management of minor irrigation systems and safe drinking water. Funds from Prime Ministers program have been raised; and hand pumps in draught prone areas have been installed to improve people's participation.

## 2.5 Case Studies

To support our project goal, we explored case studies that describe using traditional forms of agriculture. These studies illustrate significant components considered for such utilization, such as the successes and failures of implementing these systems.

### Case study 1: Irrigation in South Bihar

One case study that we examined focused on reviving the traditional *ahar-pyne* irrigation system in South Bihar. The *ahar-pyne* irrigation system is an interesting method that dates back over two thousand years. The *pynes* (canals) bring water into *ahars* (tanks). The *ahar* recharges the ground water and so the nearby wells draw water. The system also helps to divert rainwater, which reduces potential flooding of larger rivers.

The people in the village realized that they could store the available water of the *Pachuhuan*, which is a "seasonal stream that flows through the community and then falls into the nearby river called *Punpun*" (Koul et al., 2012, p. 270). With this, they concluded that the land could be used as a reservoir and enabled as an irrigation system. The residents needed the strategy for livelihood security. Through collections and contributions of money that started in May 1995, the villagers were able to revive the *ahar-pyne* system. It had a successful outcome; farms were able to produce good crops, with the community now able to grow two cereal crops and one crop of vegetables every year. The study also explored the integration of a new and old system. In the 1950's, the planners wanted to use this indigenous *ahar-pyne* system and so they increased the capability of the "run-of-the-river scheme on a rain-fed river" (Koul et al., 2012, p.270). They relied on the contribution of the system by drawing in maximum possible water. However, the integration of *ahar-pynes* with new systems was hard to do on a large scale.

Repairing and reviving the system required intensive manual labor during dry seasons and relied on funding from sources like the Minor Irrigation Department. Due to limited considerations of proper maintenance, the old and new integrated system was a failure (Koul et al., 2012; Pant, 1998).

### Case study 2: Use of tanks in Maharashtra

Dhangarwadi, Maharashtra, is one of the most drought-prone districts with limited rainfall every year. Thus, a sustainable irrigation system for agriculture is essential. Because of this, two dams were built with the collaboration of the local Dhangharwadi residents and a local NGO known as Dilasa. The dams connected the water from a percolation tank located near the village. Shallow canals were dug along the contours of the land to have the water flow through the fields. As a result, the system was able to provide sufficient water. Farmers were able to produce good quality crops. Adhire, a Dhangarwadi local resident said, “the wheat output of our lands has gone up five to ten times after the tank was revived” (Pallavi, 2008, para. 13). However, other parts of the district were not able to receive proper aid. For tank revival projects like this, issues with funding exist. The government only funded some parts of the district. In addition, villagers assumed the help that will be provided to them. They borrowed money to make the required payment when the tank was constructed for water usage. Moreover, a water management expert, Desarda, said that an irrigation system would need “afforestation, soil conservation, desalting and other labour intensive works” for maintenance (Pallavi, 2008, para.14). For this reason, the revival of the tank system was postponed and delayed for a year. The villagers thought this Dhangarwadi project was stopped. Due to these concerns, the second phase of the project was delayed which caused misunderstandings among the residents in the village. Ultimately, the primary concern focused on financial stability (Chandrasekaran et al., 2009; Pallavi, 2008).

### Case study 3: North-Eastern Traditional Practices of Artificial Recharge

As the region under observation is a hilly region, the third case study focuses on locations that have terrains similar to Himachal Pradesh. Northeastern states such as Assam, Nagaland, Manipur, Mizoram, Tripura, Meghalaya, Sikkim and Arunachal Pradesh have a major percentage of mountainous regions. In these states, particularly Meghalaya, irrigation techniques similar to *kuhls* are used. However, instead of creating canal-like structures, bamboo is used to divert the water from the forest to the fields. The water is transported over hundreds of kilometers to provide water directly to the roots of the plants using drip irrigation. Lots of water is lost while being transported, but even then, substantial amount of water is collected using this irrigation.

Moreover, other traditional sources of water in Meghalaya include springs, known as *tuikhur* or *jhoras*, streams, waterfalls and rooftop rainwater harvesting. Due to the high average rainfall in Meghalaya (2050 mm annually), rooftop rainwater harvesting structures are constructed to increase water supply for post-monsoon season. The Central Ground Water Board helped implementing six schemes in the state, three in schools and three in government buildings, having a total cost of 20.32 lakhs (Central Ground Water Board Ministry of Water Resources, 2011).

With these case studies, we gained more insight of some factors involved in utilizing a traditional irrigation system. They can be successful but only with careful oversight and planning. The integration of new and old system needs to have a thorough examination for success. It is also essential to have proper funding for a maintainable irrigation system. Moreover, the irrigation method design focused on systems suitable for hilly terrains due to the landscape of Himachal Pradesh.

## 2.6 Summary

In this chapter, we introduced the purpose of irrigation in agriculture as well as the common traditional irrigation methods. We also learned that there are different factors influencing irrigation design such as the environment, technology and economy. Indian governmental control has become more centralized with regard to policy concerns around farming.  Finally, we concluded with relevant case studies that will support gaps on the research such as the integration of new and old system and the usage of water-harvesting technique on hilly areas with abundant rainfall on monsoon season. These backgrounds provided a better understanding to our project.

# Chapter 3. Methodology

Our goal was to evaluate traditional methods of irrigation and to design a model to provide farmers at higher altitudes with a sustainable, self-sufficient, and cost-effective water management system. The goal was accomplished through four objectives:

- We identified and evaluated factors that influence a design for irrigation.
- We assessed the government policies and public responses to these policies and irrigation issues.
- We evaluated villages situated on different altitude levels and assessed their irrigation techniques.
- We designed a model of water harvesting and made recommendations that can support farmers.

Here we outline the methodological strategies we chose to pursue these objectives.

## 3.1 Identifying and Evaluating Factors that Influence Irrigation Design

Our review of the literature revealed some factors that pertain to successful irrigation design. We took these factors and identified the three local characteristics that pertain to each. These characteristics included the topography of the area, the available water sources and monsoon patterns, the types of crops with corresponding water requirements. We found this data through archival and online research, site assessments, and informal interviews using a sample of convenience.

### 3.1.1 Topography of the Area

The first factor we identified is the topography of the area, to know about the possible difficulties in accessing and transporting water to the fields. To determine the elevations of the area surrounding Mandi and Kamand, we looked at a topographical map of the region through Google Maps. We also performed site assessments and observations on villages at varying altitude levels, taking photos of the fields for comparison.

### 3.1.2 Types of Crops, Corresponding Water Requirements

In order to collect information about the types of crops and their corresponding water requirements, our group looked at written records in the Central Library.  We also explored the web for relevant documents. We visited and assessed the nearby villages to explore more about the various land patterns, different seasons for cultivation, types of crops grown and the corresponding water requirements. We conducted informal interviews with local farmers to get an idea of the kind of methods they use currently. The interviews also shed light on their traditional occupations to understand their viewpoint regarding the drift from traditional methods to the modern techniques. We asked the farmers what issues they are facing currently due to lack of proper irrigation techniques.

## 3.2 Assessing the Government Policies and Public Response

To accomplish the second objective, we conducted archival research at the library and online research by studying the numerous acts passed by the government. We evaluated current major and minor projects that are implemented to improve agriculture. Furthermore, we conducted in-depth qualitative interviews with farmers and government officials. The questions were semi-structured, and were adjusted depending on the interviewee's response. Interview questions can be found in Appendix A. We began by asking the participant's opinion about the shift from traditional irrigation methods to modern irrigation methods and/or government policies. We visited and interviewed the District Agriculture Officer of Mandi to find out about the current policies and ongoing projects. We also visited the Irrigation and Public Health Department to inquire various water programs provided to local farmers and villagers. During our site visits to local farms, we also interviewed and gathered feedback from the farmers about the existing government policies, how useful they are, and the improvements that could be made.

## 3.3 Evaluating Villages and Assessing Irrigation Techniques

We visited local villages according to their respective elevations. Farms with varying access to a steady supply of water, such as the river, were assessed in comparison to villages that were located higher in the hills. During our site visits to local farms, we also interviewed and gathered feedback from the farmers about the existing government policies and schemes, how useful they are, and the improvements that could be made. Moreover, we asked about their water needs regarding irrigation or drinking water. With the help of our IIT teammates, we managed the differences in language. Indian students translated the interview questions between English and Hindi to local farmers and government officials. We learned local participants provide better responses to our questions in Hindi.

## 3.4 Designing a Model and Recommendations

The last objective of the project was to design a model that is suitable to the hilly terrain of Himachal Pradesh. Our model is inspired by some techniques of irrigation being used in this area as well as the others, such that it did not violate any government policies. We also evaluated the different sources for water that were available and designed a plan that farmers can use for their farms located on hilly terrains. Finally, a scale CAD model using SolidWorks was created to demonstrate the proposed idea's effectiveness.

# Chapter 4. Findings and Analysis

In this chapter, we present the findings of our fieldwork over the course of seven weeks, and discuss the results of our research.

## 4.1 Identifying and Evaluating Factors that Influence Irrigation Design

Using Google Maps, our team found a topographical map specifying altitude levels of different villages. Kamand and Kataula have an average altitude of 1200 meters. Nearby villages, Khani, Hadbon and Kathindi have around 1500 meters elevation. The map indicates the steep terrain, access to water, and the distribution of small villages throughout the district as seen in Figure 11 below (Google Maps, 2013). Rainwater, especially during monsoon season, covers about 70% of total rainfall per year.

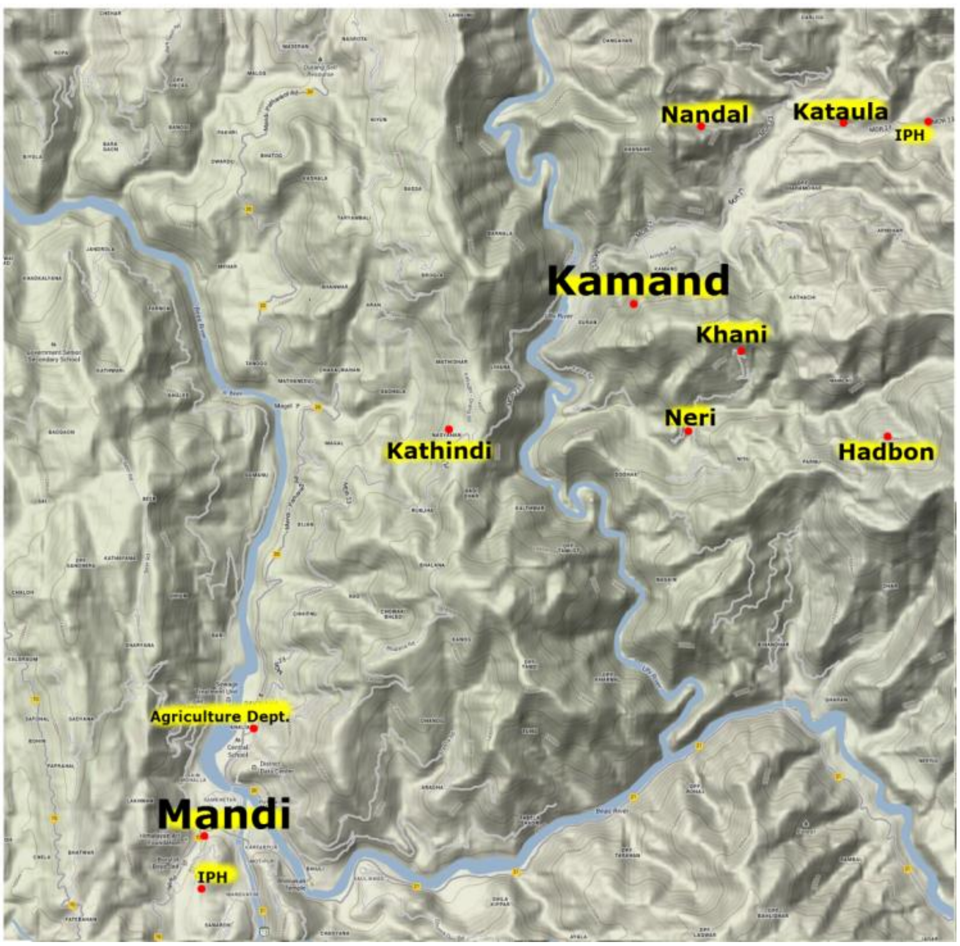


Figure 11: Topographical Section of Mandi District

At the Central Library in Mandi town, we found sources about agriculture in Himachal Pradesh and the types of crops with corresponding water requirements. We learned that different types of crops are grown in specific zones. Due to the difference in altitudes and temperature levels, the state is divided into four zones. Agro-climatic zones in Himachal Pradesh produced varying crops from cereals to vegetables. Mandi district is situated between the two middle zones, with 914 meters to 1524 meters as mid-hill soil zone and 1524 meters to 2133 meters as high-hill zone. The agro-climatic map can be seen in Figure 12 below (Department of Agriculture Himachal Pradesh, 2001).

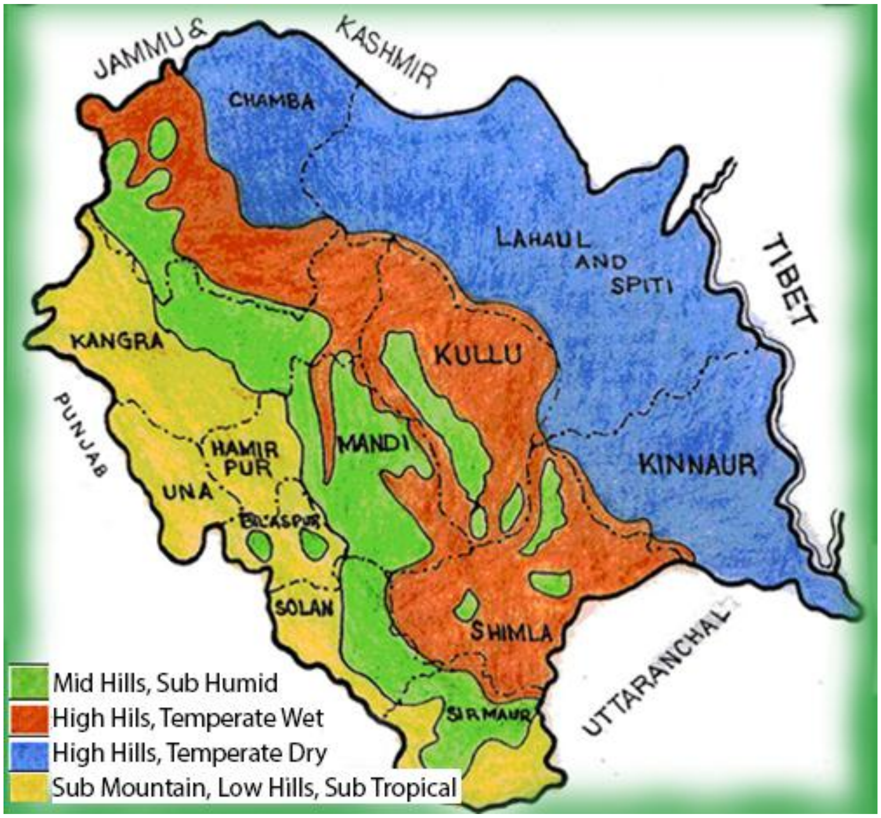


**Figure 12: Agro-climatic Map of Himachal Pradesh**

The main crops produced in Himachal Pradesh include maize, rice, wheat, vegetables, fruits, and fodder crops. As shown on Table 1 (State of the Environment Report Himachal Pradesh, 2000 p.7), we present common crops with corresponding average water requirements.

| Name of Crop | Season | Number of Watering |
|---|---|---|
| Maize | Kharif | 1 or 2 waterings depending on water requirement of the crop |
| Rice | Kharif | Vary from 3 to 6 |
| Oilseeds | Kharif | No irrigation given. |
| Pulses | Kharif | No irrigation given. |
| Vegetables | Kharif | 2 to 5 depending on the type of vegetable |
| Fodder | Kharif | 2 waterings |
| Orchard | Kharif | 2 waterings |
| Sugarcane | Kharif | 2 waterings |
| Oilseeds | Rabi | 2 waterings |
| Pulses | Rabi | Nil to 1 watering |
| Vegetables | Rabi | 2 to 6 watering depending on the type of vegetable |
| Fodder | Rabi | 2 to 8 waterings depending on the type of fodder |

**Table 1: Irrigation Scheduling of Crops**

*On other crops, there is a need to provide watering for the critical states of crop growth and on the basis of soil moisture conditions (State of the Environment Report Himachal Pradesh, 2000 p.7).

## 4.2 Assessing the Government Policies and Public Response

To learn about the government policies and irrigation schemes for our project, we interviewed local government officials representing branches of agricultural planning such as the Agriculture Department and Irrigation and Public Health (IPH) Department. Most were in agreement that the need for irrigation was high, but noted that cost and terrain as key reasons for inaccessibility. The most surprising finding was that agency officials use a cost-benefit analysis to determine action. They focus on assisting villages that could provide better income as well as helping more people. Farmers living on hilly mountains received minimal help as they are remote areas and have lesser population.

Government plans were created to improve agriculture and accelerate the process of implementing irrigation facilities. Through archival research we found that in Himachal Pradesh, government projects such as The National Watershed Development Program has created strategies to increase the productivity of agriculture. These strategies included soil and water conservation, production of high quality fruit and vegetable seeds, and better marketing facilities. The 12$^{th}$ draft of the five-year (2012-2017) plan of the government in Himachal Pradesh aims to improve agriculture by providing farmers access to irrigation facilities and productivity of their crops. As of March 2012, 413 schemes were completed across the state. The Accelerated Irrigation Benefit Program (AIBP), which was created in 1996-1997 aimed to complete the ongoing irrigation projects faster. Because of the program, 17374.86 hectares of land has been produced for irrigation since December 2006.

We interviewed Mr. Prakash Thakur, AEO (Agriculture Extension Officer) and Mr. Pooran, ADO (Agriculture Development Office) from the Agriculture Department that is situated in Jawahar Nagar, Khaliar. According to them, there are several government schemes and projects implemented throughout the district to improve irrigation on fields. The MGNREGA scheme that is being implemented in Kataula has helped farmers by constructing *kuhls* using concrete for more permanent structures. Similar schemes such as the Sigali Sadog, Kandla, Bathari, and the Arang *Kuhl* were constructed more than 15 years ago. Presently, these schemes fund the maintenance of the channels, which includes clearing of sands in the *kuhls* when they become blocked.

In the Department of Irrigation and Public Health Department (IPH) of District Mandi, we interviewed Mr. Santosh Sharma (Assisstant Engineer, IPH Dept.) who explained to us about the various programs that are being implemented in and around Mandi town. For higher altitude villages, the government is providing large subsidies, where it pays 80% of the construction cost to farmers that cover the one-time initial investment to build tanks for storing the rainwater or to utilize modern irrigation techniques.

Through interview, we also found that modern techniques such as the micro-irrigation system and poly-houses were introduced to produce better quality crops. One of the major schemes the government is implementing is the “Pandit Deen Dayal Kisan Bagwan Samridhi

Yojna" that was stated about 5 years ago to promote modern and more efficient irrigation facilities. This scheme had an average total budget of INR 553 Crores for the entire state. Under this scheme, a technique that the government is successfully implementing is the Micro Irrigation System (MIS), which consists of sprinkler and drip irrigation systems. This technique also implements protected cultivation by utilizing poly-houses that are used for off-season crops. This scheme was open to all people and places. One area such as Sundernagar benefitted greatly from this scheme while places such as Kathindi and Kataula are still lagging behind.

We spoke with Mr. Hans Raj Kaudid, Junior Engineer, who stated that there are no irrigation schemes currently being implemented in the Kamand region. Instead, we were able to gather about other schemes in other locations such as Nandal and Sundernagar. In Nandal, the government constructed the Lift Irrigation System (LIS), which gathers water from the nearby rivers then pumps the water uphill to villages. However, the government is unable to provide any help at the heights of 200m or more from the river, as it is difficult and not cost-efficient. The cost efficiency is measured in terms of Benefit Cost Ratio, which is evaluated using the ratio of the monetary gain and the construction cost. Moreover, Kathindi, located between Mandi and Kamand, is at a high altitude of over 1500m. No irrigation system is possible in this village. Due to the lack of water sources such as rivers that are naturally present in lower altitude villages, there is no water to irrigate with. Similar to Kataula, villagers in Kathindi cannot implement *khatris* and Persian wheels because the ground water level is too low. The government is unwilling to invest in these villages because the project would be costly for such a small percentage of the population.

In Balh Valley in Sundernagar, we learned about a large-scale irrigation scheme that began its operation one year ago supplying water to villages in and around the area. It is one of the largest irrigation schemes in Himachal Pradesh; it cost INR 96.76 Crore to build and with 15 km of main line, it irrigates a total of 2355 hectares.

According to the government officials we interviewed, there are mainly two demands from the people. First, they demanded the government to establish sources of water by tapping the monsoon rains, which accounts for 70% of the annual rainfall between the months of July and August, using rainwater harvesting. Although there are modern advancements, the people's need for irrigation is not fully met. Farmers also demanded implementation of modern irrigation systems such as MIS, poly-houses and LIS. The government is unable to provide any help to villages at higher altitudes as it is not cost-efficient. Therefore, the only water source for irrigation is rainfall.

## 4.3 Evaluating Villages and Assessing Irrigation Techniques

We evaluated and assessed the fields of seven villages in and around Kamand including Kataula, Kamand, Kathindi, Hadbon, Neri, Khani and Sundernagar. In each, we identified irrigation methods farmers used, ongoing government projects (if applicable), local crops produced, and water and irrigation issues farmers were facing. When we visited the local villages, we discovered that there were many commonalities between them. In the villages located near plentiful water sources there was, in every case that we encountered, an occurrence of *kuhls*. The farmers would divert water from the river through their farms and back to the river. These *kuhls* are used, in addition to irrigation purposes, in the operation of mills. In only one scenario did we find that the *kuhls* were government subsidized, everywhere else they were hand dug by the farmers who operated the farms. At the higher elevations we found that the farmers were much more self-reliant; they use smaller fields to grow crops for self-consumption. As the crops being grown are not being used for profit, they are not putting active efforts towards improving the irrigational methods and rainwater is sufficient for the time being.

### Kataula

We visited the village of Kataula, which is near the north campus of IIT Kamand. It is a village that lies between village of Bagi near Parshar and Kamand. There are mainly three types of traditional sources of irrigation: mud *kuhls* (temporary ditches that have to be re-made with every harvest), rainfall, and mud tanks. Other forms of irrigation such as *khatris* and Persian wheels cannot be implemented in Kataula because the ground water level is too low.


Figure 13: Kataula Village (left) and Nearby Spring (right)

When we visited, it was after the end of monsoon season. Walking through the farms, we observed stone huts that were sheltering mills that are used to turn wheat to flour. These mills are powered by water that would be diverted from the river.


Figure 14: Stone-hut Mills in Kataula, Exterior (left), Interior (right)

When we were talking to the owner of one of the farms, she explained that the *kuhls* were government subsidized. These were more permanent than other types of diversion channels that we had seen at other locations such as Kamand because they were made of concrete.  When we investigated, however, they were full of silt and non-functioning. This was not a problem due to the abundance of rainwater courtesy of the recent monsoon season. She explained that if the *kuhls* were needed the farmers would simply clear them of silt using spades or other similar devices.

**Figure 15: Opening of *Kuhl* Irrigation in Kataula**

As we were leaving, we happened upon a government run nursery as seen in Figure 16, below. They were cultivating mango, pomegranate, and bamboo plants being grown for transplantation purposes. This was at a higher elevation than the other farms that we had visited. They had no practical way to get water from the river to the plants so they used tanks that would collect rainwater. This water was then used when necessary to sustain the plants during the drier months.

**Figure 16: Kataula Government Nursery Farm**

## Kamand

In Kamand, near the southern IIT campus located by the riverside, is another government run nursery. Here, they had a *kuhl* that was used to water the plants. Unfortunately, it was non-functioning due to a landslide that blocked it during the monsoon season. Unlike the one in Kataula, this *kuhl* was hand dug and far less permanent than its concrete counterpart. Due to the channel being out of commission, a rudimentary tank is being used to store water from rain; crops are then watered by pail.

**Figure 17: Kamand Government Nursery, Temporary Tank (left) and Kuhl (right)**

## Kathindi

In Kathindi, located on higher level of the mountain, population is roughly 550 people. As per the importance of agriculture as an occupation in the region, most of the population follows the traditional of cultivating crops as the main source of income. Many farmers produce crops on a large scale for mass trade, while some, like shopkeepers, grow vegetables and crops in small fields and sell them to local people. A few of the villagers also grow crops for self-consumption.

Rainfall totals in the region vary from approximately 200mm during monsoon season to only up to 30mm for the remaining months of the year. The agricultural crops are categorized as per the two main seasons. Winter crops include wheat. Summer crops include maize, some lentils and vegetables like cucumber, eggplant, gourd and cauliflower.

Natural and geographical limitations in developing irrigation systems in Kathindi are as follows: Since the river is very far away, there is no way bringing the river water into use for irrigation purposes. Since Kathindi is situated uphill, there is no water channel flowing downwards to tap *kuhls* or to store water in depressions for manual sprinkling. Implementing Persian wheels or wells is not feasible since the ground water level is very low. There is no other natural source of water like seasonal or perennial springs, so *khatris* or some other water storage system cannot be developed to store water. On the part of the government, a lift system has been implemented nearby the village but only for drinking water purposes. No support has been extended for irrigation purposes under any of the previous or ongoing schemes like MGNREGA.

## Hadbon

In Hadbon, an estimated 20 kilometers away from Kamand, the fields are mostly situated on hilly mountains, thus utilizing terrace farming. From observations, we found that most of the fields are formed along the mountains as shown in Figure 18.

**Figure 18: Hadbon Village Fields**

According to the farmers we interviewed, they do not use any traditional irrigation systems besides the rainwater. They did not have any irrigation issues since most of the crops grown, especially corn, do not require a lot of water. No government irrigation projects were implemented in the village except for the water pipes established primarily for drinking purposes. The farmers here live well, apart from one catastrophic drought that happened in 2007. During that year, farmers were unable to produce good quality crops. Moreover, the government did not help them in any way because, as a remote area, it was difficult to access to the fields. However, after that year, the farmers were able to endure and yield productive crops.

Figure 19: Farmers Plowing Fields in Hadbon

## Neri

Neri is a small village about 10 km away from the IIT Kamand Campus. The main crops of this village are corn, while other crops such as cauliflower and radish are also grown in small quantities. Average villagers have received no governmental help for irrigation. The farmers utilize mostly rainwater for irrigation. Only a few farmers made *kuhls*. These *kuhls* were hand-dug for temporary usage and had to be re-dug every time a new harvest was being planted. There were more permanent *kuhls* but, based from our interview, they were primarily used for running the mills, having no irrigation purposes at all.

Figure 20: Neri Village Fields with Nearby Spring

While most farmers have not pursued any external help, few farmers have utilized government help. For example, a government initiative called Himachal Pradesh Energy Development Agency (HIMURJA) provided some farmers with a device that used the water flow of the river to irrigate the fields without using electricity or any other energy source. However, the pipes for the device were stolen and the device was out of commission as seen in Figure 21.

**Figure 21: Unused Water Pump in Neri**

Moreover, we interviewed one farmer who utilized the Micro Irrigation System (MIS) using sprinkler and drip irrigation system in his poly-house as seen in Figures 22 and 23. The facility was 23 square meters with a cost of around INR 4 Lakhs for construction. Under the "Pandit Deen Dayal Kisan Bagwan Samridhi Yojna" the state government of Himachal Pradesh government subsidized 80% of the cost. Although the crops grown from the poly-house generated higher profits, the farmer complained that the materials used to make the poly-house were not of good quality, the tarp/plastic covering it started to tear. In addition, the sprinklers have started to malfunction only after 2 years of operation.

Figure 22: Poly-house in Neri

Figure 23: Water Tank Used for Poly-house (left), Water Travels through Pipes (right)

## Khani

Another village we visited is Khani, which is located across from Neri, situated at a higher elevation on the mountain with around 1400 meters of altitude.

Figure 24: Khani Village

Through observation, we found a tank storage system used by the villagers (see Figure 25 below). The tank, covered with a cement roof and a hole for maintenance, uses ground water lifted using electric pumps. According to the farmer we interviewed, villagers only use the tank for drinking, not for irrigation purposes.

Figure 25: Tank Storage System in Khani

In addition, we found that most of the crops grown in the area are only for self-consumption. Farmers do not use any irrigation systems and are, therefore, dependent on rainfall as source of water. They simply grow corn, wheat, pumpkins, and chili during monsoon season (see Figure 26 below). The government has not helped them except for the implementation of tank storage system used for drinking.

**Figure 26: Some Fields in Khani**

## Sundernagar

In Sundernagar, we visited the Irrigation and Public Health (IPH) Department who directed us to Jain Irrigation office. Jain Irrigation is a company that was responsible for constructing and maintaining the Balh Valley Irrigation Project, which was the biggest irrigation project in Himachal Pradesh costing INR 96.76 Crore and irrigating a total of 2355 hectares. There, we learnt how their central facility de-silted water and transported it to other smaller pump houses throughout the district. After visiting the central automation system of Jain Irrigation, we also visited a local farm and interviewed local farmers. We learned that the farmers were satisfied about the corporation coming in and providing them with water. Prior to the company, these farmers had to depend on rainwater, which was not sufficient; they hardly made enough harvest for self-consumption. Now, farmers are yielding crops for mass production, which has greatly improved their standard of living.

## Nandal (South-Eastern Corner)

We visited the Lift Irrigation System (LIS) in Nandal. The construction of this LIS started in 2004, taking approximately 3 years to build. The motor that lifts the water is 75 HP (horsepower). Water is brought from the river using gravity and stored in a tank that holds 25,000 liters of water. The pumps then divert the water to three different regions, about 100m higher than the facility. The villages on Una, Salgi and Pataasasi are irrigated from this facility through one diversion channel per village. As the case during our visit, this LIS is inactive every month; facility shuts down during the monsoon as there is plenty of water available.

## 4.4 Designing a Model and Recommendations

Due to increasing demand, government is focusing more on drinking water than irrigation. This has led them to build storage tanks for local villagers. We found through interviews and site assessments that water is unsafe; residents suffer severe stomach illnesses. We researched efficient purification systems and discovered two cost-effective and easily accessible methods such as the solar water disinfection (SODIS) and the sari filter, described below.

### Solar Water Disinfection (SODIS)

SODIS, first used in Cameroon, provides drinking water using low tech processes. Water is stored in transparent PET plastic bottles, and left to sit in sunlight for at least six hours. During cloudy days, the water bottle is exposed for longer amounts of time. This allows the UV rays to penetrate and kill all the microorganisms in the water thus purifying it. The bottle can be placed on top of newspaper articles to check if the letters are readable. If they are, then water is suitable for drinking (Swiss Federal Institute of Aquatic Science and Technology, 2011).

### Sari Filter

A second simple method for water purification is the use of sari cloth as filtration systems. In Matlab, Bangladesh, women utilize their old sari cloth; fold it four to eight times to minimize space present in between the threads. The cloth is rinsed and dried under the sun after use. This method is proven to reduce as much as 90 percent cholera bacteria and other pathogens that are usually present on ponds and river. A study was conducted 5 years after the introduction of the system to check on how many people, those with proper training and no education at all, continued using the method. Results showed that only a small percentage of people continued to use the sari method. This indicates that proper instructions on usage of the system to local people would have a beneficial outcome to its sustainability (Huq, Yunus & Sohel, 2010; American Society for Microbiology, 2010).

## 4.5 Analysis

Based from the information we gathered through research, site assessments and interviews, three common themes emerged in our findings: the altitude, access to irrigation systems, and cost. Over the course of our investigation, we found that government help is provided to the farmers but there does not appear to be too many participants. Reasons for why very few farmers are taking advantage of these opportunities include indications of mistrust of the government, lack of awareness, and lack of water sources.

Villages situated on lower levels of the mountain have nearby springs and rivers that local farmers can access, while villages situated on higher altitudes have limited access to these springs and thus lack source of consistent water. These farmers living on hill slopes rely on rainwater or government help. There are also only a few people living in these locations, as they are remote areas. Because of this, the government is unwilling to support the residents. The government schemes focus on helping villages with larger population since they can assist more people and possibly gain more income. This is calculated using a ratio of the cost of materials and labor divided by the number of people who will benefit from the scheme.

Aside from springs and rivers, farmers have to rely on rainwater that is limited to the monsoon season. They have to store this water to provide for crops and themselves. However, storing water for an amount of time could contaminate the drinking water and pollute the system. As we have seen from evaluating local villages, stagnant water is a breeding ground for insects and algae, whereas the constantly flowing water in the nearby rivers is not.

In villages, such as the ones we visited, information travels slowly, if at all, especially between villages that are very remote or with no road access. Information about the irrigation schemes and new modern irrigation techniques rarely gets spread according to government officials in the Mandi Agriculture Department. Due to this, people are unable to change their means of livelihood. When we talked to the governmental officials, this idea was reinforced. At the same time, the farmers said they knew about the schemes but the government was not helping them. We are uncertain if the farmers told us the whole story because they looked resigned to the fact that the government was not going to help them. This idea gets echoed through society and begins to make people reluctant to trust or participate in government programs.

There are rarely people taking the opportunity to accept the government's offers because of paperwork walls in place that make it difficult to get the full incentive. This coupled with farmers not being willing to see the whole process through makes it even harder for these schemes to get to the communities. What we have found is that in order for the people to capitalize on the offers, certain obstacles, such as an application process and passing the cost benefit analysis, are unavoidable. While talking to the farmers in the surrounding villages we found evidence that some farmers had to bribe officials to get what they needed. We feel that this is a reason why people are so reluctant to participate in these programs. If they want it, then they have to be willing to put up with ridiculous amounts of bureaucracy and in the end, there is a very real possibility that they will never receive what they applied for. In most cases, just for simplicity's sake, it might be better if the farmers are just willing to bribe the government to get results.

After assessing irrigation methods and water needs of villages in Mandi district, we realized that insufficient drinking water within the villages was a problem and so we re-evaluated our project parameters. We started to research efficient water collection and purification systems. We determined that a rainwater harvesting technique would be applicable, especially since these areas receive abundant rainfall during monsoon season. A purification system that we discovered was solar water disinfection (SODIS).  This water purification strategy was incorporated into our final design due to the ease of implementation as well as its cost-effectiveness.

# Chapter 5. Recommendations and Conclusions

Our findings revealed that villages are facing drinking water issues rather than irrigation issues. Villagers as well as farmers are vulnerable to drought and other risks associated with climate change. With this, we recommended the utilization of water-harvesting techniques as an additional water supply in times of need.

## 5.1 Recommendation/Prototype Design

Since rainwater is abundant in monsoon season, a design to capture water could be used by villagers as a back-up source. In our model as shown below in Figure 27, rainwater will be diverted from the roof to the storage tanks using the gutters. As rainwater is fresh and already clean, the water being collected will not have many impurities. If there are any contaminants, there will be a filter at the connection point between the gutters and the pipes as well as the entrance into the tank so contaminates will be trapped. Then, the water moves to a storage tank that will hold the water. A pump will then circulate the water back into the tank so it is aerated to keep away the formation of algae or other microorganisms. An outlet leads to a water purifier that will clean the water utilizing the SODIS concept. A second outlet can be used for irrigation if required.

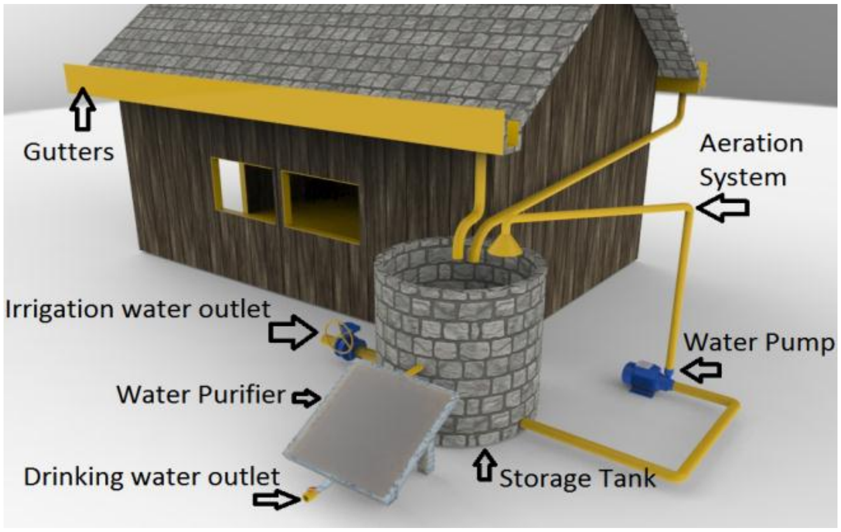


Figure 27: Recommended Design

We wanted our model to be as cost effective as possible while easy to install. For this we suggest the gutters be made from PVC pipes, by cutting it into halves and connecting the halves on the roofs by using customized metal brackets. Although PVC pipes costs INR 29 per feet, it will be cut into halves so it would cover twice the distance. Metals such as aluminum and tin are other viable options. Aluminum would cost INR 22 per $ft^2$, while tin would cost INR 20 per $ft^2$. Also, since the metals come in sheets, it would have to be shaped into gutters and the connections would have to be riveted together. All of this requires more labor costs. According to the shopkeepers we interviewed, the gutters will start to leak from the connection points in the metal so it is not as durable as the PVC pipes; therefore, we recommend the PVC pipe as the material for the gutters (see Table 2, below).

| Materials | Quantities | Asking Prices (INR) |
|---|---:|---:|
| 1/2 inch ball valve | 1 | 150 |
| 1 inch  ball valve | 1 | 320 |
| Aluminum sheet | 1kg [12 $ft^2$] | 270 |
| Bricks | 6 | 1 |
| Cement | 50 kg | 380 |
| Clear plastic sheet | 1 $ft^2$ | 95 |
| Fibers sheets | 1kg | 220 |
| Gravel | 1 Truck [~4000 $ft^3$] | 4500 |
| Plastic pipes | 1ft | 11 |
| PVC pipes | 1ft | 29 |
| Sand | 1 Truck [~4000 $ft^3$] | 4000 |
| Tin sheet | 1kg [24 $ft^2$] | 490 |
| Water pump | 1/2 HP | 1500 |

**Table 2: Cost-analysis of Construction Materials**

The storage tank is the most essential part of our design. For this, we found two materials to build the tank. First is using traditional fire bricks, cement, sand, and aggregate combination. According to several construction workers and an executive civil engineer, the mixture ratio for cement, sand, and aggregate is 1:4:8 respectively.  Cement costs INR 380 per 50kg bag, sand costs INR 4000 per truck, and aggregate costs INR 4500 per truck and 6 bricks cost INR 1. The brickwork tank will cost approximately INR 15 per liter that will last for over 50 years. Instead of the tedious work required for making this concrete tank, another solution, a plastic tank, will be much easier to install. It costs around INR 10 per liter for a standard PVC tank, which has a lifespan of 20 to 25 years. One problem with the plastic tank is the transportation to higher altitudes with no road accesses. Since it will be almost impossible to carry a large plastic tank to the remote locations, people can either construct tanks using conventional methods or carry many smaller plastic tanks and combine them with pipes for water storage.

For the water purification stage we designed a simple solution. Conventional method for SODIS requires PET type plastic bottle being filled up and kept on the roof for 6 hours and then manually taken out. This could be a difficulty because people might not want to repeat this process every day. So we came up with a simpler solution that is integrated into the water catchment system. From the storage tank, an outlet leads to a rectangular box made from clear plastic with the back side of tin. A valve will control when and how much water fills the box. Another valve will be in form of a tap that can be opened for clean, purified water. This design is suggested for the most amounts of sunlight the box will receive for maximum purification capability and the user-friendly design where the water will be purified with the least amount of work on the villager’s part.

In all, we calculated the estimated cost for building the system without the tanks to be around INR 4550 as shown in Table 3. We have assumed that an average house is 25 feet in length and 10 feet in width and 10 feet height to the gutters. Each house has different needs so the cost will fluctuate. Labor costs and prices for the materials will also vary when it is bought in bulk and negotiated. If the government is willing to subsidize the farmers 80% of the building cost like some of the current irrigation schemes, farmers will only have to pay around INR 910. The final cost will differ according to the capacity of the tank, the construction materials and the labor charge.

| Materials | Asking Prices (INR) | Quantities Needed per House [Estimated] | Prices (INR) |
|---|---|---|---|
| 1 inch ball valve | 320 per valve | 4 | 1280 |
| Clear plastic sheet | 95 per $ft^2$ | 2 $ft^2$ | 190 |
| Plastic pipes | 11 per ft | 20 ft | 220 |
| PVC pipes | 29 per ft | 30 ft | 870 |
| Tin sheet | 490 per kg | 1 kg | 490 |
| Water pump | 1500 per pump | 1 | 1500 |
| **TOTAL** | | | **4550** |

Table 3: Estimated Cost of the System without the Storage Tank

## 5.2 Conclusion

This project revealed an important water issue that villagers are facing besides irrigation for fields. In 2007, there was a drought that destroyed the harvest; for this reason, it would be useful to have a system in place that could alleviate unanticipated natural disasters. The ability to recover for these calamities can also be a struggle particularly for communities on higher elevations. We designed a model that can augment water supply to these hilly areas especially in times of drought. Since most of the farmers utilize rainwater for irrigation, our design uses rainwater harvesting that collects rainwater through roof gutters and stores it in a tank. Our project sought to improve the lives of farmers particularly those situated at higher altitudes by creating a model of water management system that is easily accessible and maintained.

We realize that this scheme may not be under constant use but it does provide a certain level of safety and assurance that even during extreme weather the livelihood of the farmers will be preserved. This contribution can help villagers and farmers on hilly areas around Himachal Pradesh and other states that have limited access to surface water but have abundant source of rainwater. Our design reduces their vulnerability to unforeseen disasters by making them more resilient in a time where climate change’s effects are just starting to be felt. Our project sought to provide awareness to the community of how much government help is given as well as the views of these farmers.

One of the major benefits of a project like this is that it is in no way confined to one region or country. The whole system could be moved to the hills of the Andes Mountains in Peru or it could be modified and certain parts could be utilized by themselves. For example, the SODIS water purification concept can be used in the cities of developing Sub-Saharan Africa while the rooftop harvesting portion is used in Central America. There is nothing keeping parts getting pulled from or added to this design. We, as engineers and fellow human beings, would love to see this get implemented and even if it only helped one person, we would consider this experience more of a resounding success than it already is.

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# Appendix A

## Basic Interview Guide

### Questionnaire for Farmers

- How was the farm run when you were a child?
- What kind of irrigation method did you use? Is it the same as you use today?
- Was it easier to run the farm when you were younger using the other methods you mentioned before?
- What were the difficulties you had?
- What made you change from the above mentioned methods to the current ones you are using now?
- What could improve your irrigation system?
- What problems do you have with the existing system?

### Questionnaire for Government Officials

- What policies have been implemented by the government?
- Why were they implemented?
- How well are these policies implemented?
- How helpful are these policies?

## Appendix B: Poster