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Designing a Water Filtration Device to Remove Chemical and Biological Contamination in Mandi District

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Designing a Water Filtration Device to Remove Chemical and Biological Contamination in Mandi District

An Interactive Qualifying Project submitted to the
Faculty of Worcester Polytechnic Institute in partial
fulfillment of the requirements for the degree of
Bachelor of Science

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Abstract

Government reports over multiple years in Mandi District have revealed high levels of water contamination in many villages that may put residents at risk of negative health effects. This contamination can result from poor sanitation, an expanding industrial sector, and agricultural practices. Our goal was to create a small-scale filtration technology to address the drinking water needs of residents living in affected communities. To realize the goal, we assessed drinking water perceptions, behaviors, and water quality in the Sundernagar area of Mandi District. We designed a filtration device to address two concerns: iron and biological contamination. We designed and tested a filter prototype that can be further tested, refined, and potentially implemented in this region.

Executive Summary

Himachal Pradesh is a state in the northern region of India, home to over 6 million people, where agricultural and manufacturing industries are expanding at a rapid pace. There is a disconnect between the speed of growth and the infrastructure in place to mitigate harmful effects of industrialization. The people of Himachal Pradesh now face the risk of consuming water with high levels of chemical and bacterial contamination (Kamaldeep, Rishi, Kochlar, & Ghosh, 2011).

Contamination in water sources can be a result of many different factors, both natural and artificial. Although small amounts of contamination can occur from natural processes such as earthquakes and rainfall, it often stems from human activity. Rise of industry greatly contributes to water contamination due to runoff and improper disposal of waste products (CEF, n.d.). Surface water bodies including rivers, lakes, and streams are frequently polluted and are not reliable for obtaining clean water. The most polluted rivers are characterized by their "highly toxic organic and inorganic compounds and bacteria, viruses, fungi, protozoa and parasites" (Kurunthachalam, 2013). Polluted rivers and water sources pose a risk to nearby residents due to the health concerns that are associated with exposure to the various contaminants. These chemicals and bacteria can be tasteless and odorless, making them a serious problem that can go unnoticed during years of exposure.

Our Approach

The goal of our project was ***to assess the presence of chemical contamination and the need for water filtration technology in areas that face chemical water contamination in Mandi District***. To meet this goal, we completed three objectives:

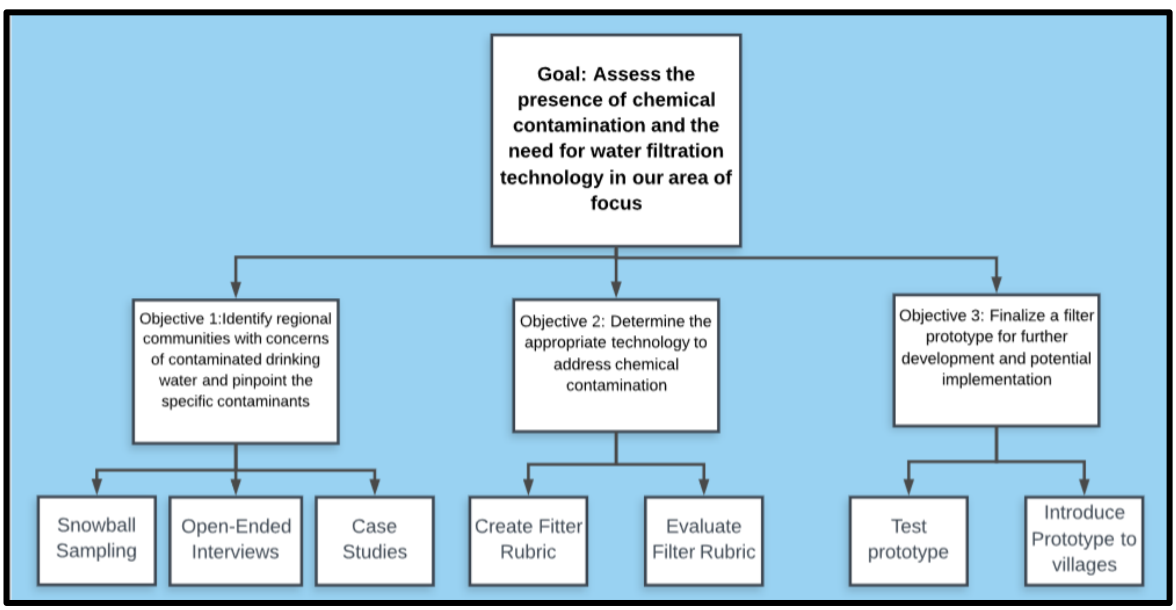


Figure 1: Project approach.

Our Results

First, we identified our area of interest by interviewing local officials and retrieving data from the National Rural Drinking Water Programme on villages within Mandi District reporting levels of contaminants over accepted limits. Data revealed levels of iron in four Sundernagar villages during 2016-2017, and six Sundernagar villages during 2017-2018 exceeded their acceptable limits. We then conducted site assessments where we identified residents in rural villages obtain water from wells, taps, and hand pumps, all of which are monitored by the government.

Second, we determined the appropriate small-scale filtration processes to address this type of contamination based on research regarding different ways to remove common chemicals found in drinking water. We conducted additional research on iron removal and the health effects of iron when consumed. Then we concluded that zeolite filtration would best remove iron contamination. Additionally, we decided to include activated carbon and ceramic filtration in the filter as a method to remove biological contamination.

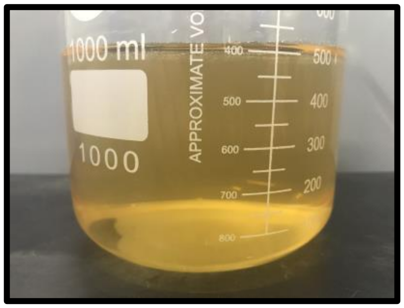
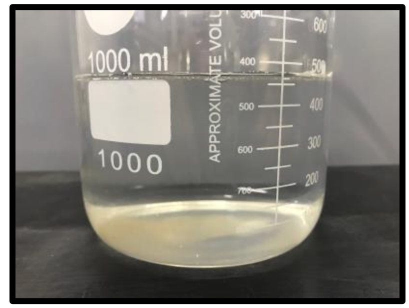
Finally, we designed a filter prototype for further development and potential implementation. Our filter design makes use of two large, stacked buckets with an internal ceramic piece holding zeolites and activated carbon. We chose the design for the filter based on the interview data we collected during our site visits, including responses about the size and filtration rate of our prototype. Table 1 illustrates the general needs expressed by residents, as well as if and how our filter meets that need.

Table 1: Prototype Features.

Need of User	Filter meets the need?	Feature
Multiple liters of water used by families in a day	Yes	Can filter and store up to 6 liters at one time
Filters out bacteria	Yes	Activated carbon, ceramic base
Filters out iron	Yes	Zeolites
Filters 10 liters in 6 hours	No	Filters about 6 liters in 6 hours
Small enough to fit in kitchen space	Yes	70 cm tall x 20 cm wide

After designing and building the prototype, we completed several tests to determine its effectiveness in removing iron contamination. Although we were not able to determine a highly accurate iron removal percentage, our qualitative analysis shows a very significant amount of iron removed through our filter.

Table 2: Qualitative Analysis of Iron Removal through Prototype Filter.

 **Water containing Fe^{3+} ions.**		 **Filtered water.**

Based on the images above, our filter appears to be very effective in removing iron contamination from water. However, our experience throughout this project has led us to compile a few suggestions for any continuation of this project or any similar project work in the future.

Our Recommendations

We proposed four recommendations:

First, increase the efficiency of production for our water filtration device to accommodate for future needs. This can be done through the creation of a mold, which would allow for larger scale production as well as making replication more feasible. We suggest that this production take place at the Enabling Women of Kamand (EWOK). This initiative allows local women to learn skills and to pursuit entrepreneurial ventures. If the women created a mold, then the filters could be efficiently built and sold. Second, we suggest that the Himachal Pradesh Irrigation and Public Health (IPH) Department, or another local organization provides low-cost, easy-to-use water testing kits to residents who are prone to contaminated water supplies. Next, we believe the IPH Department should implement a systematic water testing method in areas of Mandi District that have more exposure to industrial runoff and are regarded as a higher priority in terms of the need for water testing. Finally, the Society of Technology & Development NGO should create a public awareness campaign about water quality issues through the use of small signs attached to water sources, such as public taps and wells, that encourage in-home water treatment.

Acknowledgments

Our team would like to thank the following people for their help and collaboration throughout the duration of this project:

- Our sponsors Dr. Rajnish Sharma and Dr. Dericks P. Shukla for their vision and expertise throughout this project.
- Our advisors Dr. Ingrid Shockey and Dr. Seth Tuler for their guidance and support throughout this project.
- Our teaching assistant Abhay Guleria for assisting our team on site visits and helping build our prototype.
- Dr. Shilpa Sharma of the Society of Technology & Development NGO for assisting our team in locating villages within Sundernagar and helping facilitate interviews with residents.
- Residents that we interviewed for generously dedicating their time and participating in this study.

Authorship Page

All WPI team members collaborated during research, field work, and completion of this written report.

All IIT members were pivotal in interview processes, given the language barrier, as well as with the development of our prototype and revisionary input on this written report.

Top row (left to right): Priyanshu Meena, Pramod Jonwal, Joseph Genga
Bottom row (left to right): Avnish Kumar, Mary Sheehan, Megan Concannon, Peter Nash

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Chemical and Heavy Metal Contamination in India's Drinking Water

The state of Himachal Pradesh, in northern India, is vulnerable to chemical pollution from industrial and agricultural runoff. Since the early 2000s, districts including Solan and Shimla have been expanding industrial development in an effort to create the first industrial hub of the region (Sharma, 2017). Increased presence of industry, such as cement and textile factories, has led to a heightened level of concern about contamination in water supplies from industrial runoff and byproducts (Kamaldeep, Rishi, Kochlar, & Ghosh, 2011). Informal reports from residents of Mandi and the Indian Institute of Technology suggest increased public concern regarding industrial pollution in Mandi District, especially in areas near Sundernagar.

Growth in industry increases the potential for facilities to pollute water sources with chemicals from their waste products, especially when infrastructure development is poorly regulated and poorly planned (CEF, n.d.). Studies from southern Himachal Pradesh in the past decade have shown dangerous levels of heavy metals in local water sources, as well as a lack in effort from local governments to address these issues (Kamaldeep et al., 2011; Sharma, 2017). These reports have specifically highlighted traces of iron, copper, and lead as substances of special concern given their adverse effects on human health when ingested or through dermal exposure.

Exposure to these substances can lead to detrimental long-term health effects such as cancer, cardiovascular diseases, neurological hindrances, birth defects, and more (Barrett, n.d.). Given the life-threatening implications of consuming contaminated water, it is necessary to address mitigation strategies for this problem. To combat this issue in Himachal Pradesh, the state Pollution Control Board has sought to impose stricter regulations on industries in an attempt to prevent large-scale pollution. However, the contamination that already exists in water supplies will continue to affect communities and put lives at risk (Sharma, 2017). Thus, a more immediate response is needed to provide safe water to residents in areas affected by industrial pollution.

To this end, the goal of our project was to assess the presence of chemical contamination and the need for water filtration technology in our area of focus. From our research it was clear that chemical contamination exists, but determining the specific chemicals present required further research. To meet this goal, we composed three objectives. First, we identified regional communities with concerns about contaminated drinking water and pinpointed the specific type of contamination. Second, we determined the appropriate small scale filtration processes to address this type of contamination. Finally, we finalized a filter prototype for further development and potential implementation. Through this project, our team aimed to design a product that could improve the quality of water for communities affected by chemical contamination.

Study of Water Contamination and Small Scale Filtration Techniques

In this section, we investigate the background material on the issue of water quality in Himachal Pradesh, discuss its implications, identify available filtration technologies, and assess the applicability of a water filter in our area of focus.

Site Description

Himachal Pradesh is home to more than 6 million people, spread across 55,673 square kilometers. It hosts twelve districts, and 49 cities and towns. The region contains several main rivers, including the Chenab, Yamuna, Beas, Ravi, Sutlej, and Spiti Rivers, which provide water throughout the state (Maps of India, 2012).

Despite the impression of pristine mountain environments, citizens in this area may be vulnerable to contaminated water supplies, especially if they receive water from unregulated sources such as rivers and unfiltered public distribution systems. In northern India, the primary sources for drinking water include government wells, hand pumps, and surface water.

There are two types of government wells in northern India, bore wells and tube wells. Both are vertically drilled into an underground aquifer and carry water to the surface. Occasionally, electric and solar pumps are installed to pump the water out of the source to ground level. Residents most often access tube wells for drinking water, as well as for a place to bathe or wash clothing (Indiawaterportal, n.d.). These wells typically contain clean water but can sometimes be contaminated with dirt or natural metals from the underground source.

Figure 2: Child retrieving water from a local pipe in Mandi District

The second common source of water is hand pumps, through which water is pumped from the ground and dispensed through a spout. Seen throughout communities in India, these hand pumps provide a place to fill containers, wash clothing, and bathe. User satisfaction with these sources is based on the distance from one's home to the tap and on the quality of water being provided (Paul, 2006). Similar to government wells, these sources can become contaminated from underground chemicals and particulates. Additionally, residents retrieve water from natural water sources such as rivers, streams, springs, and ponds.

Water Quality and Industrial Pollution

Contamination in water sources can be a result of many different factors, both natural and artificial. Although small amounts of contamination can occur from natural processes in underground aquifers and other water sources, it often stems from human activity. Rise of industry greatly contributes to this issue due to runoff and improper disposal of waste products (CEF, n.d.).

Industrial waste is an unwanted consequence of production. This waste is often mishandled and can cause chemical and heavy metal pollution. According to a 2005 study, "large-scale production of a variety of chemicals and energy and other developmental activities like agriculture, urbanization and health care during the past four decades, in India have led to the release of huge quantities of wastes into the environment" (Virendra & Padley, 2005). To work toward water pollution mitigation, the Water Act of 1974 introduced stricter standards. One of these standards includes the recommendation to adopt an Effluent Treatment Plant (ETP). An ETP treats industrial wastewater to reduce contamination under the limits set by the Bureau of Indian Standards (AEF, n.d.). Unfortunately, in the industrial belt of the BBN district there are over 1,600 industries but only 401 of them use ETPs. With 1,200 industries in the area not using ETPs, a large quantity of chemically contaminated water is entering the environment. The types of chemicals that can be in the water depend on the type of industry near the water source, with the most commonly detected chemicals being arsenic and chromium (Arora & Bhagi, 2012).

As many districts in Himachal Pradesh have grown in the past decade, they have begun to introduce more industry. In the Solan District, which neighbors the Mandi District, industries have been rapidly expanding since 2003, when Himachal Pradesh received a government subsidy package to begin developing a "Model Industrial Town of North India" (Sharma, 2017). However, this grant ushered in a poorly planned and poorly regulated development project. Negligence from industrial expansion in this area has resulted in increased pollution in the air and in water sources. More than 2,000 industrial units are currently operating in the Baddi-Barotiwala-Nalagarh (BBN) area of the Solan District.

Unfortunately, surface water bodies including rivers, lakes, and streams are frequently polluted and are not reliable for obtaining clean water. One of the major concerns regarding freshwater sources throughout the Himachal Pradesh region is the growing presence of environmental pollution, stemming from the disposal of sewage, garbage, plastic bags, and domestic waste in the river. The most polluted rivers are characterized by their "highly toxic organic and inorganic compounds and bacteria, viruses, fungi, protozoa and parasites" (Kurunthachalam, 2013).

Polluted rivers and water sources pose a risk to nearby residents due to the health concerns that are associated with exposure to the various contaminants. These chemicals and bacteria can be tasteless and odorless, making them a serious problem that can go unnoticed throughout years of exposure.

Health Effects of Heavy Metal and Chemical Consumption

Heavy metals, by definition, are elements with relatively high densities and atomic weights. Elements such as copper, lead, arsenic, and chromium are categorized as heavy metals, whereas PCBs, fluorides, and chlorides are referred to as chemical contaminants (Lenntech, n.d.[a]). Health effects associated with consumption of these substances vary depending on which chemical a person is exposed to and at what concentration. When present in drinking water, these metals and chemicals can affect humans in many ways. The Bureau of Indian Standards has declared acceptable limits for specific contaminants in drinking water. Ten of these substances that are commonly found in water supplies are listed below in Table 3, along with their acceptable limits in milligrams per liter.

Table 3: Common Metals and Chemicals Found in Water Supplies.

Substance	**Accepted Limit (mg/L)** (Kumar & Puri, 2012).
Arsenic	0.01
Chromium	0.05
Copper	0.05
Nitrates	45
Polychlorinated Biphenyls (PCBs)	0.0005
Lead	0.01
Iron	0.3
Manganese	0.1
Chlorine	250
Fluoride	1.0

When levels of these substances are above the limits they can have negative health effects. For example, consumption of arsenic has been shown to cause visceral cancer, skin problems, neurological effects, cardiovascular diseases, respiratory diseases, and diabetes (Yoshida, Yamauchi, & Sun, 2004). These adverse health effects can result from not only consuming the water, but also using contaminated water to bathe. Chromium and copper can cause problems in the digestive system including diarrhea, liver damage, vomiting, and Wilson disease. Wilson disease is when the body cannot remove excess copper and leads to copper build up in the organs, which can be fatal if not treated (Tchounwou et al., 2012).

Nitrates, when consumed in excess by infants, can cause a fatal blood disorder known as methemoglobinemia or "blue-baby," when the amount of oxygen that red blood cells are able to carry is severely limited (BFHD, n.d.). Lead contamination in water is also extremely dangerous, and consumption of lead by infants can cause brain disorders, a lower IQ, and problems within the circulatory system (WHO, n.d.[a]).

Although chlorine is added to water to remove harmful bacteria, in excess it has been shown to increase cancer rates among affected people. Also, bathing in highly chlorinated water can lead to skin deformities and rashes (WHO, n.d.). Consumption of fluorides, which can be found naturally in water located at the base of large mountains, can lead to a disease known as fluorosis, which affects the teeth and bones (WHO, n.d.[b]).

A recent study in Himachal Pradesh reported that there has been an increase in the number of renal diseases and gallbladder stones in the village of Nalagarh, within the Solan District. This is believed to be a result of prolonged exposure to industrial pollution within the village (TNN, 2018). Similarly, research studies on water quality in the cities of Talwandi Sabo and Chamkaur, in the neighboring state of Punjab, revealed that cancer rates in northern India are increasing. This increased cancer rate is believed to be due, in part, to the presence of heavy metals in drinking water, such as arsenic, magnesium, copper, lead, and selenium. Recorded concentrations of these metals in common drinking water sources were much higher than the recommended levels set by the Bureau of Indian Standards (Thakur et al., 2008).

Current Small-Scale Filtration Technologies

To mitigate the health effects from heavy metal and chemical contamination of public water sources, various methods of water filtration can be used. Some can be developed from local materials such as sand and clay, and others require manufactured products such as activated carbon and zeolites. Each of these media can be implemented in a water filter for specific purposes. Certain filters are more efficient at removing bacteria, while others are more efficient in removing chemicals or heavy metals.

Activated Carbon Filters

Applying extreme heat and reducing oxygen levels to charcoal results in highly-dense activated carbon. This media is porous resulting in an increased surface area and increased absorption capacity. These characteristics give activated carbon the ability to filter out a multitude of contaminants from water. Reports from the EPA claim that it can separate 32 organic contaminants, 12 herbicides, and 14 pesticides (MNDH, 2016).

Figure 3: Activated charcoal pellets.

Activated carbon has also been proven to remove heavy metals. In experimental trials, activated carbon removed 86% of cadmium, 83% of lead, 90% of nickel, 70% of arsenic, and 83.6% of zinc (Karnib et al., 2014). More specifically, there are two types of activated carbon filters known as the Powder Activated Carbon (PAC) and the Granular Activated Carbon (GAC), which are differentiated by the particle size of the activated carbon used in the filters. Particles in PAC filters are smaller, giving a higher surface area to volume ratio, and resulting in a slower but more effective filtration process (MNDH, 2016).

Ceramic Filters

A ceramic filter utilizes a medium with microscopic pores, where water can pass through to filter pathogens and some heavy metals. Porous ceramic is formed through a multi-step process that includes mixing clay with a sawdust or flour, molding its shape, and heating it in an oven to harden into a ceramic. During this process, the sawdust or flour burns off, leaving small pores. Pore size can range from one to five microns in diameter. Ceramic filters may take several shapes but most commonly are crafted into circular and candle-shaped filters. Circular shaped filters are cylinders with the pores residing at the bottom, while a candle shape filter resembles an upside-down candle. Both shapes have positive qualities, but the candle style is usually smaller, while the circular style is larger and has improved filtration rates. Ceramic filters are effective in the removal of pathogens and some chemicals but can be used in conjunction with another filter media (CDC, 2012). For proper metal ion removal, it is necessary to use an ion exchange resin on the filter. Although it is not able to filter a significant number of chemical contaminants, ceramic pieces can be added to other filter designs to improve effectiveness.

Zeolite Filters

Zeolites are natural and synthetic crystalline solid structures consisting of aluminum, silicon, and oxygen. These structures create cavities where either heavy metals cations can be exchanged, or small molecules can become trapped. Zeolites are effective in removing chemical contamination from water because the material exchanges dangerous heavy metals with ions that are safe for consumption. Zeolites are used in wastewater treatment plants where water is highly contaminated with heavy metals. Zeolites can also replenish the naturally occurring minerals that are often lost in the filtration process, but that are important to taste and consumer well-being (Peskov, 2018).

Figure 4: Zeolite powder.

Problems relating to water treatment and zeolite usage involve choosing the wrong form of the compound. The complex and varying crystalline structures of different zeolite forms are only able to accept one type of metal ion. For example, a specific type zeolite called analcime can remove sodium, potassium, calcium, rubidium and cesium due to its cubic structure. However, another type of zeolite called laumontite can only remove sodium, potassium, and calcium with its monoclinic structure (Margeta et al., 2013). If the water becomes contaminated with a different heavy metal, it is possible that the specific zeolite will not be able to remove it.

Electrochemical Purification

According to the Gadgil Labs website, arsenic contaminated water can be called the "world's largest case of mass poisoning in history", as over 100 million people are exposed to arsenic worldwide (Gadgil Labs, 2012). In a lecture at the Indian Institute of Technology in March 2018, Professor Ashok Gadgil of the University of California Berkeley explained his approach for developing technology for the "bottom of the pyramid". This term refers to the largest and poorest socioeconomic class which faces problems due to a lack of education and resources. In areas such as rural India, the "bottom of the pyramid" must succumb to poor water quality because there is no other choice. Professor Gadgil and his team have developed an electrochemical purification method which uses electricity to form rust in water where arsenic contamination binds to the rust particles. The rust is removed and the sludge waste can safely be introduced as an aggregate into a concrete mix design (A. Gadgil, personal communication, March 27, 2018). The unique aspect of this method is that the water treatment is used in conjunction with a business model structure which happens on a community-wide scale. Clean water from the filtration plant is sold at minimal cost and a technician who oversees the maintenance of the facility is given this profit as a wage. This facility and business model are self-sustaining while providing clean water to entire communities (Pujol, 2015).

Assessing the Need of a Filtration Technology

When considering the implementation of a new technology in a community, it is important to assess the need and potential for acceptance of this product in the region of focus. For instance, our team could produce a fully-functioning filter for residents in Himachal Pradesh, but they might not be inclined to use it. This idea is supported by a case study in Tanzania, in which researchers analyzed the implementation of a water filtration technology in rural households.

This study sought to “help people identify a point of use water treatment system that was both effective with the primary water sources in the study areas and stood the best chance of seeing daily use in rural households.” Secondly, it “sought to evaluate the appropriateness and effectiveness of structured decision making (SDM) approaches set in a developing country context” (Arvai & Post, 2012). Through their experiment, Arvai and Post studied the effectiveness of five different filtration methods in two rural villages in Tanzania. Results revealed that people were most likely to choose a filter that was both convenient and effective. Boiling water, although effective, was thought to take too much time and effort. This time constraint caused villagers to find more time effective methods.

After speaking with residents from both communities, they revealed that this was the, “first time that Western researches had taken the time to discuss with them in detail their objectives and concerns, and how these could inform their preferences, in any community development context” (Arvai & Post, 2012). We gathered similar input from our communities of focus for the development of our filter prototypes.

In sum, residents in many areas of Himachal Pradesh continue to face water quality issues, due to growing industry, subsequent runoff, and waste products. Without access to clean water or the means to filter and disinfect water, many residents are at risk of suffering life altering health effects. There are several methods of filtration that can remove heavy metals, chemicals, and biological contaminants. It is important to weigh the benefits of each method to determine which option provides the optimal solution to local water issues. The most important finding is that many social and cultural factors can influence the willingness to accept and utilize a new water filtration device. Therefore, it is important to rely heavily on the input and feedback from stakeholders when designing prototypes.

Methodology: Site Visits and Prototyping

The goal of our project was to assess the presence of chemical contamination and the need for water filtration technology in our area of focus. Through this project we assessed the presence of chemical contamination and the need for a water filtration technology in Mandi District. From our research it was clear that chemical contamination was present, but we needed to identify the specific chemicals that affect communities. We wanted to develop an appropriate technology that could address the needs of our stakeholders. To achieve our project goal, our team compiled a series of three objectives, as illustrated in detail below:

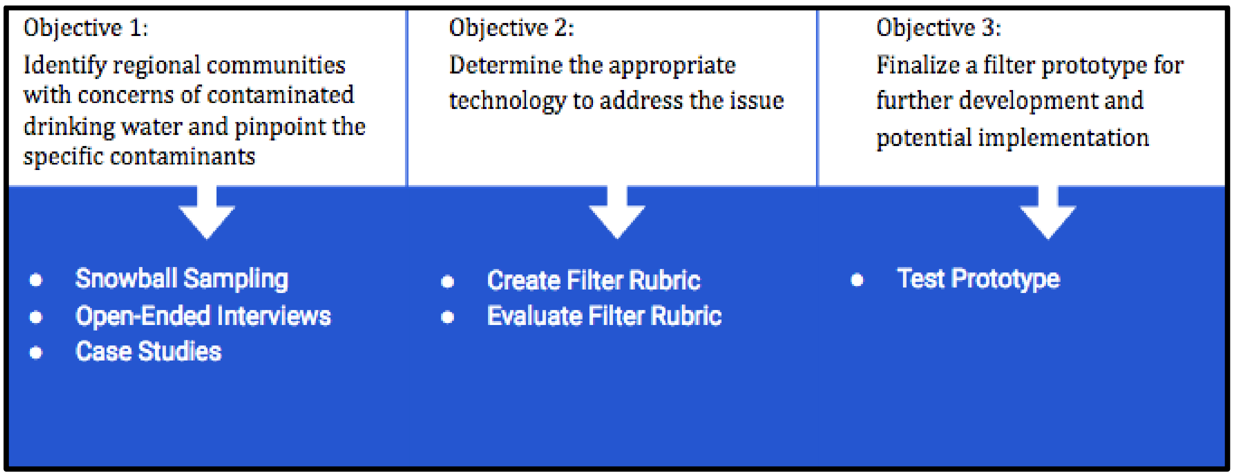


Figure 5: Outline of project objectives and steps.

Identify regional communities with concerns of contaminated drinking water and pinpoint the specific contaminants

We employed snowball sampling techniques, using existing contacts to identify communities with concerns of contaminated water (Johnson, 2014). In particular, we met with Joginder Walia of the Society for Technology and Development, an NGO that is aware of Mandi villages that suffer from chemical contamination and could benefit from a technological intervention. Mr. Walia helped us to identify villages that may be experiencing chemical contamination of their drinking water supply.

We visited five villages, located between IIT Mandi and Sundernagar, and interviewed residents. This helped us to gain a greater perspective and understanding of their sources of drinking water, current filtration practices, and willingness to adopt and utilize a water filter. To assess the current needs and perceptions surrounding water, we held open-ended interviews. These interviews consisted of questions, which can be found in Appendix A, that allowed the participant to express personal opinions.

Determine the appropriate technology to address chemical contamination

To understand contamination removal, we compiled information about common chemicals and heavy metal contaminants, their health effects when consumed, their origins, and how to filter them (see Appendix B). From interview data and available water quality reports from the Himachal Pradesh Irrigation and Public Health (IPH) Department and the Indian Ministry of Drinking Water and Sanitation, we determined that iron contamination was a primary contaminant. Subsequently, we tailored the planning of our prototype to remove this specific substance. Other research and information led us to add a feature that will remove bacterial contamination, as well. We also studied information from interviews based on the desired size and flow rate of our filter.

We conducted additional research on iron removal and the health effects of iron when consumed by humans and determined that zeolite filtration would best remove iron contamination. Furthermore, activated carbon and ceramic filtration could also help remove other chemicals that might be present in lower quantities, in addition to some quantities of bacteria.

Finalize a filter prototype for further development and potential implementation

We speculated which filtration method would best fit the needs of residents relying on contaminated water and proceeded with brainstorming designs for the final filter prototype. We retrieved materials necessary to build a prototype and began experimenting with different designs, as seen Figure 6.

Figure 6: Different ceramic filter shapes and sizes.

Materials used included clay, sawdust, activated carbon, zeolites, and other filter elements such as buckets, spouts, sealer, and polypropylene paper. We created a prototype for the selected filter design and performed a filtration assessment to determine the flowrate and percent of iron removal. It was clear, from interviewing individuals, that other parameters such as size of the filter are important and were taken into consideration.

After we created our prototype and completed testing, we proposed our final filter prototype design to the five villages we previously interviewed. Residents were shown a detailed image of our design and received an explanation of its specifications and capabilities. We collected feedback regarding the design of our filter, if residents would use the filter, and any recommendations they had for our design. This helped us gain an understanding of the villagers' opinions on our water filtration device we designed.

Results and Discussion

Part 1: Results

Communities with Concerns of Contaminated Drinking Water

We used a snowball sampling technique to understand where areas with suspected drinking water concerns exist. This sampling led our team to working with a non-profit organization and we learned that residents living in villages in and around Sundernagar were suspected to have concerns of contaminated drinking water. We conducted preliminary interviews with two residents of Bhadyal village and were led through the village to learn about water access and contamination in the area. Here, we observed discolored water samples and learned that at least four main wells had been closed due to iron contamination. Water from one well, below in Figure 7, appears to be highly contaminated with dirt, salt, and iron, given the orange coloring.

Figure 7: Water sample from a closed tap, showing possible iron contamination.

To further identify our area of interest, we retrieved data from the National Rural Drinking Water Programme that reported high levels of iron in four Sundernagar villages during the 2016-2017 year, and then six Sundernagar villages in the 2017-2018 year (Table 4). According to the Bureau of Indian Standards, the acceptable limit of iron in drinking water is 0.3 mg per liter. However, in many of these villages the tested water contained more than double that limit (MDWS, 2018).

Table 4: Villages in Sundernagar with high iron content in water supply (MDWS, 2018).

Village	Source Type	Test Date	Conc. of Fe (mg/L)	Amount over Limit
Bharari	Tube well	Feb. 2018	0.330	1.1 times the limit
Chambi	Tube well	April. 2017	2.400	8 times the limit
Kaned	Tube well	March 2018	0.820	2.7 times the limit
Ghangal	Tube well	March 2018	0.420	1.4 times the limit
Ghangal	Tube well	March 2018	0.730	2.4 times the limit
Mahadev	Tube well	June 2017	0.680	2.3 times the limit
Mahadev	Tube well	April 2017	0.730	2.4 times the limit
Khatarwar	Tube well	March 2018	2.030	6.8 times the limit

Officials from the Himachal Pradesh IPH department also provided us with six water sample evaluations. All these reports, dated within the past few weeks, revealed iron levels between 1.09-2.03 mg per liter in water from several hand pumps in Mandi District.

We continued our study in the villages of Chambi, Bharari, and Mahadev, where we conducted 23 interviews with local shop owners and residents. Some interviews were conducted with multiple people at once, in cases such as family homes or places of business, thus we received input from about 30 people total. There was a consensus from interviewees on the satisfaction with odor and color of drinking water. Some variance exists in their satisfaction with taste and this will likely motivate residents to use a water filtration device.

Their ages ranged from mid-30s to 70s. Out of these interviews, average satisfaction with water quality was:

- Taste: 3.81 out of 5
- Odor: 4.43 out of 5
- Color: 4.29 out of 5

Most of the residents interviewed reported that their water supplies are compromised by turbidity mostly during rainy seasons, and many people expressed their desire for a filter to ensure the quality of their water. Only five people of 30 reported that they would *not* be interested in obtaining a filtration device.

Additionally, we interviewed residents in the villages of Navlay and Nandoli. Although these areas were not listed in the reports from the National Rural Drinking Water Programme, we felt that gaining knowledge about drinking water perceptions in other areas of Mandi would be beneficial. We interviewed two older men in Navlay who expressed little-to-no concern about the quality of their water. However, they still informed us that they could benefit from a water filter to remove turbidity during rainy seasons. In Nandoli, we interviewed 10 people. The majority of individuals reported that they had some concerns regarding waterborne illnesses, primarily affecting children and occasionally adults. Residents reported that they would use a filter, especially during the rainy season.

During these site assessments, we also identified the most common ways residents access drinking water. In rural villages, residents obtain water from wells, taps, and hand pumps, all of which are monitored by the government and can be seen below in Figure 5. In urban settings, like Mandi Town, wealthier residents have filtered water piped into their homes. Residents without plumbing can collect water from a government tap, seen on the far left of Figure 8. Individuals in Mandi were also seen using the water directly from the tap to bathe and wash dishes and clothing.

Figure 8: Government taps, well, hand pump in Mandi District.

All images above were taken by the team during field visits.

Lastly, we interviewed government representatives of the IPH and learned that all of the water that is dispensed through government taps within local villages is treated with either bleaching tablets or potassium permanganate prior to distribution. IPH technicians sometimes run the water through a slow sand filter to remove biological contaminants if the water has been collected from a source closer to ground level. Water is then distributed to government taps through galvanized iron pipes. Two government officials working with the IPH have expressed their concerns with excess iron in the water, and some pipes within the villages have been closed.

According to representatives of the IPH Department, residents living in villages between Mandi and Sundernagar pay 30 rupees per 2,100 liters of treated water, which usually sustains a family for one month. This is equivalent to about one rupee per 70 liters per day. There is usually a one-to-two-hour block of time each day for families to collect running water from the pipes. Restricting time of water access helps conserve water, especially during dry seasons.

Technologies to Address Water Contamination

From our site evaluations, we observed and learned of several current home water treatment techniques, outlined below in Table 5, that residents use to remove impurities from their drinking water. Based off of the data collected in the site evaluation interviews, we learned that only 45% of interviewees treat their water prior to consumption. Our prior research confirms that each of these methods may decrease some number of potential contaminants. Notably, many residents boil their water during rainy seasons to remove possible bacterial contamination.

Table 5: Current Small-Scale Methods of Filtration in Mandi District.

Type of water treatment	**Contaminant(s) removed**
Boiling water (for ~30 minutes)	Biological
Filtration with cloth	Turbidity, cholera, particulates
Sedimentation	Turbidity, particulates
Bleaching Powder/Potassium Permanganate (Government distribution)	Biological

Based on existing research from the National Rural Drinking Water Programme, iron is the main substance of concern, in addition to bacteria and turbidity, in drinking water supplies within Mandi District (MDWS, 2018). As listed in Table 6, all these contaminants have different origins, but all have negative health impacts when consumed.

Table 6: Effects, Origin, and Removal of Iron and Biological Contamination.

Contaminant	Health Effects	Origin of Substance	Methods for Removal
Iron	• Hemorrhagic necrosis • Sloughing of mucus in stomach	• Naturally occurring • Construction material • Leaches into water via iron pipes	• Ion exchange • Zeolites
Micro-biological	• Diarrhea • Nausea • Vomiting	• Fecal contamination • E. Coli	• Slow sand filtration • Boiling water • Ceramic filtration • Activated carbon (limited potential)

(sources: Lenntech, n.d.[b]; WHO, n.d.[b]; & WHO, 1996).

Iron has long-term detrimental effects on human health when consumed. Biological contaminants can also produce immediate health-related consequences such as diarrhea and vomiting, which can further develop into diseases like cholera and typhoid. Each of these contaminants requires a different method of filtration to be removed from drinking water. To remove iron, we included zeolites in our filter and to remove bacteria, we used a combination of activated carbon and a ceramic base.

During interviews in Sundernagar, most of the residents who expressed interest in receiving a filter said they would be willing to pay about 500 rupees for the device. Two of the people interviewed said they would pay as much as 1500 rupees. Therefore, we took cost into account when we designed our filter. When asked if they have space available for a filter, people interested in having a filter said they have, or can make, sufficient room for a device.

Filter Prototype: Ceramic, Activated Carbon, and Zeolites

We designed and developed a prototype that combines ceramic, zeolites, and activated carbon filtration methods. This design removes iron, turbidity, and bacteria from contaminated water samples, which were all contaminants that people were concerned about. Our filter design, seen below in Figure 9, makes use of two large buckets stacked on top of one another. At the base of the top bucket there is a ceramic filtration device. Within this device is a layer of activated carbon and a layer of zeolites, separated by a film of polypropylene paper. Consumers can retrieve water from their desired source and pour the water into the top bucket. Water is then filtered through the device and collected in the bottom bucket. About 6 liters of water can be filtered and stored at one time, and filtered water can be dispensed through a bottom tap. We believe that residents would use this water mainly for drinking and cooking, rather than bathing.

Figure 9: Final prototype.

To create the ceramic piece for our filter, our team acquired clay bricks from a factory in Sundernagar and sawdust from a carpentry shop in Mandi Town. We broke down and sifted clay particles through a 75-micron sieve and then sifted sawdust through a 425-micron sieve, collecting 2,200 grams of clay and 670 grams of sawdust. The clay, sawdust, and 1,350 mL of distilled water were mixed and molded by hand into a flower pot. Our mold was then left to dry for 48 hours before being placed in a kiln at 600 degrees Celsius until all moisture was removed. In the kiln, the heat burned away the sawdust, leaving finite pores that water can travel through. Based on the size of sawdust used, the size of pores in the ceramic would be approximately 425-microns. Pores of this size can remove some larger microorganisms and particulates. However, filtering many other bacteria requires pore sizes between 0.2-3.0 microns. This can be achieved with advanced equipment or other burn-off materials that our group did not have access to. Our final ceramic base measured 20 cm tall by 17 cm wide at the top and 10 cm wide at the bottom. The entire prototype is about 70 cm tall and 20 cm wide.

Figure 10: Peter and Pramod sifting clay particles.

We chose the design for the filter based on the interview data we collected during our site visits. Some of our questions pertained to the size and filtration rate of our prototype, and responses were taken into consideration in our design and creation of the device. Table 7 illustrates the general needs expressed by residents, as well as if and how our filter meets that need.

Table 7: Prototype Features.

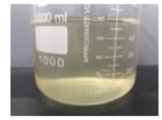
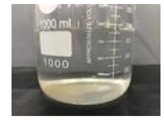
Need of User	Filter meets the need?	Feature
Multiple liters of water used by families in a day	Yes	Can filter and store up to 6 liters at one time
Filters out bacteria	Yes	Activated carbon, ceramic base
Filters out iron	Yes	Zeolites
Filters 10 liters in 6 hours	No	Filters about 6 liters in 6 hours
Small enough to fit in kitchen space	Yes	70 cm tall x 20 cm wide

Preliminary tests for filtration rates ranged between 0.8-1.0 liters per hour. Although this does not meet the needs that residents expressed, it can still provide a substantial amount of clean water. For instance, if left filtering overnight, it could provide at least 9 hours of filtered water the next morning, which could sustain multiple peoples' drinking water needs for the day. Activated carbon and zeolites, which we obtained in powdered form, are able to remove iron and other chemical contaminants.

To measure percentage of iron removal of the prototype, we ran two trials of the procedure found in Appendix C. For one trial, we measured the iron content with a centrifuge technique, and for the second trial we used a simple filter paper method. Using a centrifuge gave a result of 34.3% iron removal, whereas using filter paper revealed a 63.5% iron removal rate. Due to time constraints, only these two trials could be completed, but it was apparent that these procedures were inconclusive. Therefore, we completed a separate qualitative procedure by dissolving fixed amounts of iron (III) nitrate in water to compare to our filtered water.

This qualitative procedure seemed to indicate that our prototype can remove at least 95% of iron contamination from water. We determined this by comparing the color of our filtered water sample to multiple control samples of different iron concentrations, seen in Table 8 below. Our initial contaminated sample measured about 138 mg per liter, and after one pass through the filter became almost completely clear. Such a high concentration was necessary in order to visibly see the change of color due to varying levels of iron concentration. Theoretically, if it had removed any less than 95% of iron, it would have maintained some shade of yellow-orange, as seen in the control samples below.

Table 8: Qualitative Analysis of Iron Removal through Prototype.

						
0% removal (0.0691 g of iron)	**20% removal** (0.0553 g of iron)	**40% removal** (0.0415 g of iron)	**60% removal** (0.0276 g of iron)	**80% removal** (0.0138 g of iron)	**95% removal** (0.0035 g of iron)	**Filtered water from our prototype**
138 mg/L	111 mg/L	83 mg/L	55 mg/L	28 mg/L	7.0 mg/L	<7.0 mg/L

Our testing methods were not able to determine the drinkability of our filtered water. In Himachal Pradesh, iron is acceptable in drinking water up to 0.3 mg per liter. However, with our testing equipment, we were not able to measure such finite concentrations. Before being implemented, our filter would need to undergo rigorous testing to ensure the safety of water produced. Based on our tests, our initial prototype is effective at removing a significant amount of iron contamination, turning dark orange water to clear water.

Feedback from Communities

After completing the prototype, we revisited the villages of Chambi, Bharari, and Mahadev to collect feedback on our design. We interviewed 30 people, ranging from 20-70 years old. During this site visit, 29 out of the 30 interviewees reported that they would use a generic water filter. We proposed our filter design to the interviewees and explained that the filter prototype would be able to remove iron and biological contaminants, as well as other potential substances such as arsenic, copper, chlorine, lead, and polychlorinated biphenyls. We informed residents of the filter's capabilities such as current filter rate of approximately one liter per hour and the cost of about 800-1000 rupees (a cost breakdown can be found in Appendix D). When asked about our specific design, 21 out of 30 residents reported that they would use the filter prototype, but 11 people said they would only be willing to pay up to 500 rupees. Additional suggestions for improvements to the filter included increasing the storage capacity of the filter, from its current 6-liter maximum, to accommodate for larger families or households.

Part 2: Discussion

Our data collected throughout this project shows the contrast of reality versus perception in terms of water contamination in Mandi District. Although many data sets from the Himachal Pradesh IPH Department and other water quality reports show high levels of iron and other contaminants, in addition to doctors reporting hundreds of annual cases of diarrhea and waterborne illnesses, residents do not report any adverse effects or outstanding issues of water quality. However, the looming potential of chemical, bacterial, or sedimentary contamination still convinces the majority of residents to obtain a filtration device to ensure the cleanliness of their water. Without a filter, many residents rely on the taste, smell, and color to determine the quality of their drinking water, which can leave them vulnerable to invisible health threats and subsequent illnesses or long-term health effects.

Information on pollution in Sundernagar is becoming more readily available, but our research and project work have shown that many communities in the Sundernagar area are affected by iron contamination in their drinking water. Based on our research and results, we anticipate industrial expansion, and this will likely lead to an increase in pollution. For example, the neighboring district of Solan has been experiencing excessive industrial pollution for the past decade after introducing hundreds of industries in the area. A search of industries currently operating in Sundernagar reveals a list of brick factories, steel manufacturers, and other facilities that are prone to pollute waterways, and negatively affected water quality in the Solan District. It is our hope that strict regulations from the Himachal Pradesh government, as well as improved waste disposal practices from local industries, will lead to a decrease in the amount of pollution in water sources.

In the meantime, our filter can provide a point-of-use solution for residents that are vulnerable to this contamination, regardless of where the contamination originates from. In our specific target region of the greater Sundernagar area, our filter can address the issue of iron, bacterial, and sedimentary contamination. However, the nature of the materials used in the filter allows for an identical or similar prototype to be applicable in many other locations that are affected by different water contaminants. Activated carbon and zeolites have been shown to remove other chemicals such as lead, chlorides, arsenic, nitrates, and fluorides. If used for drinking water and cooking purposes, our filter could provide a reliable means of obtaining safe water. In turn, this could reduce the frequency and seriousness of many illnesses and long-term health defects.

Project Outcomes and Recommendations

Through our findings we have determined several recommendations to streamline the prototype as well as the building process. Additionally, conducting interviews and gauging knowledge surrounding the issue of contaminated drinking water in rural Mandi District has led us to recommend an education program and a public awareness campaign. We recommend the following:

1. Increasing the time-efficiency of producing the water filtration device to accommodate for potential community-wide implementation by designing a reusable mold and establishing necessary relationships with material suppliers.
2. Implementing a systematic water quality testing method for at-risk villages in Mandi District.
3. Introducing low-cost, simple-to-use, and understandable water sampling kits to residents living in rural areas of Mandi District.
4. Creating public awareness of water contamination by posting small signs at water sources, which would outline risks of drinking water and encourage filtration prior to consumption.

Press Mold and Established Relationships for Increased Production Efficiency

To increase the efficiency of the filter building process, we propose creating a press mold. Our filter is composed of several parts including a ceramic piece for biological filtration. Forming the ceramic base of the prototype by hand demands hours of lab time and leaves room for human error. Creating a mold (Figure 11) where the components can be added and simply pressed into the ceramic filter shape would save time and prevent cracking. This mold can allow for large-scale production of the water filter prototype by making replication more feasible.

Figure 11: Model of plastic mold for ceramic piece to increase efficiency.

Aside from molding the ceramic by hand, creating the ceramic filter still required a significant amount of time. To build our filter, we obtained clay blocks and sawdust chips that needed to be broken down into a fine dust. The sawdust acted as the burn off material in the ceramic base firing process but resulted in pores that were not small enough to remove most bacteria, viruses, and protozoa. We recommend purchasing premade clay and a smaller burn off material for future iterations of the ceramic base. Similarly, establishing a relationship with a local Mandi vendor able to provide these materials would increase time-efficiency and production capacity. Ideally, this vendor would be able to wholesale supplies to cut down on costs and remove the need to frequently order materials. Purchasing larger buckets for the filter, to increase the volume and flow rate, is also recommended based off of the feedback we received from our stakeholders during our site revisit.

We recommend that this relationship be established between a vendor and the Enabling Women of Kamand (EWOK) initiative located on the IIT campus. With the mold and access to proper materials, the women at the EWOK can begin producing the filters at a high volume. Most residents interviewed said they would be willing to pay for the filtration device. During a visit to EWOK, we learned that women in the program are experimenting with crafts and other goods to sell. We feel that the water filters could become an item that the EWOK can create and sell to residents, fulfilling the desire for an entrepreneurial pursuit.

Systematic Water Quality Monitoring

Currently, there is no schedule in place by the IPH or other government agencies to routinely test the quality of water sources in rural areas of Mandi District according to local engineers. This lack of planning has led to significant gaps in water quality data for the region. Our recommendation is to create a systematic way to ensure the IPH is visiting areas in a timely manner. As industry rises and water sources face greater strains, a systemic water testing method will become increasingly beneficial. Areas within Mandi District that have more exposure to contamination are regarded as a higher priority in terms of the need for water testing. In Figure 8, we have identified the villages that we have been corresponding with during site visits, and we suggest that representatives from the IPH perform trimonthly water testing. Ideally, we would like them to test for the presence of bacteria and various heavy metals, as well as other variables such as salinity and pH of the water.

Test Kits and Citizen Science

Our recommendation is to provide residents in rural areas of Mandi District with simple, low-cost water sampling kits through the Irrigation and Public Health (IPH) Department. If the IPH is able to provide these kits, members of the community can participate in citizen science by collecting information about the quality of local water sources. Thus, consumers can gain better knowledge of the quality of their water, instead of relying on its taste, smell, and color. Additionally, this local participation will allow residents to contact the IPH if they are experiencing recurring contamination issues.

Water Quality Awareness Campaign

During interviews, we gauged residents' knowledge surrounding water quality and potential health effects. Many individuals had awareness about the health effects of bacterial contamination, such as diarrhea and nausea, but almost all people interviewed reported no issues with water quality in the area. Contrarily, many government and health clinic reports tell the opposite story. Thus, it is apparent that residents are not made aware of these issues. Specifically, there is no information available to residents about long-term health effects of consuming water with certain contaminants. We recommend that the Society of Technology & Development NGO partners with the IPH to create a public awareness campaign to inform residents and encourage the use of water filtration. This campaign would be small-scale, mostly consisting of signs attached to public taps and wells (Figure 12 & 13). These signs would inform consumers of the potential contaminants in their water supply and suggest precautionary treatment steps to clean their water.

Figure 12: Example sign attached to tap to encourage users to filter water prior to consumption.

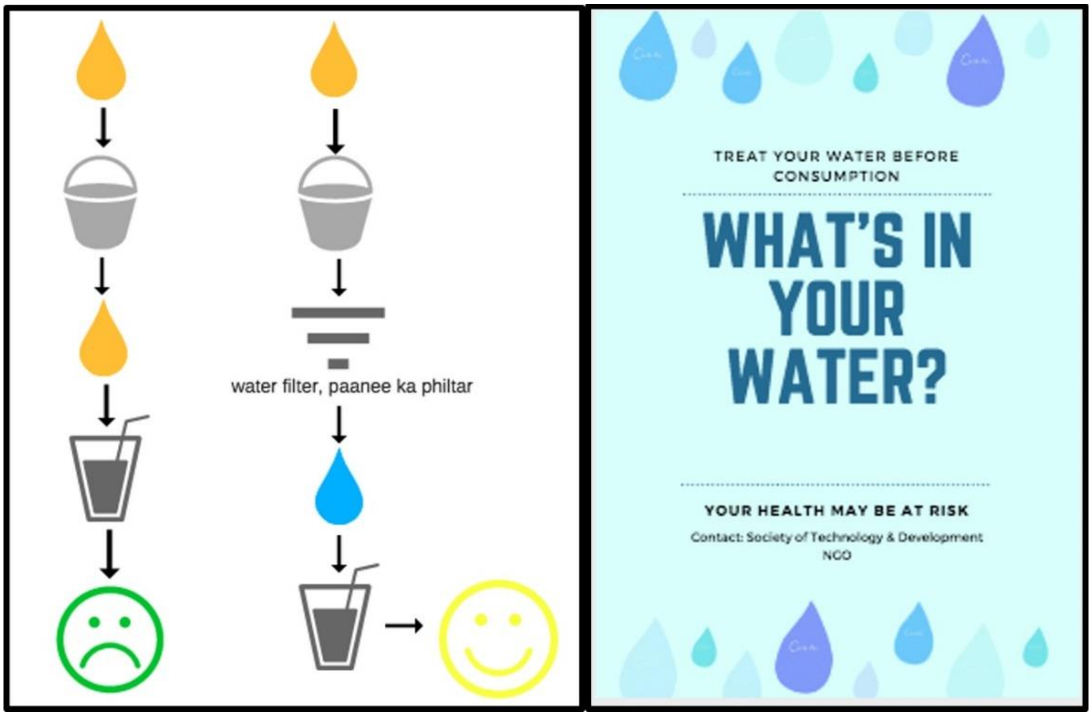


Figure 13: Example signs encouraging treatment of water prior to consumption.

We have been in contact with Dr. Shilpa Sharma and other representatives of the Society of Technology & Development throughout this project and we hope that this organization will continue working with villages facing issues regarding drinking water quality. The signs will outline the risks of drinking untreated water, both short and long-term effects. The signs will also include an area in the village to obtain an IIT water filtration device or a point-person from either IIT, EWOK, or the IPH to contact if interested in a water filter.

Conclusion

Through this project, we developed a water filter technology to address the issue of chemical and bacterial contamination in communities between Mandi and Sundernagar. Currently, people within this area are facing iron and bacterial contamination of their water supply. Certain hand pumps in the area have closed, forcing residents to find other sources of drinking water or turn to unregulated surface water sources, like rivers, for drinking water. The purpose of our filter was to ensure and improve the quality of drinking water to those residents located within Mandi and Sundernagar, as well as neighboring residents which may be facing the same issue. We hoped to improve the daily life and health of our stakeholders by removing the stress of a lack of clean water and by providing a water filter which has a relatively fast flow rate, removes iron and bacteria, and improves the taste and color of the water.

While chemical contamination is not currently considered to be a pressing issue in Mandi District, as industry begins to grow and expand, the threat of chemical contamination in the drinking water supply of villages will increase. Many residents between Mandi and Sundernagar were not aware of chemical contamination in their water, but research has proven the presence of excess iron in their drinking water supply. The effects of chemical contamination are usually not immediately seen or felt, but rather appear after years of exposure. If this issue and threat of chemical contamination is not addressed, the residents of these villages may experience negative health effects in the future due to prolonged exposure to chemicals. The purpose of our filter was to address the current issue that villages are facing regarding chemical contamination, as well as anticipate the issues that they may face in coming years as industry grows and the risk for industrial pollution increases.

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Appendices

Appendix A: Interview Questions

Open-Ended Interview Questions for Government/NGO Officials

Biological Contamination:

1. What are the symptoms of waterborne diseases?
2. How will a person know if they have bacteria, parasites, or other harmful contaminants in the water?
3. What are reasonable precautions to take if one is not certain about the quality of their water?

Chemical Contamination:

1. What are the direct and indirect human causes of chemical contamination of water?
2. What are the heavy metals you have found while testing your water?
3. What are the different techniques being used to remove heavy metals from water?
4. Which communities are most prone to suffer due to chemical contamination of water?
5. What are the diseases people have encountered in past due to drinking contaminated water?
6. What are the initiatives the government has taken to keep a to reduce the amount of heavy metals in the water?

Open-Ended Interview Questions for Residents

Participants for the close-ended survey were chosen based on a semi-standardized basis.

1. Where do you source your water?
2. Do you treat your water prior to consumption?
3. Are you happy with the quality of your water?
   Taste: (unhappy) 1 2 3 4 5 (happiest)
   Odor: (unhappy) 1 2 3 4 5 (happiest)
   Color: (unhappy) 1 2 3 4 5 (happiest)

1. How often do you get sick from waterborne or foodborne illness within a year? Is there any specific time of year when you get sick?
2. Do you have a desire for a water filter? Would you use a water filter? How much are you willing to pay for one?
3. How much do you currently pay for water?
4. On average, how much water do you use for cooking and drinking each day?
5. Is there room in your home for a water filtration device?
6. How long would you be willing to wait to filter 1 liter of water?
7. Have you heard of water contamination in surrounding areas? Places like Mandi and Sundernagar?
8. How often do you have access to water?

Open-Ended Interview Questions for Residents Regarding Prototype

1. Where do you source your water?
2. Do you have any interest in using a filter?
3. This filter is able to remove biological contaminants, iron, and other potential contaminants, such as arsenic, copper, chlorine, iron, lead, polychlorinated biphenyls. It can filter 1 liter per hour. This filter costs 800-1000 Rupees. Would you use this filter?
4. How would you improve this filter?

Appendix B: Information on Chemical and Heavy Metal Contaminants

Table 9: Information on Common Chemical and Heavy Metal Contaminants.

Contaminant	Health Effects	Origin of Substance	Methods of Filtration
Arsenic	• Cancer • Skin lesions • Cardiovascular disease • Diabetes • Negative impacts on cognitive developments • Increased death rates in young adults. (WHO, 2017).	• Naturally occurring • Alloying agent • Used in pesticides (WHO, 2017).	• Reverse osmosis • Ion exchange • Nano filtration • Ultrafiltration • Activated alumina • Coagulation/ Flocculation (Nicomel, Leus, Folens, Voort, & Laing, 2015).
Chromium	• Cancer in the stomach and small intestines • Damage to the male reproductive system • Headache • Nausea • Diarrhea (Bayley, 2010).	• Naturally occurring element • Used in the production of metal alloys (Bayley, 2010).	• Coagulation • Ion exchange • Lime softening • Reverse osmosis • Activated carbon (limited capacity) • Iron filter (limited capacity) (WaterFYI, 2010).
Copper	• Affects respiratory organ systems and lungs (WQA, 2015).	• Industrial discharges • Copper plumbing materials (WQA, 2015).	• Reverse osmosis • Distillation • Cation exchange • Zeolites (WQA, 2015).

Chlorine	• Creation of free radicals in the body • Causes asthmatic attacks in children (GHC, n.d.).	• Used to disinfect the water (GHC, n.d.).	• Charcoal filter (GHC, n.d.).
Fluoride	• Cause fluorosis which affects the teeth and bones. • Joint stiffness and pain. (WHO, n.d.[b]).	• Occurs naturally (WHO, n.d.[b]).	• Bone charcoal • Contact precipitation • Activated alumina (WHO, n.d.[b]).
Iron	• Causes hemorrhagic necrosis and sloughing of areas of mucosa in the stomach (WHO, 1996).	• Naturally occurring • Construction material • Enters drinking water through iron pipes (WHO, 1996).	• Ion exchange • Zeolites (Lenntech, n.d.[b]).
Lead	• Bioaccumulation • Cognitive and developmental effects • Complicates pregnancies (WHO, n.d.[a]).	• Lead pipes and containers (WHO, n.d.[a]).	• Zeolites (Lenntech, n.d.[b]).

Manganese	• Toxic to the immune system (APEC, n.d.).	• Naturally occurring • Due to underground pollution sources (APEC, n.d.).	• Direct Oxidation • Precipitation • Particle Removal • Oxidation • Physical filtration (Tobiason, Bazilio, Goodwill, Mai, & Nguyen, 2016).
Nitrates	• Causes severe illnesses in infants • Causes a condition where red blood cells cannot carry oxygen (Linton, 2017).	• Naturally occurring • Used in fertilizers (Linton, 2017).	• Reverse osmosis • Iron exchange (Linton, 2017).
Poly-chlorinated Biphenyls (PCBs)	• Acne and rashes • Liver and kidney dysfunction • Depression and fatigue • Nose and lung irritation • Increased risk of cancer (OHA, n.d.).	• Used in flame retardants • Added to inks and fertilizers (OHA, n.d.).	• Activated carbon filters (OHA, n.d.).
Micro-biological	• Diarrhea • Nausea • Vomiting • Food Poisoning (WHO, n.d.[b]).	• Fecal matter • E. Coli (WHO, n.d.[b]).	• Slow sand filtration • Boiling water • Reverse Osmosis • UV radiation (WHO, n.d.[b]).

Appendix C: Chemical Testing Procedures

To calculate the percentage of iron removal for our prototype we used the following materials and procedure. We suggest using a more precise procedure for this determination, as there are some factors that may affect the validity of results from this procedure.

Materials:

1. 2 grams of hydrated iron (III) nitrate, $Fe(NO_3)_3 \cdot 9H_2O$
2. 2 grams of sodium hydroxide, NaOH
3. 2 liters of *deionized* water (MUST be deionized)
4. Large 1000 mL beaker (must be large enough for ceramic filter to sit on)
5. Small 500 mL beaker
6. Stirring rod
7. Centrifuge, or filter paper and funnel

Procedure:

1. Add 500 mL of deionized water to the smaller beaker
2. Weigh 0.5000 grams of iron nitrate and add to smaller beaker. Stir until dissolved.
3. Place the ceramic filter on the larger beaker so that filtered water will be collected.
4. Pour iron-water solution into filter. Let filter completely.
5. Weigh 0.1490 grams of sodium hydroxide. Add to filtered water. Stir.
6. Allow a few minutes for any reaction to occur.
    a. Note: Any dissolved Fe^{3+} ions remaining in the water will react with dissolved OH^- ions to form a solid orange precipitate, iron (III) hydroxide, which can then be separated.
7. There are two different procedures that we used to separate the precipitate:
    a. Centrifuge (must be familiar with operation of these machines):
        i. Pour equal amounts of the filtered water into centrifuging tubes. Place in centrifuge for 20 minutes at 8000 rpm.
        ii. When done, pour off excess water and consolidate into fewer tubes. Place back in centrifuge for 20 minutes at 8000 rpm.
        iii. Repeat above steps until left with about 1 mL of water (with precipitate). Place 1 mL sample into a 1 mL centrifuge tube and place in smaller centrifuge device for 10 minutes at 8000 rpm.
        iv. When done, remove excess water. Allow other water in the tube to evaporate.
        v. Weigh a blank 1 mL tube. Weigh the tube with the precipitate. Subtract the blank mass to find the mass of the precipitate.
    b. Filter paper:
        i. Weigh a dry sheet of filter paper.
        ii. Place filter paper inside a funnel and place over a 500 mL graduated cylinder.
        iii. Pour filtered water through the filter paper in increments until all water has been filtered.

iv. Place wet filter paper in a clean and dry oven-safe bowl. Place in a hot oven at 100^{o}C until dry.
v. Weigh the dry filter paper. Subtract the original mass to find the mass of the precipitate.

8. Multiply the mass of the precipitate by 0.523 (the mass percent of iron in the precipitate) to find the remaining mass of iron. Subtract from the initial mass of iron (should be 0.0691 grams if 0.5000 grams of iron nitrate were used. Adjust calculation if necessary. Using the difference in initial and final iron masses, calculate the percent of iron removed.

After performing both procedures (using centrifuge and filter paper) it became apparent that the data is not reliable for various reasons. For example, it is very difficult to isolate just the iron (III) hydroxide precipitate. As a result, the recorded mass of precipitate could have been increased by other substances such as dirt, ceramic dust, or excess water. Since the measurements were on the magnitude of milligrams, this could have highly affected the accuracy of the recorded percentage of iron removed.

It may be more accurate to use a different procedure, potentially using spectrophotometry. This alternative method must also be able to detect iron at concentrations less than 3.0 mg per liter.

Appendix D: Cost Breakdown of Filter Prototype

Table 10: Cost Breakdown of Filter Prototype.

Material Used in Prototype	**Estimated Cost (Rupees)**
Clay	₹165 per 1 kg
Sawdust	Can obtained for free
Zeolites	₹800 per 2 kg
Activated Carbon	₹478 per 1 kg
Bucket (x2)	₹190 per Bucket
Sealant	₹15
Spicket	₹50
Total Prototype Cost	**₹810 (Approx. $12.50)**

Appendix E: Before and After Filtration

Table 11: Results Before and After Filtration through the Prototype.

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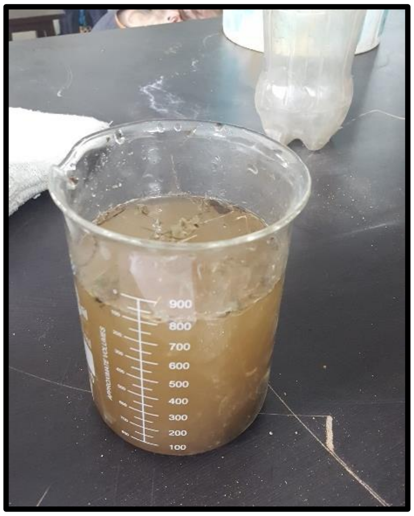
<td>
Water containing dirt and mud.</td>
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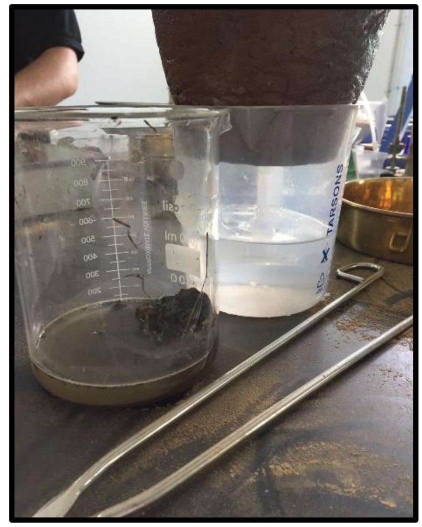
<td>

Filtered water.</td>
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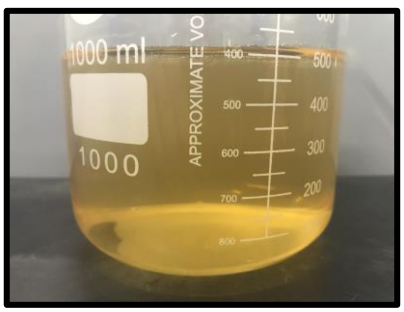
<td>

Water containing Fe^{3+} ions.</td>
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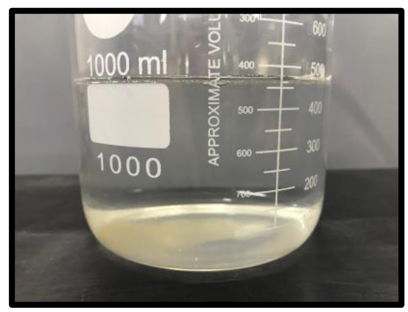
<td>

Filtered water.</td>
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Appendix F: Presentation Poster

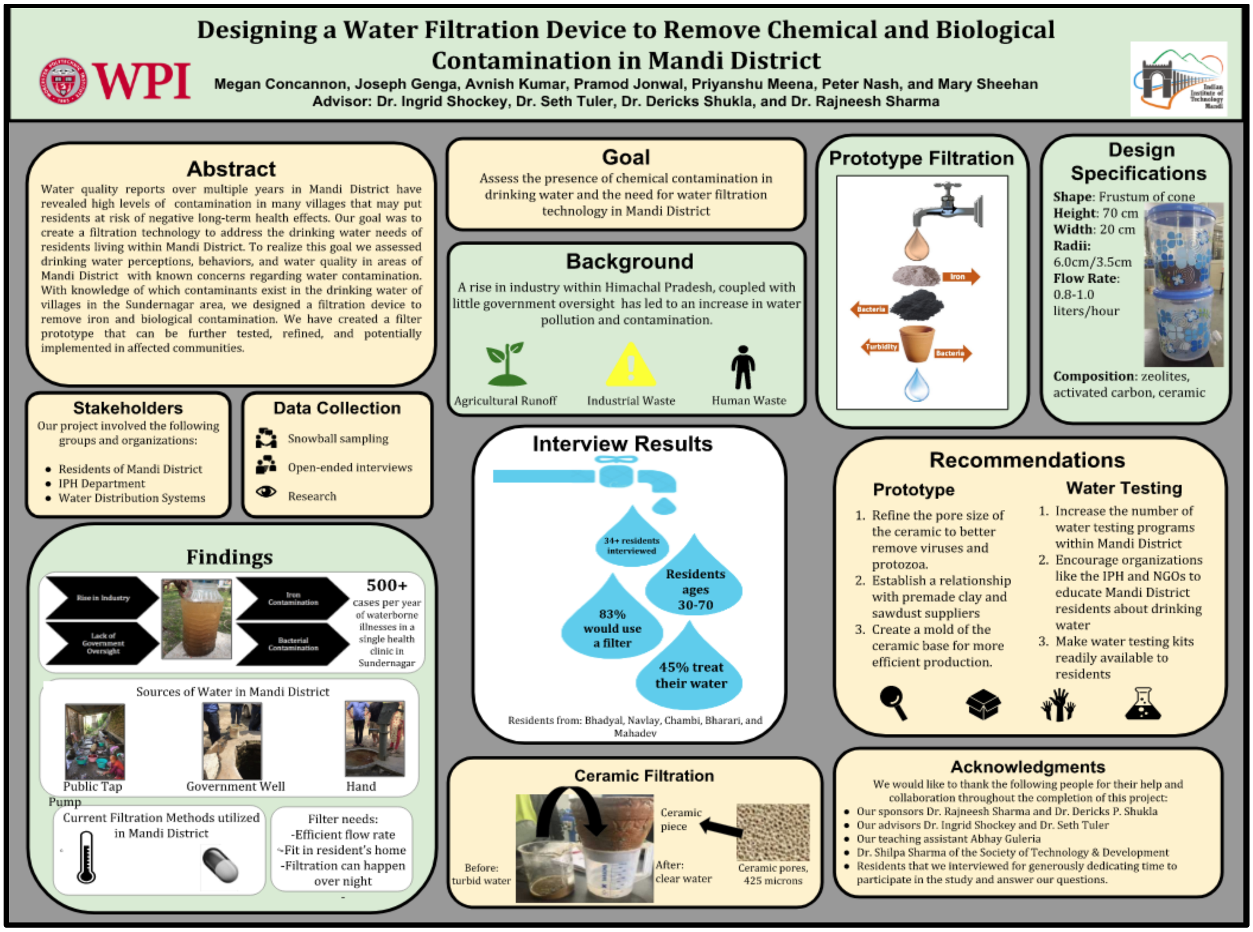

Figure 14: Presentation Poster for ISTP Open House.