WPI/IIT Mandi Project Center: 2018 Annual Report

Kamand, Himachal Pradesh, India

15 March - 2 May 2018

Greetings from the Director, IIT Mandi

ISTP-2018 marks the completion of 5 years of the joint ISTP-IQP run by IIT Mandi and WPI. To recap some history, in March 2012 the faculty of IIT Mandi held a curriculum retreat in which we conceived the unique IIT Mandi BTech Curriculum. An important element was a 4-year Design & Innovation Stream, starting with the core Reverse Engineering in the 1st year and the Design Practicum in the 2nd year. In the 3rd year, students could opt for the Interactive Socio-Technical Practicum (ISTP) capped by the Major Technical Project in their final year.

During 2012-13, Dr. Arti Kashyap of IIT and Dr. Ingrid Shockey of WPI defined the ISTP, to be run in conjunction with WPI's IQP. They developed the mission, depth, and appropriate tone of projects situated in local communities. A key aspect was mixed teams of IIT+WPI students working together on their ISTP+IQP. Dr. Kashyap and Dr. Shockey thrashed out the modalities of running a WPI Project Centre in IIT Mandi. They cooperatively founded the ISTP in August-October 2013 when the pioneering batch of 15 WPI students joined hands with 16 IIT students in our new campus in Kamand. In 2014, Dr. Venkata Krishnan took over the mantle with an IIT-only ISTP.

From 2015 onwards, we have had joint WPI-IIT ISTP-IQP in March-May every year, with 20-25 WPI students and 2 WPI faculty spending the WPI D-term in Kamand. In 2015, Dr. Venkata Krishnan brought his own stamp of systematic organisation to the course, scaling up the programme with larger numbers of students and mentors, and producing the ISTP Booklet as a lasting record. Since 2017, the course has been run by Dr. Devika Sethi from our School of Humanities and Social Sciences. She developed and integrated SSHS practices into ISTP through her own teaching and by bringing in valuable guest lecturers. She has improved the synchronisation between WPI's C- and D-terms and IIT's even semester.

While each of the ISTP coordinators has put her/his unique stamp on ISTP, they have been ably assisted by several other faculty co-coordinators. Given the essential social nature of the ISTP, I expect that in the future Dr. Devika Sethi and her colleagues in SHSS will continue to lead ISTP, assisted by colleagues from the engineering and sciences Schools. This will help to retain and enrich its unique flavour. Dr. Ingrid Shockey has been the bedrock of the ISTP since its inception. Her enthusiasm is infectious, motivating WPI students to cheerfully adapt to the ups and downs of life in the Uhl River Valley, far from the familiar comforts of home in New England. In recognition of her contributions, IIT Mandi has appointed her as Adjunct Associate Professor in SHSS.

The ISTP is a tremendous learning experience for our usually technology-focussed BTech students. The cross-cultural exposure brought in by the WPI contingent is valuable preparation for the increasingly globalised world of tomorrow. So far, there has been limited benefit for society. Successes include EWOK, a business incubator for village women, and some ISTP ideas taken up for implementation by the Mandi administration. However, there is scope for much more payback to society. I hope that students and faculty will convert some ISTP projects into long-term ventures.

My congratulations to the students and mentors for the continuous effort you've put into your ISTP projects. I'm sure the Open House on 27th April will be an intellectual and visual treat to the thronging visitors!

Timothy A. Gonsalves
Director IIT Mandi

Welcome from the Project Coordinators

2018 marks the 6th year of Interactive Socio-Technical Practicum, and the 5th year of joint programming between the Indian Institute of Technology Mandi and Worcester Polytechnic Institute! Over the years, we have grown from a few dedicated faculty and students living on the South Campus to a program that has expanded along with the university in scale and scope. This year brought 22 students from WPI to work in collaboration with 38 students from IIT Mandi. Our projects were guided by 16 mentors and further supported by 10 TAs, to whom we are most grateful.

In addition to pre-requisite courses, this year we welcomed Dr. Rinki Sarkar at the start of our program to advance our fieldwork studies in local communities. She took small groups to villages around Mandi District to teach students how to conduct interviews and interact with local stakeholders, who in turn kindly volunteered their time to engage with our students. Her lessons were invaluable in providing insight and stress-free practice for newcomers to social science research methodologies!

Our projects this year ranged across many important topics, including several on improving water quality, on waste management, on Smart City initiatives, and on other innovative strategies to improve the environment, health, and well-being of area residents. Overall, the benefit of our programming comes in several forms. Our students learn to overcome the challenges with working as a team, and in some cases as an international team. They learn to ask questions and to listen to the experiences of local residents. They learn that solutions to socio-technical projects are rarely as simple as they expect. Creating an effective technical design means refining the art of multi-stakeholder engagement, and incorporating the feedback into the process. The weeks that students spend on ISTP are rarely easy, but they re-enforce the idea that good design means careful consideration of both context and user needs.

We hope you enjoy these reports, and that they encourage future efforts to build on the research that was started over these months.

IIT: Dr. Devika Sethi, Dr. Dericks Shukla, Dr. Aditi Halder

WPI: Dr. Ingrid Shockey, Dr. Seth Tuler

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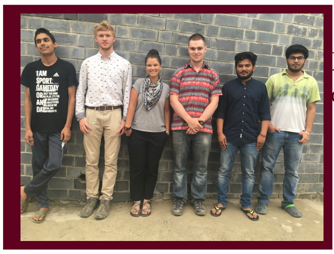

The reports in this booklet represent the work of WPI and IIT undergraduate students. For more information about this collaborative project center, see the WPI Global Projects page: http://www.wpi.edu/academics/igsd/iqp.html Or the IIT Mandi ISTP page: http://www.iitmandi.ac.in/istp/index.html

Developing Drowsy Driving Mitigation Strategies in Himachal Pradesh

Abstract

The goal of our project was to develop and improve strategies to mitigate drowsy driving in Himachal Pradesh. To achieve this, we spoke to local taxi and bus drivers to identify current drowsiness prevention strategies and preferences on improvements to these strategies. Using what we learned from our stakeholders, we created different prototypes to help the drivers get better rest and prevent drowsy driving behavior. These prototypes include a portable and comfortable seat cover, a facial recognition device to detect drowsiness, a blue-light system to inhibit melatonin production in drivers, and two taffy flavors to keep drivers awake. After the initial design and development phase, we were able to do preliminary testing of these prototypes to find areas for improvement. Our recommendations include the future improvement of these prototypes and legislative policy to prevent the overworking of drivers.

Team Members:

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Introduction

Drowsy driving is an issue that has been troubling various countries for years, and parts of India face compounded risks due to the country's geography and driving style. Driving while drowsy is especially dangerous when paired with poor road conditions in rural, mountainous areas, such as what is encountered in Northern India ("Consultancy Services," 2017). The Ministry of Road Transport and Highways in India reported in 2015 that 53.8% of total road accidents took place in rural areas, which led to 61% of the fatalities and 59.1% of the injuries in the country (Government of India Ministry of Road Transport & Highways Transport Research Wing, 2015). While there is a lack of data pertaining to accidents caused by drowsy driving, studies by health organizations and universities in some low to middle income countries with driving conditions similar to India have detailed the prevalence of driver drowsiness. Data from these studies show that 75%, 44%, and 22% of commercial truck drivers have experienced drowsiness while driving in Thailand, Argentina, and Brazil respectively (Herman et al., 2014). In India, the only category drowsy behavior could fit into is fault of driver, which is split into two categories: speeding and intake of alcohol or drugs (GIMRT & HTRW, 2015).

Figure 1: Construction on the road in Kamand on March 27, 2018.

Strategies have been developed to keep drivers alert. The most common strategies for drivers in Himachal Pradesh are to use tea stops or pay attention to cautionary road signs that are placed in higher road elevations by the Border Roads Organisation, a government entity that controls road infrastructure in north and northeastern India (Border Roads Organisation, 2016). Some technological strategies include mobile phone applications that detect the closing of eyes and play loud alarms and GPS systems that recognize when a driver starts veering out of their lane due to inattentiveness (You et al, 2013; Bergasa, Almeria, Almazan, Yebes, & Arroyo, 2014). More compliance with these strategies needs to be mandated, however, as exemplified by three drowsiness-related accidents that took place in Himachal Pradesh within 24 hours of each other. These accidents led to the deaths of 41 people when three buses fell into gorges (Express News Service, 2016).

The goal of our project was to develop and improve drowsiness mitigation strategies applicable in Himachal Pradesh. First, we gathered information from bus drivers and taxi drivers about their experiences with drowsy driving. In certain situations, some drivers may be forced to drive without a healthy amount of sleep. Second, we researched drowsiness prevention strategies and evaluated how drivers used them. This research involved analyzing the effectiveness of certain detection and prevention strategies, as well as using data from our interviews to understand how acceptable these strategies might be. Finally, we developed different prototypes to assist the reduction of drowsy driving. Utilizing these three objectives, we developed long term strategies to mitigate driver drowsiness in Himachal Pradesh.

Background

Himachal Pradesh has approximately 33,000 km of public roads, with rural roads accounting for 75% of the total road network. In one study, 55.3% of the main users (truck drivers, taxi drivers, and private car owners) reported feeling unsafe while commuting on Himachali roads. The three most common reasons cited for feeling unsafe were high traffic speeds, blind turns, and bad or narrow roads (Consultancy Services, 2017). Combining the 625,154 licensed drivers on Himachali roads with poor driving conditions greatly exacerbates the inherent risks of drowsy driving (Himachal Pradesh Department of Transportation, 2017).

Commercial transportation companies can require their drivers to remain awake on the road for long periods of time. Many popular trips for commercial passenger drivers include routes from Manali to Delhi, which can take up to 13 or 14 hours. Once they arrive at that location, they often have to turn around and immediately drive back with little to no rest in between. Long hours of driving considerably increases the risk of drowsiness and emotional or mental stress (Ghuman, n.d.). In the US, certain regulations limit the amount of legal driving time to a maximum of 11 continuous hours, based on time off-duty and whether the driver is carrying property or passengers (Federal Motor Carrier Safety Administration, 2017). Such laws are not in place for drivers in India.

Understanding the aspects of drowsy driving

All of the occupational pressures and long working hours create conditions that can induce driver drowsiness. Drowsiness is classified as Stage I of sleep, or the transition between awake and asleep, and is the feeling of being sleepy for various reasons, which can cause a person to fall asleep at inappropriate times throughout the day (Sahayadhas, Sundaraj, & Murugappan, 2012). This sleep stage causes a decrease in brain activity, which is largely associated with boredom, either in general or due to monotonous driving (US National Library of Medicine, 2017). As a result of the decreased brain activity, driver performance and awareness significantly decline (Lal & Craig, 2001). Worsened driving performance can be observed as slower response time on turns, eye closure for multiple seconds on long, straight roads, weaving between lanes, and sudden accelerations if the driver has been startled after dozing (Seen, Tamrin, & Meng, 2010).

To emphasize the danger of drowsy driving, the Centers for Disease Control and Prevention compares drowsy driving to drunk driving. If a driver has been awake for eighteen hours, their mental state is the same as driving with a blood alcohol content (BAC) of 0.05%. Additionally, being awake for twenty-four hours straight can be the equivalent of having a BAC of 0.1%. Considering that the legal BAC limit in India is 0.03%, this driving behavior is absolutely dangerous (Ministry of Law and Justice, 1988).

There are some noticeable symptoms of drowsiness that could serve as indicators to a driver. These indicators can include difficulties when focusing, eyelid heaviness, consistent yawning, and restlessness or irritability (National Sleep Foundation Drowsy Driving Prevention Week, 2018). As a person becomes more sleep deprived, the electrical activity in their brain and their heart rate slow down, which causes slower response times (Johnson et al., 2011). With these symptoms, there are many options in determining what to monitor to identify drowsy drivers.

Daily schedules of these drivers also influence drowsiness. For instance, circadian rhythms are the cycles in which a persons body operates throughout the day, and influence the release of certain hormones such as melatonin, which notifies the body that it needs to sleep. (National Institute of General Medical Sciences, 2017). In India, the highest percentage of road accidents in 2015 took place between 15:00-18:00 hours and 18:00-21:00 hours (Figure 3)(GIMRT & HTRW, 2015, p 25).

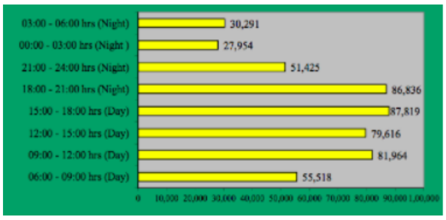

Figure 2: Distribution of accidents vs. time (GIMRT & HTRW 2015, p 25)

These times take place at the end of the work day and during traditional tea time, and then again around dinner time or post-dinner time when the sun has gone down.

Current drowsiness prevention strategies

Current strategies for drowsy driving prevention in the Himachal region mostly consist of tea breaks, cautionary road signs, and music playing (Team-BHP, 2018). In the future, technology-based strategies may provide a better way of detecting drowsiness through quantitative metrics.

Simple driver strategies

Clever signs are one of the most popular ways that the Border Road Organisation, has used to mitigate drowsy driving (Border Roads Organisation, 2016). Their signs have fun sayings on them intended to catch drivers attention, but also warn of the dangers that the roads can present (in Figure 3).

Figure 3: Example of Border Roads Organisation Sign (Bhatia, 2017).

Alongside the use of road signs, some popular strategies on an Indian driving forum, Team-BHP, include splitting up long trips, using a co-driver, and only driving during daylight hours. To stay alert while driving, the same forum recommends keeping fresh air circulating through the air conditioner, keeping the windows rolled up, and listening to fast-paced music (Team-BHP, 2018). Although these strategies are used and recommended by this forum's drivers, there have been no official studies to prove the effectiveness of these strategies.

Facial recognition applications

Facial recognition applications are on the forefront of drowsy driving detection technology. Typically, these are smartphone applications that require a front-facing camera to scan the drivers face for signs of drowsiness. For example, CarSafe uses facial orientation and blinking rates of the driver to detect drowsiness and distraction (You et al, 2013). The application recognizes prolonged blinking as an indication of microsleep, which is defined as three to fifteen seconds of sudden, unintentional stints of sleep (Tirunahari, Zaidi, Sharma, Skurnick, & Ashtyani, 2003). Metrics such as PERCLOS (PERcent CLOSure of the eyes) have been developed to detect the onset of this phenomenon; these measurements are derived from tests involving the proportion of eye closure to eye openness during a one-minute period (Vaca, 2005). The measurements allow the program to determine how long someone has been blinking and alert the driver to wake up if their eyes have been closed for a certain amount of time. The use of this metric positively correlates to improved driver performance (Vaca, 2005).

Vibrations and alerts

Multiple studies have explored the use of vibrations or alarms to alert drivers of their drowsiness. One particular study of 25 participants was conducted using a prototype steering wheel with vibration capability and a loud buzzer. When a driver displayed signs of drowsiness, the wheel would vibrate and the buzzer would sound, alerting the driver of their drowsy behavior. In general, subjects reported that the buzzer was more effective in alerting drivers, but also significantly more annoying than the vibrations (Tan et al. 2013). The study was based on a relatively small sample and produced mostly qualitative data, so the study is relatively incomplete if used on its own to propose a broader solution to drowsy driving. Despite the small sample, the study shows potential options for alert systems.

Blue light

With the introduction of blue light, the body becomes more alert because the light suppresses the creation of melatonin and shifts circadian rhythms as much as three hours with the right amount of exposure (Harvard Health Letter, 2012).

Figure 4: Example of blue LEDs (fotographos, N.D.)

In a study, the introduction of a constant blue light with a wavelength of 468 nm led to a decrease in the amount of times the driver crossed the centerline while driving by around 45%, as compared to the placebo given to participants (Taillard J. et al, 2012).

Summary

A review of the literature led us to three key points that guided our work in India. First, we learned that drowsy driving can be comparable to the dangers of drunk driving due to the depletion of motor skills and lack of awareness. Second, strategies for drowsy driving already exist in the form of cautionary road signs and tea stops, but may not significantly prevent accidents. Third, alerting devices or stimuli can greatly improve the chances of a drowsy driver from entering microsleep phases. With this prior research, we were able to establish our approach to introducing new drowsiness prevention strategies in Himachal Pradesh with regards to our stakeholders' driving conditions.

Methodology

Given the need for a more consistent and effective way to prevent drowsiness on Himachali roads, the goal of this project was to develop and improve drowsiness mitigation strategies applicable in Himachal Pradesh. To accomplish this goal, we completed three objectives:

1. Document and compare drivers' experiences with drowsy driving
2. Identify key aspects of existing strategies to prevent drowsy driving
3. Develop and test prototypes to mitigate drowsy driving

These objectives and our strategies to collect data are outlined in Figure 5 below.

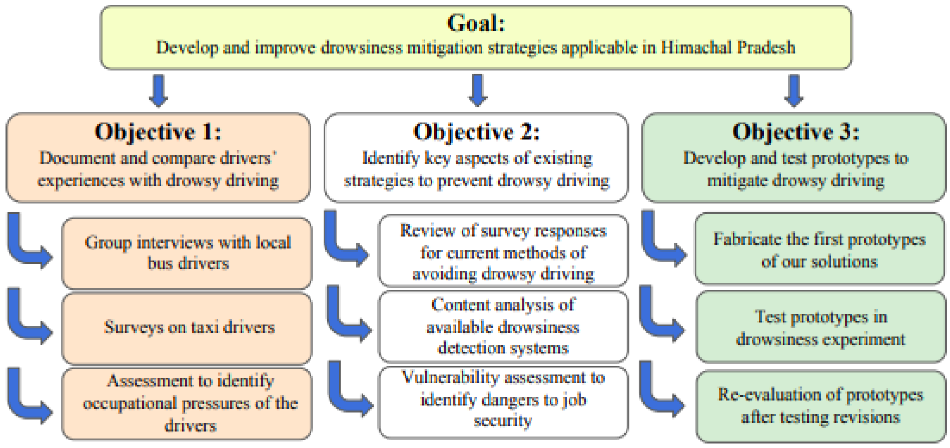

Figure 5: Methodology process

Objective 1: Document and compare drivers' experiences with drowsy driving

Based on the implications of drowsy driving on passenger safety, we determined that our main stakeholders consisted of bus drivers and taxi drivers, and we conducted a group interview with 15 local bus drivers. We asked the bus drivers 23 questions about their current drowsy driving prevention strategies, pressures and motivations, personal experiences with drowsy driving, comfort levels with potentially intrusive aspects of prototypes, and ability to pay for a technological anti-drowsiness strategy. Subsequently, we created a survey of questions similar to those from the group interview for 30 taxi drivers, using a sample of convenience. From the survey responses, we conducted a baseline assessment of the drivers' occupational pressures and working conditions to gauge whether the drivers believed occupational policy change was necessary.

Objective 2: Identify key aspects of existing strategies and technologies

From the surveys, we determined the respondents' preferences for certain anti-drowsiness strategies. We realized that multiple strategies needed to be developed to meet the most needs of the stakeholders. Using these preferences, we assessed both the drivers' own drowsiness prevention strategies and previously researched technologies based on criteria such as ease of use and intrusiveness. Then, we examined available strategies, such as eyelid detection and vibration, to evaluate the applicability and cost effectiveness of potential solutions.

Figure 6: Two team members performing fieldwork at the taxi stand in Mandi on March 26, 2018

Alongside the preliminary ideation of these strategies, we considered the potential risk to job security that detecting driver drowsiness might entail, such as having video stored of drivers sleeping on the job. To address potential pitfalls, we compared preferences of drivers with respect to video caching, and brainstormed methods to store data without risking the drivers' employment standings.

Objective 3: Develop and test prototypes to mitigate drowsy driving

From an evaluation of driver preferences, manufacturability, and cost effectiveness, we gathered the necessary materials to create our anti-drowsiness solutions. We created prototypes using SolidWorks, OpenCV, various light-sensitive cameras, a raspberry Pi, and taffy recipes. Upon the completion of our first prototypes, we orchestrated a drowsiness experiment with 15 participants to test the effectiveness and ease of use of our prototypes.

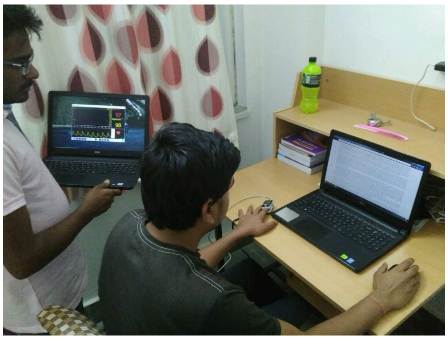

Figure 7: Setup for testing with a control group participant on April 18, 2018

The experiment consisted of splitting the participants into three groups: control, blue light, and taffy. The control group took a psychomotor vigilance test (PVT), which measures the participants' response times to a timer popping up on a screen, read Scientific American Supplement No. 841 for fifteen minutes, and then took a second PVT test (Various, 1892). The blue light group and taffy group did the same, but also used the prototype during the ten minutes to help keep them awake while reading. Immediately after testing, participants were given a feedback survey to collect their opinions on our solutions. Using the gathered feedback, our prototypes were then re-evaluated and modified to address the concerns from the testing phase.

Results and Discussion

The results of our interviews with fifteen bus drivers and surveys with thirty taxi drivers indicated three key details of the experience of a fatigued driver:

1. There is significant pressure on drivers to continue on the road despite drowsiness, whether from their passengers or employers.
2. Many existing strategies to stay alert are known among drivers and can be improved even beyond their current level of effectiveness.
3. Most respondents are willing to purchase and use a technological device to help them stay awake on the road.

Objective 1: Drivers experiences with drowsy driving

We asked 30 taxi drivers working at the bus stand and taxi stand in Mandi about their experiences with drowsy driving, their strategies for avoiding driving drowsy, and their preferences on strategies we were willing to develop. Of the 30 taxi drivers, 43% claim to be pressured by their passengers to continue driving, even as they become drowsy (Figure 8), while 57% reported being asked by their passengers to pull over and rest (Figure 9).

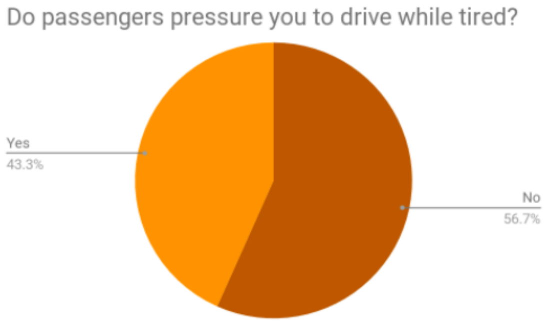

Figure 8: Passenger pressure

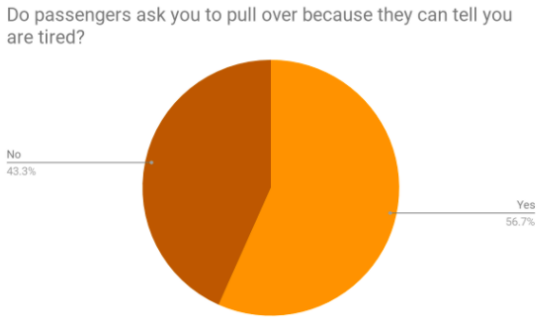

Figure 9: Passenger permission

In the group interview, we learned that bus drivers must adhere to strict schedules, as some passengers need to catch a plane or a train at the end of the drive. These bus drivers all discussed driving long hours with little to no rest, making it difficult to find time to accomplish small tasks each day, such as showering or getting sufficient sleep. Moreover, the bus drivers do not get quality rest at their bus stops because the stops are uncomfortable and noisy. Another common response among these bus drivers was that sometimes they had to drive faster than they preferred to reach their scheduled destination on time to satisfy their passengers.

Objective 2: Strategies drivers currently use to combat drowsiness

The most popular current strategies among respondents were drinking tea, stopping to rest, and washing their face (Figure 10). Using their answers on strategies that were effective and comfortable, we identified blue lights and alarms as viable prototype options.

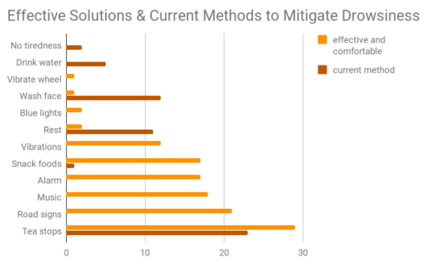

Figure 10: Effective and comfortable solutions

Moreover, considering the possible need for a technological strategy, our research indicated the advantages of a camera monitoring system. Ninety-three percent of drivers responded positively to having an unobtrusive camera monitoring them for drowsiness detection. Although previous studies such as CarSafe had used cell phone cameras, our interviews with bus drivers revealed that the use of cell phones while driving is prohibited (You et al, 2013). Thus, a separate device would be necessary.

We asked drivers if they would rather have video data from the camera saved or deleted due to potential risks to job security. Notably, 67% of drivers responded that they preferred the video be saved so that it can be recalled in the event of an accident or altercation where the driver was not at fault. Therefore, the drivers typically considered saving the video data as a benefit to job security as opposed to a detriment.

Objective 3: Prototypes to mitigate drowsy driving

We decided to consider both technological and non-technological approaches in our prototype design. The first technological strategies we explored involved a drowsiness detection component to recognize driver fatigue, and an action component to alert the driver. We chose this two stage strategy since all existing technological strategies follow this model. For the detection aspect, we focused on using an OpenCV camera for facial detection. Using a raspberry Pi, which is a small computer common for prototyping, and its compatible camera, we wrote code in Python that utilized OpenCV to recognize eye closure for the facial recognition software. If the driver's eyes were closed for 48 frames, or the equivalent of one second, the computer triggers the aforementioned action component of the device. We knew that facial recognition would be a useful strategy to work with from all our survey data and literature review.

The action component of our technological device was designed to alert the driver when drowsiness was detected. Considering the potential for distraction, we used only an alarm to alert the driver of their drowsiness. Respondents also positively reacted these ideas, with 56% agreeing to alarms, which is further supported by previous studies (Tan et al. 2013).

Alongside the detection-action strategies considered, we also developed three strategies designed to make the drowsiness mitigation less intrusive. To be less intrusive, we developed a candy for drivers to eat whenever they felt drowsy, since 56% of drivers indicated they eat when drowsy. To satisfy the respondents tastes, we developed two taffies: one containing red chilli for spiciness, as 33% of respondents preferred spicy snacks, and the other containing black tea, orange, and soya flakes for sweetness, as 43% of respondents preferred sweet snacks.

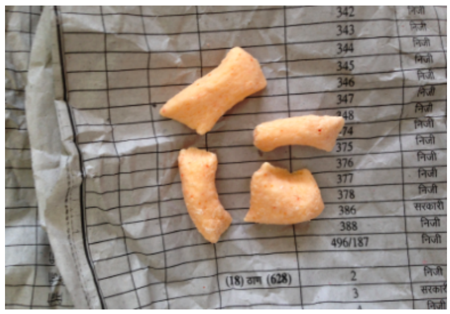

Figure 11: A few of the spicy taffies made on April 4, 2018

A second strategy we conceived was a cushioned seat cover that could house any of the technological prototypes that we have designed, such as the blue light system or the raspberry pi. We created the seat cover in response to the common complaint in our bus interviews and taxi surveys for a more comfortable driver's seat. The drivers typically rest in their seats when off duty, and 93% of respondents mentioned that they were comfortable with a seat cover to hold additional devices. Furthermore, since many bus drivers resort to sleeping in the aisles of their buses, we designed the seat cover to function as a portable sleeping mat. The mat gives the drivers the opportunity to have more restful breaks, reducing their overall fatigue and their chances of driving drowsy.

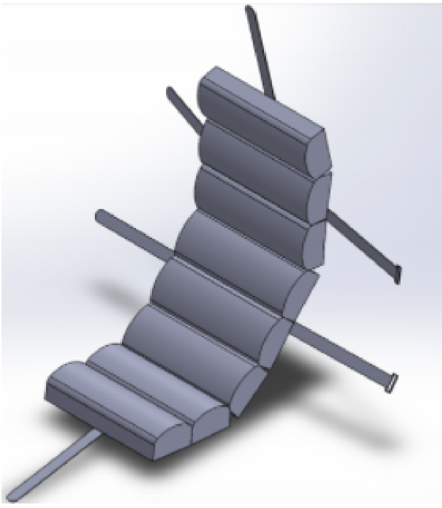

Figure 12: CAD design of our seat cover prototype

While the blue light strategy only garnered two out of thirty positive responses, we prototyped a small set of blue LEDs because the LEDs were relatively simple to implement and required that the drivers test it for themselves to understand its potential effectiveness. This was also due to the recent research done in the field of blue lights and its association with driving (Taillard J. et al, 2012). The lights were designed to diffuse enough blue light to reach the driver's eyes to reduce the production of melatonin, but not to mimic something like headlights that could pull the driver's attention away from the road.

After fabricating our prototypes, we completed eight preliminary tests, with three in the taffy group, three in the blue light group, and two in the control group. We found that both the taffy and the blue light increased the participants' heart rate more than the control group (Figure 13). The taffy and the blue light group also had significant improvements from their first to second PVTs.

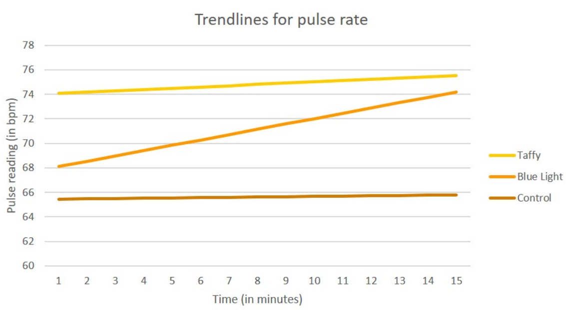

Figure 13: Pulse vs. method of testing

Discussion

Two of the most challenging aspects of this project were the time and funding constraints. The constraints pushed us to come up with multiple strategies to test which ones worked best, rather than creating only one prototype that may be unwelcome or ineffective.

Prototype	Pros	Cons	Use
Eye detection	-Can detect when a person's eyes are closed too long - Room for improvement to detect other facial features as well - Most reliable mode of detection	- May have to be re-calibrated for every driver in order to account for eye shape - Requires a power supply in the car - Can't use standard cameras due to drivers being drowsy at night	- Detection
Seat Cover	- Can be used as a sleeping mat - Houses other devices - Portable and washable - Allows for better rest between shifts - Prototype materials and manufacturing locally sourced in Mandi	- Could be difficult to manufacture	- Means of holding alert devices - comfort for drivers
Edible solution (50 candies)	- Gives a quick burst of energy - Enjoyable - Low cost	- Limited effectiveness time	- Continuous drowsiness protection
Blue lights	- Can prevent the amount of melatonin produced in the body to keep drivers awake	- Most drivers expressed disapproval - May be distracting	- Continuous drowsiness protection

Table 1: Pros and cons of our prototypes

While our focus is mainly keeping drivers awake at the wheel, the difference between awake and alert is extremely important. Even if our solutions are perfectly effective, the brain's functioning will still be significantly slower and less dependable than if the driver has gotten proper rest.

While being more awake reduces the danger of falling asleep at the wheel, extended wakefulness does not eliminate the potential for driver error due to overtiredness and overworking. As mentioned previously, motor skills and reaction time invariably suffer as the brain fatigues, which is something that our strategies cannot completely remedy (Lal and Craig, 2001). One major concern with our strategies is that they could inadvertently encourage companies to overwork drivers further. Since our strategies can be wrongly perceived as "solutions" for fatigue, companies may impose more frequent night shifts or longer hours for their drivers. To properly implement our recommended strategies, drivers and their employers must be held accountable for the health and safety of the drivers. Therefore, a maximum hours-of-service policy regulation for drivers is imperative to coincide with the implementation of our recommended strategies.

Moreover, some limitations we encountered during our project were due to our taxi driver sampling in Mandi, because many of these drivers do not make as many long distance trips as drivers stationed in larger cities such as Delhi or Manali. Additionally, the taxi surveys were designed to gather information quickly. Because of the time constraints, some of our ideas may not have been properly explained to the drivers, such as the blue light system. Many drivers were against the idea, but we did not have time to properly explain the benefits supported by research behind this concept.

Conclusion and Recommendations

We developed four prototypes that we recommend drivers to use to stay awake on the road: a portable seat cover, a camera-based drowsiness detection system, a caffeinated snack, and ambient blue lighting. We have identified areas for improvement and future work for these prototypes, as well as two additional recommendations to mitigate drowsy driving in Himachal Pradesh.

Recommendations for new strategies

First, our seat cover provides a more comfortable ride for the drivers, causing less physical strain on their bodies. In addition, it can be laid flat to double as a sleeping mat to give drivers more restful breaks. Finally, this cushion was designed to have a pocket behind the headrest which can house our other devices, such as our prototype computer vision drowsiness detection system. Our recommendation of this prototype stems from its portability, versatility, and comfort.

Second, our camera-dependent drowsiness detection system consists of a raspberry pi computer, a night vision camera, a power supply, and software that analyzes facial features to detect drowsiness. It detects the closing of eyes and relays an alert that a driver may be drowsy. Currently, our prototype offers an eyelid closure detection method that is not calibrated to individual facial structures and uses a night vision camera.

Figure 14: A team member being warned of drowsiness using our eye detection system on April 3, 2018

In the future, this prototype could be further developed to include yawn detection, individual face calibration, and variable camera lighting to provide clearer images during all times of the day. Nonetheless, this strategy is recommended since it provides an unobtrusive way to detect driver drowsiness.

Third, the taffies were well-received by those who tried them. For a much larger production output, the taffies should be made on a much larger scale than our small-scale prototyping system. Bright packaging also needs to be developed to increase the drivers' willingness to buy these candies while at tea stops. This recommendation is based upon the candy's ability to be used continuously as drivers can eat the candies whenever they start feeling tired.

Figure 15: A team member pulling taffy on April 11, 2018

Fourth, the blue light solution suffered mainly in terms of willingness for the drivers to use it. The drivers were not aware of the scientific effects of blue lights on humans, which chemically delays the onset of sleep. In addition, we could have more clearly conveyed that we would be using ambient light rather than bright, distracting light. As a result, we still recommend this strategy due to the research that has been done that verifies how successful blue light is in keeping people awake.

Moreover, after the preliminary results of the prototype testing, we recommend that there be more research done on implementing a pulse sensor as a drowsiness detection method. Since there was a positive correlation in our results between how awake the participant felt and how high their pulse was, a further developed pulse sensor could be used alongside or in lieu of our facial recognition software.

To be able to properly improve our products, we would need more testing. For further development, we recommend teaming up with a driving company to have the device placed in 50 taxis to collect data on the amount of microsleep incurred by the driver, as per recommendation from our sponsor. This data would then be stored and sent back to the testing coordinator to determine the device's success rate and potential improvements for effective application in a commercial setting. To avoid threatening the participating drivers' job security, the collected data should remain anonymous.

Recommendations for policy making

Our final set of recommendations pertains to policies that could reduce drowsy driving and improve driver safety in Himachal Pradesh. As previously mentioned, the United States has laws in place that protect drivers from being forced into driving unreasonably long hours. Understanding the inherent cultural differences between the US and India, interviews with driving companies and government authorities would be necessary to determine the viability of a major policy change. If possible, we recommend legislation be implemented by the Government of Himachal Pradesh Transport Department that will enforce hours-of-service regulations upon companies and their drivers. We believe prioritizing sufficient sleep for drivers will greatly improve safety on the roads.

The second policy recommendation is to improve driver accommodations at their bus stops. Because of the unsatisfactory conditions of these stops, we recommend companies make improvements to better accommodate their drivers. The companies should implement policy that includes higher quality standards for these stops, such as having separate rooms with doors that can close and quiet hours at certain times of the day. These areas are the best and sometimes the only option for long distance bus drivers to sleep and achieve proper rest; improving these driver stops in turn improves the drivers' awareness on their next trip.

Figure 16: Taxis driving through Mcleod Ganj on April 15, 2018.

Conclusion

Interviews conducted with bus drivers and taxi drivers indicated some of the many reasons drivers feel tired while traveling, especially over long distances. Our survey results indicated that commercial taxi drivers were not completely satisfied with their current drowsiness prevention strategies, and that they were willing to adopt new strategies presented to them. Given that commercial drivers struggle with strict occupational rules, we offered them four low-risk strategies: a removable seat cover with alarm integration, ambient blue light, spicy taffy candy, and a computer vision detection system. With future development, these strategies can become common, reliable methods to improve driver safety. The issue of drowsy driving is multifaceted and relatively complex, so no single solution will permanently address the problem for every driver on the road. However, we believe that our set of recommendations and prototypes sufficiently addresses the main aspects of the issue: the underlying cause of drowsiness, methods of drowsiness detection, and alert strategies. Moving forward, our prototypes still have room for improvement. For instance, the blue light strategy can be refined and adjusted to address driver preferences, and the taffy production can be scaled up. With a bigger budget and more feedback on ergonomics, the seat can be designed to a higher quality standard to fit the drivers' need for better rest. Finally, in the future, the face detection software can be improved to be more easily calibrated to different drivers, and integrated to notice facial features such as yawning and head position. With all potential improvements in mind, our four prototypes can serve as a strong foundation to future work and improvements in the field of driver safety.

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The full report and Supplemental Materials for this project can be found at: http://www.wpi.edu/E-project-db/E-projectsearch/search using key words from the project title. Outcomes delivered after May 1 will appear on the IITs ISTP page at:http://www.i itmandi.ac.in/istp/projects.html

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Assessing Micro-Hydropower Feasibility in Himachal Pradesh

Abstract

Himachal Pradesh produces the most hydroelectric energy in India, due to dams scattered throughout the state. Our team researched the viability of providing power to individual homes with the use of a personal micro hydroelectric turbine. Interviews and surveys were conducted to understand the importance, opinions, and concerns about hydroelectricity from the local residents in village communities. Micro-hydroelectricity was found to be difficult to implement, as most households already have electricity. Information gathered directed the design of a micro-turbine prototype that was low-cost, and would work to mitigate loss of electricity during power outages.

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Micro-hydropower in Himachal Pradesh

Micro-hydropower is a promising technology that has opportunities for household-level application in agrarian communities like the northwest Indian state of Himachal Pradesh. Although Himachal Pradesh already has an impressive 99.8% rural electrification rate (Central Electricity Authority, 2016), there are opportunities for off-grid application of supplemental energy generation. India harnesses approximately 26% of its hydroelectric potential, and Himachal Pradesh already hosts a number of large-scale hydroelectric plants (HPDOE, 2017; India MoP, 2018). Focusing on off-grid or local projects may benefit communities in ways that have a purposeful and direct impact (Agrawal et al., 2015). Micro-hydropower is an adaptable technology that can be altered to suit specific site needs, and can be created from simple materials (Wazad & Ahmed, 2008). There is also the possibility of modifying existing mechanical watermills, which are abundant in the region, to generate electrical power. (Agrawal et al., 2015). Micro-hydropower could help change the adversity to hydropower in Himachal Pradesh by reducing the negative connotations that have notoriously come along with large-scale hydropower plants. The negative impacts dams have had on the environment and peoples livelihoods have fostered an unfavorable opinion of hydropower in the state (Lal, 2003; The Tribune News Service, 2015). Overall, hydroelectricity on a micro scale could be an effective option for utilizing the renewable energy of the water resources in India.

The goal of our project was to assess the feasibility of implementing micro-hydropower in the rural communities of Himachal Pradesh. To achieve this we pursued 3 objectives. Our first objective was to identify communities with an interest in micro-hydropower; villages with a need for supplemental electricity which have perennial streams to power a micro-hydro system. Second, we traveled to several of these identified locations (Figure 1) and interviewed residents to understand their electric consumption needs as well as what kinds of features or requirements they would expect a micro-turbine to have. Finally, we used these data to design and develop a micro-turbine prototype and planned to return to the villages for field testing and feedback. Our intent was not a market-ready product, but rather a proof of concept that demonstrated the potential of the technology in Himachal Pradesh.

Figure 1: Village khul

Hydropower: Challenges and Opportunities

In order to best understand the role micro-hydro could hold in Himachal Pradesh, it was important to keep in mind the historical context surrounding hydropower in the area.

A history of contested development

Himachal Pradesh is mountainous area densely packed with river networks, making commercial-scale hydroelectric power common to the area. Both the Baes and Uhl rivers run through a large portion of the district. There are currently 145 commissioned hydroelectric plants in the region, yet it is estimated that these only harness about 10,500 MW of the 27,400 MW identified total potential (HPDOE, 2017). While this underutilization has left the government and private sector eager to continue development on the rivers, rural residents are dependent on the land for cultivation and the river for drinking and irrigation, so any disruption of the land or river leads to disturbance of their livelihoods (Chand et al., 2016; Kumar & Katoch, 2015). Hydropower, marketed as a green technology, often requires heavy construction that negatively impacts the surrounding environment. Diversion of water affects water availability, blasting operations scatter debris which destroy grasslands and vegetation, and the cumulative impact of multiple projects may be a source of climate shift in the area (Kumar & Katoch, 2014). In the specific case of the Kol-dam project (800 MW), 36 - 67% of cultivated land was lost on average amongst 5 local villages (Chand et al., 2016). These are not isolated incidents as similar occurrences have been reported in Uttarakhand, India and near the Skoto river in China (Chand, Verma, & Kapoor, 2016). Even small (2 - 25 MW) hydroelectric projects can inflict considerable damage on the environment, as these systems still require mill streams or diversion channels to produce enough water flow to power the system (Kubeck, Matena, & Hartvich, 1997). Additionally, many residents of Himachal Pradesh have been generally unsatisfied with promises or compensation made by the developing parties (Kumar & Katoch, 2015).

Advantages of micro-hydropower

In light of these negative implications from large-scale hydroelectric projects, there are opportunities to research and develop small scale hydropower systems which do not require disruptive construction. A micro-hydropower system is a small scale, possibly privatized and locally based, electrical generation system. The purpose of such systems is to generate electricity through the use of waters kinetic electricity. Water is a renewable resource, and if properly developed, the electricity generated is cleaner in comparison to fossil fuel based energy resources. Micro-hydropower devices could be owned and operated by individual households, powering household appliances and allowing owners to provide for their own electrical needs. Hydropower systems can be transportable and deployable at desired locations. Turbines with these qualities are already available on the market (Idenergie 2016; Enomad 2017). Even if micro-hydropower does not completely replace other power sources in an area, it can reduce electricity costs by providing a free additional source of power. In some places users may be able sell energy produced by their micro-hydro system back to the grid (Sinclair, 2003).

In locations similar to Himachal, data shows canals, tributaries, and small waterfalls that are unsuitable for large-scale development are prime candidates for micro-hydropower systems. For example, in rural Bangladesh, a system was designed by a local resident that used an earthen dam and wooden turbine in a perennial stream to generate power for 40 households (Wazad & Ahmed, 2008). A previous IQP team evaluated the feasibility of a micro-hydro system in Kre Khi, Thailand, and determined that the local stream could provide enough power to run lights and educational tools in a nearby school (Bjork et al, 2002). A simple turbine near Luangprabang, Laos, pictured in Figure 2, was installed in a small water channel. Clearly micro-hydro has a range of applications and can be adapted to suit specific sites of implementation.

Figure 2: Micro-turbine in Laos (Tuler, 2006)

Integrating existing hydropower technology in the area with new developments can promote self-reliance and usage of local resources. The citizens of Himachal Pradesh are not unfamiliar with water based technology, as they designed the gharat, one of the oldest forms of watermills in the world (Vashisht, 2012). The gharat is a tool utilized in Northern India to grind grains using blades that are propelled by a flowing water source (Figure 2). A research team assessing gharats in 2015 recommended technological upgrades to the existing structures, and stated there was a high level of interest from gharat owners for an attachable generator that could power light bulb (Agrawal et al, 2015). The previously mentioned system developed in Bangladesh encouraged us to consider modification of gharats with an electrical component as a viable option of prototyping. Incorporating a micro-hydro turbine to an already established gharat design could provide a sense of familiarity that promotes interested households to employ the device in their everyday lives.

When designing and implementing technologies, it is important to consider needs of the stakeholders as well as unintended consequences the technology may have. Large scale hydroelectric systems, such as the one illustrated in Figure 4, require development of large amounts of land and cause the destruction of many ecosystems when a dam is built. We had to consider environmental factors that influence physically sustainable of hydropower so that we could avoid the shortcomings of large-scale projects.

Figure 3: Pandoh Dam in Himachal Pradesh

Neglecting potential effects of development on beneficiaries is an oversight of large scale projects. Talking to household owners allows greater insight to community processes that are effective, as well as aspects that have the potential to benefit from alteration (Human Centered Design, 2011). Understanding local perspectives on farmland and water loss due to large-scale hydropower projects gives us insight to hydraulic energy perceptions in the region, and deeper understanding of important factors in prototype design. In our case, micro-hydropower allows the locals to keep the environmental resources they already possess while fostering innovation by having locals become responsible for their own energy.

Methodology: Assessment, Interaction, and Design

In order to assess the feasibility of micro-hydropower in the rural communities of Himachal Pradesh, we focused on understanding the specific needs and requirements of local communities to design a device tailored to meet those interests. Figure 5 outlines our objectives and strategies.

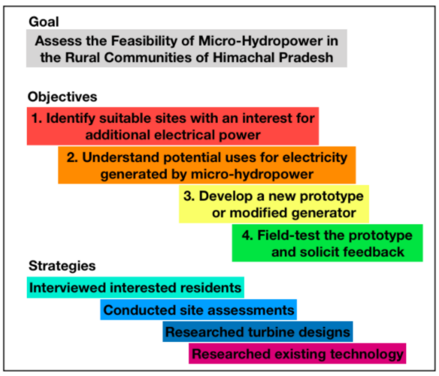

Figure 4: Work Flow Chart

Identify suitable communities

We began by traveling to nearby villages where we anticipated micro-hydro technology would be most applicable. Dr. Rinki Sarkar was very helpful in providing us with detailed information on many of the local villages, as well as giving us preliminary training in conducting interviews. We identified villages near large rivers or perennial streams and interested households using snowball sampling to collect recommendations from area residents. Respondents had a greater knowledge of the area, and steered us towards people who would be most interested in our project. Additionally, we traveled to villages that were not directly adjacent to rivers to see if micro-hydro could also have applications in these areas. Our strategy not only allowed us to locate viable sites, but also locate current functioning hydro-based technology in the area. Upon locating sites with gharats in the community, we documented the location of gharats in relation to the surrounding households and gauged opinions on their modification. Ultimately, this contributed to determining if the community was suitable for the implementation of micro-hydropower technology.

Understand potential uses

After we had been guided to interested individuals, we conducted interviews to determine the feasible applications of micro-hydropower for individual needs. We conducted 39 interviews across 7 locations using a semi-standardized interview guide (Figure 6, Appendix A). The interviews helped us to learn the citizens opinions of hydroelectric technology, energy usage, and level of interest around micro-hydro technology. We also interviewed a member of the Himachal Department of Energy and a micro-turbine owner to learn about the perspective of government involvement with these projects.

Figure 5: Team conducting interviews

Develop a new prototype

Our third objective was to design and develop a micro-hydro turbine prototype that could be installed at a suitable location to meet the needs and preferences of the user-base. The plan was to select designs that suit the desires and expectations of individuals, as determined from our interviews. Throughout the interview process we created an appropriate technology rubric, a practice adapted from previous technical projects (Slater et al. 2016). The technology rubric gauges how practical a new technology could be in any given situation and what requirements it must meet to be considered acceptable by the community. Incorporation of the site assessments, interviews, and the rubric was used to create a design matrix that guided development of our prototype. Machining and construction was completed in the IIT machine shop.

Field test and solicit feedback

The prototype was tested on the IIT Mandi campus to determine if the design met our identified basic power requirement of 100W, determined by the interviews. Once we constructed an operational prototype, we planned to returned to the villages where we conducted interviews to obtain feedback on our design. While we were ultimately unable to complete this field testing, we expected it to further involve the community in the design process and create informed suggestions for future work.

Results: Sites and Energy Uses

Here we summarize our findings from site assessments and interviews which helped us design our prototype.

Identifying suitable sites

Initially, we looked to locate villages with flowing water sources, as we anticipated these villages would be able to best use micro-hydro technology. Speaking with area residents, we identified three villages containing perennial streams: Magal, Arnehar, and Kataula. Two additional communities, Duki and Saghali, did not contain perennial streams, however both had gharats that we were able to use for research purposes. We also learned of a site between Mandi and Pandoh where a private business owner had installed his own microturbine. Figure 6 shows a map of these locations as well as the number of individuals interviewed at each location.

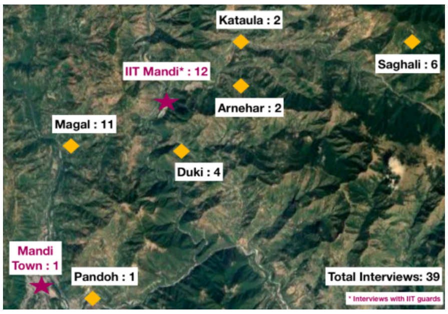

Figure 6: Locations of sites visited and number of interviews (Google Maps, 2018)

Villager energy uses and needs

We discovered that the electrical consumption of most villagers was relatively limited. Villagers mainly use electricity for lights, fans, and televisions. Only 9 of the interviewees had refrigerators or freezers, mainly due to the high costs of the appliances themselves, not the cost of the electricity required to power them. In fact, most villagers electricity bill is quite low. Figure 7 shows the breakdown of electricity costs for the people we interviewed.

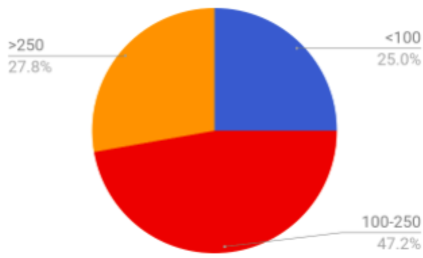

Figure 7: Average monthly cost (Rs.)

Additionally, the majority of respondents replied that they were either satisfied with their current amount of electricity or indifferent, i.e. that they were not strongly desirous of additional power. This information is summarized in Figure 8.

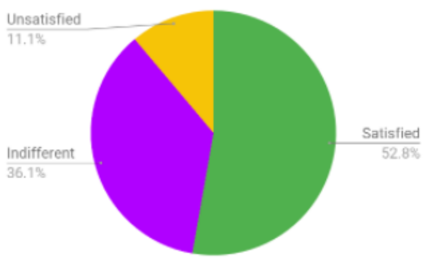

Figure 8: Satisfaction with current amount of electricity

There were conflicting responses on seasonal variations in energy supply. Around 46% of those interviewed said they had less electricity in the winter while the rest said there was no seasonal variations. These responses conflicted even within individual villages. According to the Himachal Pradesh Department of Energy, neighboring states in India are under agreement to provide electricity to each other during seasonal shortages, so the supply of electricity should be relatively consistent all year long. Those who complained of electric deficiencies in winter mainly wanted to get more use out of their appliances in the winter seasons. There were also conflicting responses on power outages. All residents experience occasional blackouts, but there was no clear consensus on the average duration of these power shortages and whether the villagers were given prior notification.

Residents expressed interest in using micro-hydro to supplement their electrical consumption. Some respondents were more apprehensive than others, stating that they would need to see a specific design or prototype before deciding if it would be suitable for their lifestyle. A major concern amongst those interviewed was losing water to the hydro turbine, as they feel there is a water scarcity already. These fears stemmed from the development of the large scale dams in the region. Villagers have experienced loss of land and water from large scale hydropower projects. They told us that when a dam is put into a river the flow downstream is almost eradicated, while upstream the river floods and causes them to lose land. In fact, villagers in Saghali were so adamant about not losing water for electricity, they voted against the development of new dams, even after being promised a 90% subsidy on the electricity produced. Additional concerns from respondents included price-point, difficulty of installation and use, maintenance, and longevity.

Interviews with a micro-turbine owner and a Department of Energy official gave us a wider perspective on micro-hydro in the area. We learned that the government is willing to provide subsidies on micro-turbine costs for commercial and private use, however there is a fairly extensive application process for these subsidies. Typically the government will coordinate with a private contractor to design and install an appropriate turbine at a given site.

Discussion: Sites and Energy Uses

There were three key observations we made through analyzing our interview and site assessment data that aided in forming our prototype design.

First, interviewees did not express need for more electrical power. Almost all residents we interviewed claimed they had enough electricity to power all of the appliance they owned. There is little barrier to people consuming more electricity if they want to, as access to the power grid is widespread and electricity is quite cheap. The low cost of electricity also has important implications on price point for a micro-turbine. Considering the average monthly electricity bill to be around 150 Rs., most residents would only be willing to pay 10-20 months-worth of their electricity bill (1,500 - 3,000 Rs.) for a micro-turbine if it could completely power their homes. This feedback further encouraged us to consider cost as an important component of our prototype.

Second, interviews with gharat owners led us to quickly discard the idea of modifying gharats. We discovered that many gharats have been abandoned in recent years as people are moving towards more modern methods of grinding grain. We also learned that the land gharats are built on is often given by the government to people living below the poverty line, so it is unlikely that these residents would be able to afford installation of a turbine for private use. As a final contrary point, many of the gharat owners we interviewed were fearful of losing land through the encroachment of turbine installations, whether government or private. All these factors led us to instead focus on developing a separate, individual turbine uni. However, the village water channels and kuhls were still considered as potential test sites.

Third, we identified two main logistical concerns about the feasibility of a micro-turbine; accessibility and preference for off-grid systems. Even in villages with rivers and perennial streams, most residents do not live directly on the water but rather at higher elevations in the mountains. This led to some concerns on accessibility. To connect a micro-turbine to the power grid, as we originally planned, would require extensive wiring, which would be costly and complex. Additionally, this would not necessarily solve any problem. While additional electricity is not a pressing need of the community, all residents reported that one of their biggest struggles was dealing with power outages. Routine maintenance or construction work on the power grid requires it be regularly shut down by the government. Therefore a turbine connected to the grid would not be useful during a grid-wide shutdown. Most residents simply deal with these outages as a part of daily life, but many were interested in off-grid ways to mitigate their loss of electricity at these times. We learned that some residents are looking into solar power and battery technologies for this application. This, combined with the highly accessible existing electricity infrastructure, led our team to believe that mitigating loss of electricity during power outages was the most appropriate role micro-hydropower could play in the area.

The feedback from our interviews was combined with feedback from similar past projects (Slater et al, 2016) and compiled into the appropriate technology rubric shown in Table 1.

Technical Requirements	Environmental Requirements	Economic Requirements
• Ideally powers entire home, lights and appliances at least • Can be off-grid • Minimal and easy maintenance • Long lifetime • Resistant to corrosion • Portable and maneuverable by single person • Easily accessible	• Does not consume water • Operational in all seasons • Does not contaminate water source • Constructed from inert materials • Endures variable weather and monsoon floods	• Max cost for individuals: 3000 Rs • Max cost for multiple households: 10,000 Rs. • Inexpensive maintenance • Implementation leads to cheaper electricity in long term • Monthly payment plan made available

Table 1: Appropriate technology rubric

Prototyping and Testing

Using site visits and interview responses, we designed a small scale turbine that was to be low-cost, have minimal ecological impact, and work to mitigate loss of electricity during power outages. We also worked to fulfill as many criteria from Table 1 as possible.

Due to time and cost constraints, we aimed at developing a proof-of-concept. We elected to build our proof of concept based off of an existing turbine blade given to us by the IIT mechanical lab as it was readily available and we were unable to machine our own turbine blade. We chose aluminum as the frame material for its low cost, ease of machining, and resistance to corrosion. Figure 9 illustrates our developed prototype.

Figure 9: Constructed micro-hydro turbine prototype

All machining and construction of the prototype was completed in the IIT mechanical lab, and the test site was located below the North Campus bridge, in a water channel for an abandoned gharat.

Discussion

The prototyping process was severely limited by time constraints, available materials, and machining methods. While aluminum was readily available, the shaft, bearings and gears were difficult to acquire. Additionally, we were unable to machine customized turbine blades, as the IIT mechanical lab did not have the capacity to machine curved surfaces. Optimal design of a micro-turbine relies on each part being designed to work together for the most possible electricity generation at a specific site. Our team simply did not have the resources to achieve this level of precise engineering. In spite of these challenges, we were able to understand the challenges of designing micro-turbines as well as their potential impact in rural communities throughout the process.

Project Outcomes

The results of our prototyping and research lead to two recommendations for future designs and implementation of micro-hydropower and other renewable energy technologies in Himachal Pradesh

Technical recommendations for micro-turbine designs

The effectiveness of micro-hydro is heavily dependent on characteristics of the specific site of installation such as river size, flow rate, and depth. Due to variation in sites of water access, designing one single prototype that will work best in all situations is far-fetched. Our prototype was only suitable for sites similar to our test site. There is the possibility of designing a prototype to operate under the widest possible range of site conditions, but this would require research and machining procedures far more advanced than our team had access to. While micro-hydro could be a solution to mitigating electricity loss during grid outages, further research must be done in order to determine how it can be best implemented. The 3 aspects that require the most investigation are how to increase access for residents who do not live near water source, how to lower the cost of a turbine, and determining which water sources can produce enough electricity to be useful. In the meantime, we recommend that any residents of Himachal Pradesh who are interested in water turbines to coordinate with their local Department of Energy, as there are government procedures and subsidies for building and installing micro-turbines.

Alternative solutions

Other opportunities and options for supplemental energy from renewable sources should be explored. Micro-hydropower is only one of several viable options of providing renewable and off-grid electricity to rural residents. There are subsidies for wind and solar power, and several residents have already looked into purchasing these technologies. Solar power appears to be particularly promising. Solar panel design is relatively site independant compared to wind and hydro, the industry is growing quickly in India (Chandrasekaran, 2017), and solar can be developed for the same uses we aimed our micro-hydro prototype at addressing (Prasad, 2016). Many villagers are also looking into battery technologies for storing power to use during outages. We recommend researching the feasibility of expanding other renewable energy sources in addition to continuing research on micro-hydropower.

Conclusions

It is difficult to say with confidence whether or not micro-hydropower is a feasible technology for Himachal Pradesh. Our research indicates that the residents do not lack electricity, but lack a consistent energy source due to power outages and perceived seasonal variations in access. Therefore, we believe the best application of micro-hydropower technology is to mitigate loss of electricity during extended power outages. Further research will need to be completed to fully understand how feasible micro-hydropower is in Himachal Pradesh and if there is a micro-hydro turbine design that is more suitable for the area. Additionally, more research could be done on the feasibility of extending solar and wind power to the rural communities of Himachal. Overall, we hope our project contributed to an increased understanding of the role renewable power technologies can play in Himachal Pradesh.

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- All of the people in IITs machine shop who guided us in machining our prototype

The full report and Supplemental Materials for this project can be found at: http://www.wpi.edu/E-project-db/E-projectsearch/searchusing key words from the project title. Outcomes delivered after May 1 will appear on the IITs ISTP page at: http://www.iitmandi.ac.in/istp/projects.html

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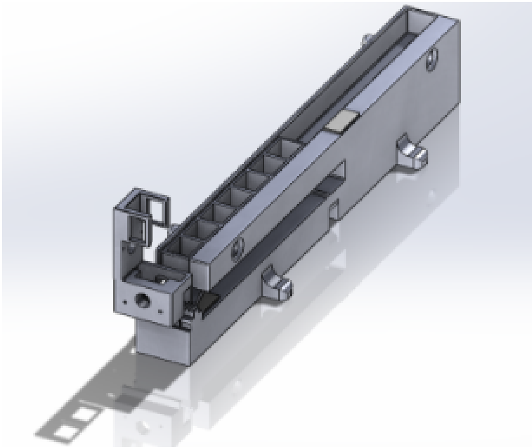
Medicine Dispensing Devices to Help Increase Adherence



Abstract

Medication nonadherence is a significant and pressing issue in northern India. This problem causes many deaths, wastes medicine, and causes communicable diseases to develop drug resistance. A medicine-dispensing device offers a potential way to help individuals create and maintain stronger medication routines, and thus improve their overall adherence. Through interviews and surveys, it was shown that doctors, pharmacists, caregivers, and patients of the region support the idea of a device. Additionally, they offered insight on the challenges behind adherence as well as device design. A prototype was designed, created, and tested to explore the usefulness of a medicine-dispensing device to help improve medication adherence in Himachal Pradesh. The proposed solution was shown to stakeholders with positive reception. The proposal was documented with various ways to improve upon the device, as well as other recommendations for research on improving medication adherence.

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Addressing Medication Nonadherence in Himachal Pradesh

A tremendous challenge in modern healthcare is ensuring patient adherence and dosage accuracy of prescribed medications. Globally it is estimated that only 50% of prescribed medication is taken correctly (Sabat, 2003). Failure to properly take prescribed medications can waste medicine, lead to an overdose or injury, or in the most serious cases, lead to unnecessary death (Choudhry et. al., 2014). Throughout the world medication is being prescribed to manage a wide range of illnesses. This includes communicable and chronic diseases. Each condition poses its own challenge and a therapy plan which can often be lengthy and complicated.

Medication nonadherence leads to antibiotic resistance, poor management of chronic illnesses, and the spreading of communicable diseases. Medication adherence is defined as the extent to which a person's behavior, such as taking medication, corresponds with agreed recommendations from a health care provider (Sabat, 2003). Therefore, when an individual does not follow the recommended medication routine, they become nonadherent. Medication nonadherence is complex and influenced by a wide range of factors. There are many challenges that exacerbate improper use of medication, including accessibility to pharmacies for refills, cognitive difficulties in remembering medication schedule and dosage amount, and even a recent trend away from family support and caregiving (Greenberg et. al., 2013). Additional factors include intentional nonadherence, which stems from the cost of medication, the adverse side effects, or, in places like India, a lack of education about or trust in western medicine (Greenberg et. al., 2013).

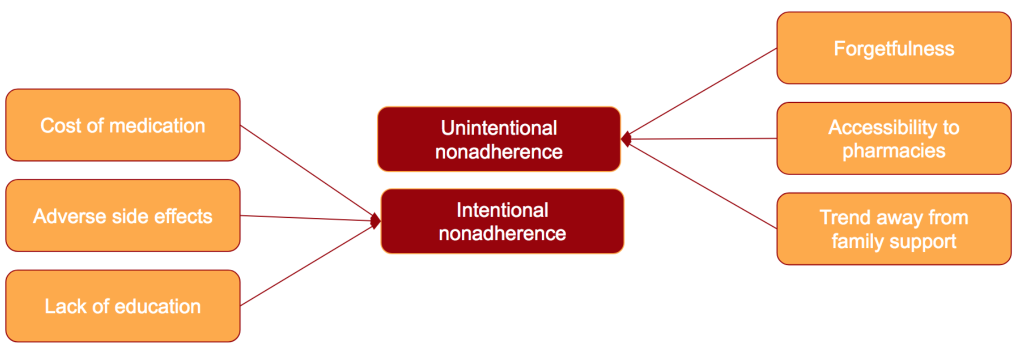

Figure 1: Factors influencing intentional and unintentional nonadherence

Another problem to consider is that rural communities face challenges in healthcare delivery. Parts of the world with small villages in very steep and mountainous terrain, poor road connections, and great distances to clinics are particularly vulnerable. These conditions can make it difficult for some patients to acquire their medications or interact regularly with a doctor (Aggarwal et. al., 2016). To address this problem, our team collaborated at the Indian Institute of Technology Mandi to determine whether or not a medication-dispensing device can be used to help improve medication adherence in Himachal Pradesh, India. Our first objective was to understand challenges faced by patient, caregiver, and medical professionals regarding a prescribed medication intentional and unintentional nonadherence. Our second objective was to identify design criteria and gauge both the practicality and potential effectiveness of a device. Finally, we aimed to create and test a criteria-compliant device that would be designed by and for the people of Himachal Pradesh. Considering the experiences of patients and doctors allowed us to understand the obstacles related to medication adherence. A device that can safely store medicine, remind its user when it is time to take a dose, and accurately prepare the correct dosage autonomously, can aid and prolong the lives of those who wish to remain independent or who are aging in place.

Major factors influencing medication nonadherence

Many factors play a role in medication adherence and nonadherence. To begin, in many parts of the world, patients have traditionally been dependent on family members during the process of aging or times of sickness (Mirza et. al., 2016). Today, a transition away from extended family support has left a gap in caregivers and leaves a vulnerable population alone during the workweek. In 2011, 14% of Indias elderly population was living independently of care of family members or additional aid, as compared to 1961 where only 10% lived independently (Liebig, 2011). With a trend away from family care, individuals must independently remember prescribed medication routines and also administer the correct dosage autonomously. Many conditions that become more prevalent with old age are often classified as chronic illnesses and must be managed with routine medication. It has been shown that 50% of medications being prescribed is given to elderly individuals. Consequently, when individuals suffer from multiple chronic conditions, medication routines can become incredibly complex (Sabat, 2003). A second factor that affects individuals regardless of age is socioeconomic status. It has been shown that chronic illnesses have a greater effect on those at or below the poverty line (Risk Factors Collaborators, 2015). These individuals are exposed to risks that make the likelihood of developing a chronic illness much higher, including poor diet, exposure to tobacco, and limited access to pharmacies and medical help. Since chronic illnesses must be managed continuously, medication can easily become so costly that patients may stop taking their prescribed therapies. In 2011, it was documented that 21.2% of Indias population was at or below the poverty level (India, 2011). This puts a large number of individuals higher risk for chronic conditions. Third, patients may stop taking medicine because of adverse side-effects, or they may feel better after a short time and believe that the medicine is no longer necessary. These actions are classified as intentional nonadherence. Others face challenges that can be exacerbated by the medical condition that is being treated, known as unintentional nonadherence. Patients can be forgetful due to old age, face limitations such cognitive impairments caused by illnesses like Alzheimer's and Dementia, or struggle with physical mobility challenges caused by conditions like Arthritis which make removing medication from packaging more difficult (see figure 2) (Patton et. al., 2018).

Figure 2: Medicine packets

Medications may also have negative side effects and cause individuals to stop taking the full dose without consulting a doctor (Tordoff et. al., 2010). Finally, cost often plays a role in why individuals choose to not adhere to a prescribed routine. Medicine can be expensive, and patients may simply not want to purchase it or be unable to afford it. When individuals choose not to take medication with the intention of saving money, they actually create a bigger cost on a national level. In the United States, $100 billion dollars is spent annually on treating patients that have been hospitalized for medical issues attributed to nonadherence (Prescriptions, 2018). In addition to the money spent directly on these hospital admissions, it is estimated that up to $300 billion could be saved annually by solving adherence-related problems (Prescriptions, 2018). Because of this, it is arguable that macro-level improvements to medication adherence issues could save taxpayers and patients money or allow national health budgets to be spent elsewhere (Seabury, 2014). While this has been shown to be a compelling incentive in the U.S., similar implications can be expected for coordinated health care systems anywhere in the world.

Improving adherence rates

There are many approaches that can be taken when looking at improving adherence, which could each help solve different factors of the nonadherence issue. We specifically focused on medical devices that have been implemented and the effects they had on improving medication adherence, as well as areas that could be improved upon. While these studies were not carried out specifically in India, each have innovations that could be applied to a device that meets the needs of our stakeholders. To begin, we evaluated some common strategies employed by commercial devices. One way to improve patient adherence rates is to identify factors that can be positively influenced or addressed, including physical and cognitive barriers that can lead to missed doses. Many devices exist that can store medicine, remind the patient when it is time for their dose, and provide it to them in an easily accessible container. There are some approaches to these problems that can be effective. Table 1, found in Appendix A, gives a brief example of the range of devices currently on the market in the United States of America that offer a wide range of features. Table 2, in Appendix A, examines common features and similarities of each device. An alarmed device has been shown to increase adherence in Mombasa, Kenya (Frick et. al., 2001). A randomized clinical trial was conducted to determine if an alarm device could aid in an increase of medication adherence. Results show that 82% of the women with alarmed devices had good adherence, defined as ingesting more than 94% of their prescribed medication. In comparison, only 36% of women with a device without an alarm had good adherence. In addition, after this trial, 99% of participants said they would use an alarmed device if they ever needed to manage a chronic illness. Another great aspect of this case study showed that these alarmed devices could also accurately compile a patient report in regards to adherence versus patient self-reporting which commonly overestimates adherence.

Figure 3: A simple device

Figure 4: A complex device

Identifying the target demographic

There are many factors to consider when designing a device for north Indian patients, including understanding attitudes towards western medication, literacy rates, and problems with access to medication. These factors have been identified as challenges to assess due to past research in the area and from studies in similar countries around the world (Aggarwal et. al., 2016; Shi et. al., 2010). Identifying the target demographic adds complexity to introducing a medicine dispenser into the community. Furthermore, it is known that other practices such as ayurvedics, homeopathic medicine, and herbal remedies are well established alternatives to western medications (Mirza et. al., 2016). Primary stakeholders include individuals who take medication on a routine basis. This includes patients of any age, condition, or disability. Secondary stakeholders include caregivers, hired aid, and medical professionals. Caregivers also must be engaged and involved in some cases when following a medication routines may be interacting with a device. Medical professionals, such as doctors and pharmacists, are at the heart of most medication routines since they oversee the prescribing of medications and educate their patients on illness and disease. Medical professionals must educate and encourage patients to adhere to their prescribed routine. The state of Himachal Pradesh hosts many regional health centers. There are smaller health centers or sub-centers that serve communities and to help with their medical needs. Pharmacies are often located close to hospitals (see Figure 5) which are further away than these small health centers which means that refilling prescriptions requires traveling great distances over a variety of challenging and dangerous terrain (Aggarwal et. al., 2016). In addition to this inconvenient spacing of health centers, hospitals and pharmacies are over-crowded, potentially making a quick trip to pick up or be prescribed medication turn into a day-long painstaking task (Bundhun, 2014).

Figure 5: Pharmacy in Mandi Town

While it is unknown how many individuals are currently taking medication in India it is known that 61% of deaths in the country are due to chronic illnesses (Dey, 2017). These diseases are most commonly hypertension, diabetes, and cancers and must be managed with routine medication. These routines are often complex which makes it difficult to remember one or more routines without the aid of someone or something else.

Approach

Our strategies for data collection were organized by objective, as illustrated in figure 6, below.

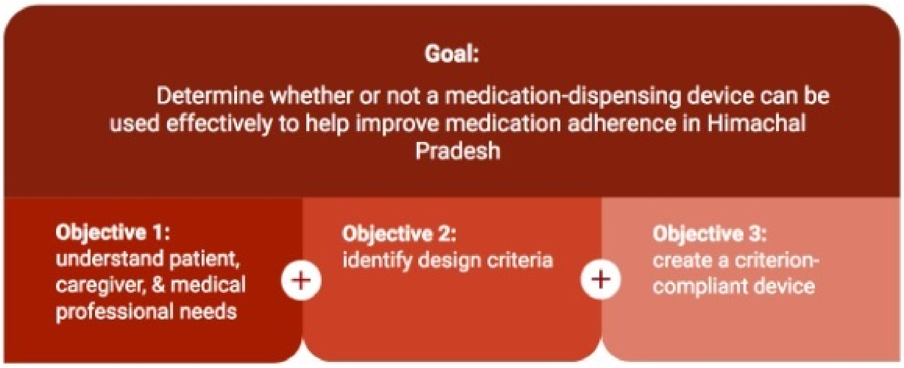

Figure 6: Goal and objectives

Objective 1: Understand patient, caregiver, and medical professionals needs

Interviews and surveys were used to gain a greater understanding of what leads to missed medication and how a device can or cannot aid in increasing medication adherence. The survey process was designed to protect the anonymity of all participants. We conducted 11 structured interviews with doctors to understand their concerns regarding medication nonadherence by visiting Mandav Hospital Mandi, Neelkanth Hospital Mandi, Primary Health Clinic in Kataula, Zonal Hospital Mandi, and Jagriti Hospital Mandi. An interview guide can be found in Appendix B. We identified which device features are regarded as important by these secondary stakeholders. We selected patients for the survey through two main methods. First, we used a sample of convenience at local hospitals and pharmacies. This allowed us to find local patients who were actively taking medicine. Secondly, we asked some willing doctors and nurses to perform surveys for us. Together, these methods gave us a large number of responses from a broad sample of patients. The Medication Adherence Questionnaire can be found in Appendix C. We identified caregivers to be family members or hired help who interact frequently with individuals who take medication on a regimented schedule. These caregivers were selected through a sample of convenience by choosing families local to the area. This provided us with another point of view towards the current state of medication nonadherence in Himachal Pradesh. The Caregiver Survey can be found in Appendix D.

Objective 2: Identify design criteria

Our second objective was to study currently-available medicine dispensing products and gauge both their practicality and their effectiveness. We searched current markets online for available products, and we interviewed pharmacists and doctors to see which products they would recommend to their customers and why. This allowed for individuals to directly influence which features were included in our device. We created a grid of features commonly found in medicine dispensers currently on the market. We then asked doctors and patients whether or not they thought each one would be useful in a device of our making. Key features were identified to highlight what users find appealing, easy to use, or effective for both the unimpaired or for those that face physical, mental, or linguistic restrictions. The members that reviewed these features were selected through a sample of convenience. For sample questions, see the Feature Importance Grid in Appendix F. To further map these criteria, we developed a rubric of desired design traits through a Strengths, Weaknesses, Opportunities, and Threats (SWOT) analysis of each feature based on the interviews and surveys. With the results from our Feature Importance Grid and multiple SWOT analyses, we distinguished which product features were worth including in our product, and ensured that our final device is effective, affordable, and designed by and for the stakeholders of Himachal Pradesh.

Objective 3: Create and test a criterion-compliant device

We used the results collected from objectives 1 and 2 to develop a design rubric that addresses the problem of medication nonadherence while meeting the needs identified by medical professionals, patients, and caregivers. Design began with looking at user preferences determined by our evaluation rubric and carefully choosing the best features to include in our product. We used 3D modeling software to design a product without wasting material. After the model was tested for safe and consistent operation, we began a process known as rapid prototyping. This includes 3D printing parts, welding, and using wood and plastics to prove a concept while having a fast development cycle. Parts were ordered that could not be made by hand such as an Arduino MEGA and an LCD screen. Once we worked through the design phase, we sent the prototype to the second phase of the cycle to undergo testing. The revision stage allowed for the prototype to be tested in the field through various studies and then improved upon based on feedback. This entailed improving ease-of-use of the product along with adaptation the product to different environments. Different doctors, caregivers, and patients were approached to assess the completeness of the product through user-based tests. As engineers of the product, we utilized a method referred to as Empathic Intelligence Testing. With this, we simulated physical impairments on ourselves by doing things such as operating the device while wearing blurred glasses and gloves filled with sand. We used this method to better understand for ourselves how difficult it is for a patient to adhere to a medication routine. By observing how both the users and ourselves interacted with the product as well as analyzing their responses to our questions, we gathered insight on how the product needed to be revised. No real medication was used in these tests; rather, we studied only the physical interactions. After collecting this data, we redesigned the design stage to apply the new improvements. We continued this iterative cycle until we did not see any more areas for improvement. Upon the improvement of the prototype, finalizations were made to allow for the continued manufacturing of the product while improving visual aesthetics and applying structural reinforcements.

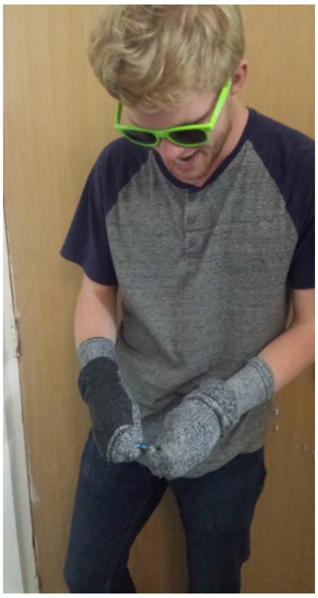

Figure 7: Empathic intelligence testing

Figure 8: Loading the device with simulated impairments

Results and Discussion

The findings from our data collection are presented here, organized by objective.

Medication nonadherence in the state of Himachal Pradesh

We began our project by interviewing eleven doctors at multiple hospitals, both private and public, in Mandi town and the surrounding villages. These doctors worked in a variety of fields, from pediatrics to skin care. Of eleven doctors surveyed:

- 91% of doctors interviewed regularly treated both chronic and acute patients
- 91% said that patient nonadherence is a pressing issue in Himachal Pradesh
- 80% claimed that intentional nonadherence is a significant problem
- 91% reported that there are immediate and potentially serious consequences of nonadherence
- 45% stated that a significant portion of their patients had the help of a relative or caregiver, and that more could if needed.
- 55% said that their patients generally manage medicine routines through only verbal or written instructions, without any additional help.

– These instructions are always written in English, but sometimes contain diagrams to help illiterate people understand their routine.

Many doctors expressed that literacy rate played a critical part in how their patients adhere to their prescribed therapies. If individuals lack education they rely heavily on remembering the verbal instructions given by doctors and pharmacists. Without being literate, they are unable to refer back to written directions which can cause a level of confusion especially if a medication routine is complex or the individual is suffering from a condition that impairs their memory. Whether or not literacy is the direct cause, our surveys do show a correlation between literacy and nonadherence - both intentional and not. Additionally, doctors express that a number of their patients will research prescribed medications and determine if they believe the side effects will be worth the benefits of taking the medicine. This causes many individuals to choose to not take their medication or only take it until they are feeling better. They do not trust the judgement of doctors and choose to medicate based on the information found on the internet. To understand patient needs, we collected information about their age, education, type of family, and the type of condition they were managing, because these areas have been shown to be factors of medication adherence (Sabat, 2003). Of 50 patients surveyed:

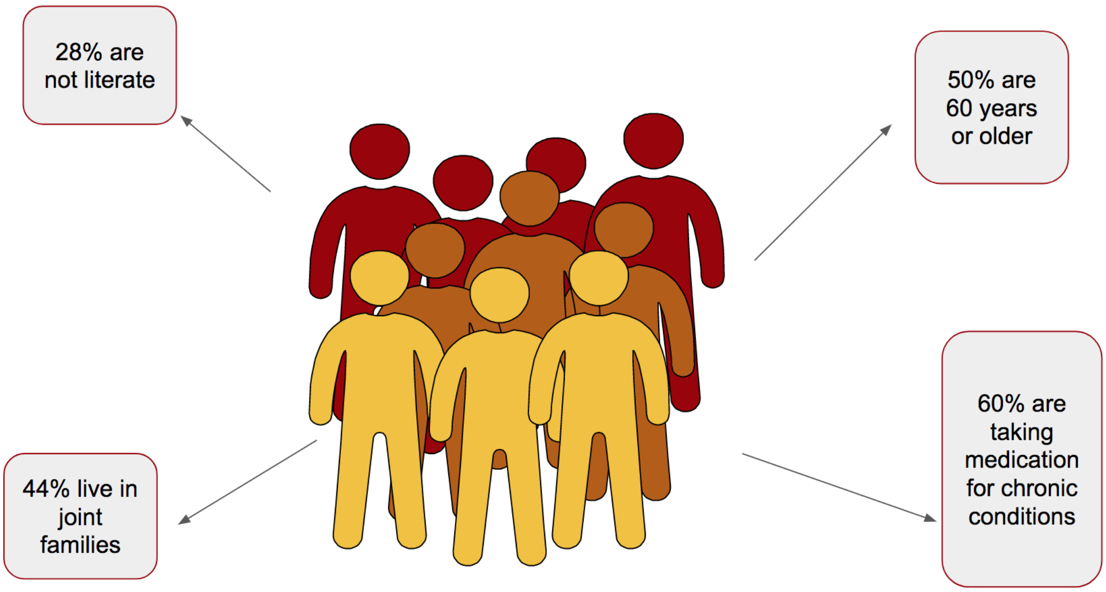

Figure 9: Patient survey demographic information

After collecting basic demographic information, we began asking questions about specific medication routines. We found that:

- The average number of pills taken each day was 4.46
  – This number increased by .4 when looking at only patients with chronic illnesses
- The average frequency of nonadherence, rated on a 1-4 scale (1 being rarely missing a dose, 4 being almost always missing), was 2.13.
  – Strangely, this number did not change much for either chronic or elderly patients
- 60% of patients surveyed sometimes forget their medicine.
  – Illiterate patients were 26% more likely to forget medication than those who were not.
  – Patients at or above the age of 60 were 16% more likely to forget medicine than those who were not.
- 28% of patients surveyed sometimes intentionally chose not to take their medicine.
  – Illiterate patients were 20% more likely to intentionally skip medication than literate ones.

- 40% of patients surveyed said they need or want aid of some kind to take their medicine.
- 44% of patients surveyed said they have medicine routines complex enough to hinder adherence.
- 42% of patients surveyed said that they had trouble dispensing their medication.

Caregivers were interviewed to assess how family members and highered aid play a role in medication routines and adherence. It was found that seven out of ten caregivers played an active role in managing a medication routine because the patient would forget to follow their proscribed therapy. Additional reasons listed by caregivers as reasons for medication nonadherence by the patient were as follows: they start feeling better and see no need for the prescribed medication, they have a casual attitude regarding their medication, or they are not educated on the medication that is prescribed to them, and therefore they do not know how the medication will benefit them.

Interest of automatic medicine dispenser to help aid medication nonadherence

Overall, the doctors that we interviewed thought that a device would be useful. When asked about the feasibility of an automatic medicine dispenser, 91% of the interviewed doctors stated that a device could help patients adhere to a prescribed medication routine. They particularly noted its usefulness for bedridden or severely sick patients, as well as those suffering from conditions that may affect memory. 73% doctors thought that patients would use a device if it was free or nearly free, and 64% made it known that including an emergency alert system for missed pills would be a valuable addition. Many doctors we interviewed also expressed interest in a generated report from the device that would allow them to survey the level of medication adherence from their patient and look for ways to increase this number or alter a prescribed routine to best fit the lifestyle of the patient. Patients generally agreed that a device would be a good idea. When they were presented with the idea of a medication device, 78% of those surveyed said that they would be interested in using alarmed-automatic medicine dispensing device. From their responses, we determined that a device has the potential to be effective and well-received by patients taking medication. However, the vast majority stated that the device must be extremely affordable and easy to use or they would not consider purchasing it. Very few were not receptive to a device. Caregivers who were interviewed all agreed that they believe an automatic medicine dispensing device would aid in increasing medication adherence. However, only 8 of the 10 who were interviewed said they would utilize a device to help the individual taking medication on a routine basis. This may be because some individuals currently have ways to effectively handle medication, such as simple medication boxes, or simply may not need a device at all. Our Feature Grid surveys allowed us to determine what patients, caregivers, and medical professionals thought of each potential feature or aspect of the device. We allowed them to choose the importance of each feature on a scale of 0-4 (0 being not important at all, and 4 being essential). In all, 17 individuals were surveyed. The averages of the results are as follows:

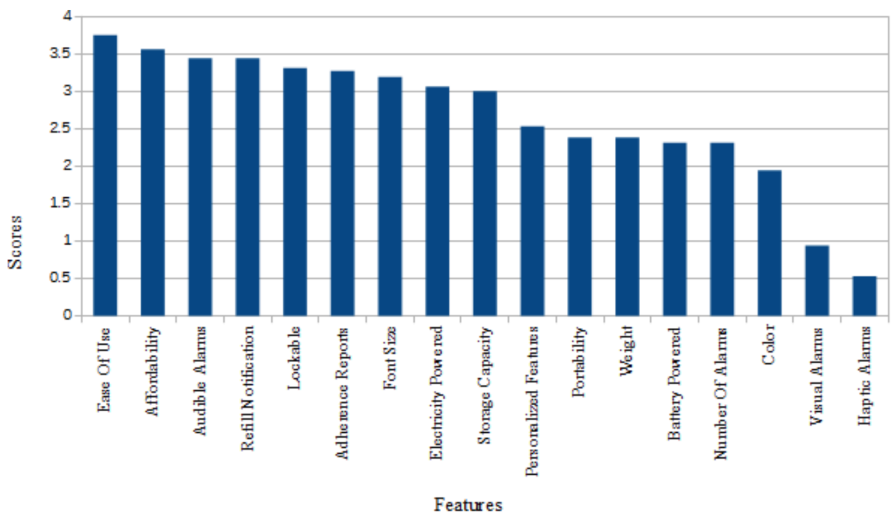

Figure 10: Ranking of features by average importance

The feature grids highlighted some important design choices in our project. For example, they confirmed for us that ease-of-use and affordability were absolutely essential to the device, as our initial interviews suggested. These scores were averages with slightly varying denominators due to people leaving features unranked. Also scoring highly were audible alarms, refill notifications, and the ability to lock the container. Interestingly, the question about the number of alarms saw mixed results, and haptic alarms were almost universally unwanted. Some other features were also suggested: one person noted that the device should be transparent, so that medicine may be visible, and another noted that it should be marked with a red cross, or other medical symbol. We used these results to focus our device design, and ultimately created a device that provided the core features listed here.

Design of the medication dispensing prototype

In our design stage, we used the information we had gathered from the surveys and evaluation rubric to determine a list of features needed in our device. From this, we began production and created a prototype. The design of a single module is shown below in figure 11, with detailed specifications available in Appendix H.

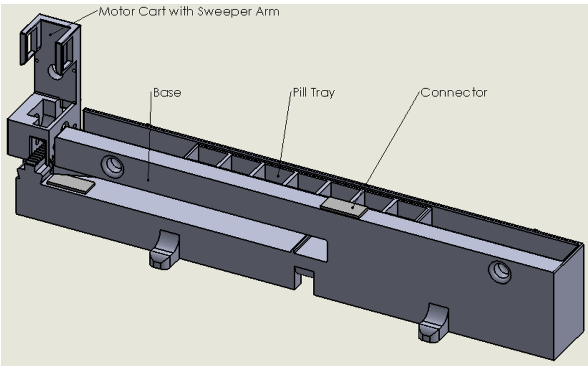

Figure 11: Design illustration

The device was made with ease-of-use in mind. It contains no buttons, and requires no inputs from the patient other than taking the actual medicine. After the medicine schedule is programed through the use of a simple smartphone app and the medicine can be loaded into easy-to-fill trays, the device automates the entire process of dispensing, providing alarms, and emergency and refill notifications. The design is modular, allowing users to purchase inexpensive modules if they take more types of medicine or require a larger capacity. This allows cost to be minimized, as users do not need to pay for more material than they need. New modules can be easily added simply by clicking them in to built-in pegs. Additionally, the entire device is driven with only two motors, and one computer. This number does not increase as modules are added, which further reduces costs. This ultimately allows the device to be produced inexpensively, albeit at the cost of physical size. Additionally, the device is lockable, can provide adherence reports, and the storage capacity can be increased according to the patients needs. Unfortunately, the device does have some shortcomings. In order to focus on certain features, we had to make sacrifices to other aspects of the device. Specifically, our design lacks portability, a battery failsafe, and is somewhat heavy. These are issues that can potentially be addressed by other products, or future designs. Empathic intelligence testing was critical in the development of our design. Through its practice, we determined that our device was easy to operate even with limitations to visibility and dexterity. The trays were large enough to allow for easy loading, and the devices construction minimized operating difficulty. We did find, however, that removing pills from containers or picking up dropped pills could be difficult.

Discussion

Through our interviews and surveys, we established that medication nonadherence is a complex issue in the state of Himachal Pradesh. Due to the multitude of factors that influence adherence, no single approach will solve the problem completely. However, through our interviews with doctors and patients, we found that a great majority were enthusiastic about a device that could be utilized by patients. They believed that a device could be helpful for a number of patients, especially if the device was affordable. While a device can be used to aid a number of people we cannot confidently state that our proposed device will meet all the needs of individuals taking medication. We learned that some issues are outside the scope of the device, including miscommunication between doctors and their patients. Both patients and doctors can work together. Medication adherence is partly the responsibility of doctors and pharmacists. To optimize a device, doctors would have to work to educate their patients on the benefits of utilizing the device, how to operate it, and be open to answer questions continuously. If a device were to be implemented without an educational or training aspect, it would be significantly less effective. One of the biggest limitations to our study was the likelihood of individuals misreporting their levels of adherence. Some cases of inaccurate reporting may be intentional misreporting because individuals may feel ashamed for forgetting to take medication or embarrassed to say they want to spread their dosages out to save money. Other patients may not even know they are taking their medication incorrectly if their routine was communicated poorly to them in the beginning.

Project Outcomes

To advance the idea of the automated medicine dispenser, and the improvement of medication adherence overall, we have several recommendations.

Device

First, we recommend adding three features to a design in a future prototype. These are features that our project simply did not have the time or resources to address:

- A battery system that can ensure operation during a power failure
- New motors with encoders could be used to allow for better and more reliable motor control
- Refining the design to be streamlined and more compact

Testing

Next, more research on the use and effectiveness of the device is needed. This may require in-depth testing or a case study. This would allow for the overall effectiveness of a device to be evaluated and observed firsthand, and is necessary to identify and address problems that may be encountered with introducing such a device to Himachal Pradesh.

Patient communication and support

Finally, the greater context of medication adherence should be further explored in more detail, as there are many factors that contribute to a patients nonadherence. Firstly, more interviews and surveys must be conducted over a larger sample size to be able to better understand these factors. In one interview with a large group of doctors, they all communicated that the device may help some patients, but that no device could address the underlying problems of the medical system and medication adherence practices in Himachal Pradesh. Namely, these problems stem from a lack of education in the general population, which leads to misuse or mistrust of the medical system, as well as the general disorganization of the government hospitals and treatment process. This was supported by our survey results, which showed that literacy can be an important factor in medication nonadherence, and particularly in intentional nonadherence. Furthermore, they noted that the government hospitals saw many, many patients in a day, and each patient spends hours waiting to see a doctor, then hours more to get their medicine from a pharmacy. If this process was streamlined, they predict, significant improvements could be seen in medication adherence. Concerns, particularly those about education, were also raised throughout many of our other interviews with medical professionals. These both presented significant topics for future studies. Ultimately, the concept of our device was accepted by medical professionals, patients, and caregivers in the region. They supported the creation of our prototype, and believed that introducing a device would help patients maintain consistent habits regarding their medication routines and aid in increasing medication adherence.

Conclusion

Our project aimed to deliver a prototype of an automatic medicine dispenser designed to increase medication adherence. We created a device that could help patients to remain independent while improving their medication routines. Balancing a routine medication schedule can be daunting, confusing, and incredibly difficult for many patients and caregivers. We designed a product that works to support the quality of patient life, lessen medication waste, and establish a healthy medication routine. Our analysis of patient, caregiver, and doctors concerns brought us greater empathy for the experiences of patients and the causes for prescription nonadherence in Himachal Pradesh. As we move towards a world where people are living longer, and with less support from extended families, there is a need to adapt and modernize our approach to medicine. Simple devices like this can save money and lives, and can also create healthy medication routines that lower hospital readmission rates and stop the spread of communicable diseases. Ultimately, we hope that our final design and prototype represent a medicine-dispensing device that will reduce medication nonadherence in the state of Himachal Pradesh.

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Pradesh.

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The full report and Supplemental Materials for this project can be found at: http://www.wpi.edu/E-project-db/E-projectsearch/search using key words from the project title. Outcomes delivered after May 1 will appear on the IITs ISTP page at: http://www.iitmandi.ac.in/istp/projects.html

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Perceptions of a Changing Climate, Exposure, and Vulnerability in Himachal Pradesh

Abstract

We aimed to characterize perceptions of exposure and vulnerability to climate change among lifelong residents of Mandi District, Himachal Pradesh. We examined local climate data and interviewed rural and urban residents to identify and map perceived exposures and vulnerabilities to climate change. We found that residents are aware of their changing climate and attribute these changes to human activity. Additional studies should be conducted to more completely assess the exposure and vulnerability of the region to climate change.

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Measuring the Complexity of Climate Change

Climate change is a complex phenomenon. Since 1880, the average global temperature has increased by 0.85 degrees Celcius (Sharma, 2016). This rise in temperature has had profound effects, including the increased prevalence of adverse weather events, such as hurricanes and tropical storms, sea level rise as a result of glacial melt, and prolonged periods of drought due to change in precipitation patterns (Loria, 2016). As a result, climate change may alter the quality of life for millions of people around the globe. Addressing this phenomenon requires an interpretation of projected and uncertain weather patterns, as well as an understanding of its implications on livelihoods and difficult choices to adapt or mitigate adverse consequences. Addressing climate change is perhaps the most significant challenge of this century. Climate change will impact individuals, households, communities, and regions in varied ways because of different levels of exposure, sensitivity, and adaptive capacity to climate change. Sensitivity and adaptive capacity collectively reflect vulnerability (IPCC, 2018). Houses built beside a river are more exposed to flooding than ones that are not. Communities without large natural water sources are more sensitive to decreases in rainfall. Regions that grow a larger variety of crops are more adaptive to changes in climate. Little is known with regard to the exposure and vulnerability of communities in the Hindu Kush Himalaya to withstand current indicators and future projections of climate change. The Hindu Kush Himalaya provides farm and rangelands to the roughly 700 million people who rely on agriculture and animal husbandry for their livelihoods (Pandey et al., 2016; Ning, 2018). These farm and rangelands are shifting to higher altitudes in response to the changing climate (Asian Development Bank, 2010). Additionally, the region delivers freshwater to the mountain communities by providing the source for many river systems through snow and glacial melt (Mukherji, 2018; ICIMOD, 2017). Delay in monsoon arrival and increased glacial melt has already been observed, simultaneously threatening water availability especially at high altitudes (as shown in Figure 1) and increasing the risk of flooding (Asian Development Bank, 2010; Pandey et al., 2016). Therefore, climate change in the Hindu Kush Himalaya may have a profound effect on the livelihoods of members of the surrounding mountain communities, including the communities of Himachal Pradesh.

Figure 1: Climate Change Affecting Water Availability in Himachal Pradesh

While there is an abundance of scientific evidence that demonstrate recent changes in climate, public perception of and social responses to climate change are far less well researched. Some limited studies have been conducted, including in the United States, Uzbekistan, Georgia and others (Broday et al, 2007; Sutton et al, 2013; Ahouissoussi et al, 2014). However, it is difficult to extrapolate these findings to other locations and communities because exposures, vulnerabilities, capacities, education, and culture are not the same across locations. Efforts to implement changes to mitigate the effect of climate change are more successful, however, when the perspectives of those at risk are taken into account. The cultural and social contexts through which people view the issue of climate change impacts how they will respond to mitigation and adaptation efforts (Besel et al., 2017). One region for which there is limited data is Himachal Pradesh, India. Therefore, the goal of our project was to characterize perceptions of exposure and vulnerability to climate change among lifelong residents in Himachal Pradesh. To meet our goal, we first compiled scientific data on current climate indicators and future projections of climate change in Himachal Pradesh. Second, we collected and assessed public attitudes and perceptions about climate change within the Mandi District of Himachal Pradesh. Finally, we identified and mapped exposures and vulnerabilities to climate change within Mandi District. By accomplishing these objectives, we obtained a better understanding of public perception of climate change in Himachal Pradesh, and thereby contributed to the body of knowledge used in the development of effective strategies to combat the effects of climate change in this region.

Climate Change in Himachal Pradesh: Risk, Vulnerability, and Adaptation

Characterizing climate vulnerability in Himachal Pradesh requires a sense for the range of experiences and livelihoods that stem from the land and how residents in the area may be impacted by climate change. It is also important to understand existing climate change adaptation policies in order to determine how these initiatives could better respond to public perception. In the following sections, we outline the social implications of climate change in Himachal Pradesh that have already been reported. Next, we discuss other evidence of? negative implications of climate change and illustrate how these implications may relate to Himachal Pradesh. Then, we discuss the concepts of exposure and vulnerability in relation to various stressors, including climate change. Finally, we highlight how public perception can shed light on the vulnerability of an area to climate change, thereby inform government agencies and policy makers.

The implications of climate change in Himachal Pradesh

Changes in weather patterns can threaten communities. Himachal Pradesh historically obtains roughly 80 percent of its annual rainfall from the summer, southwest monsoon (Saha et al., 1979; Jena et al., 2016). Decreased precipitation and late onset of the monsoon have already been observed, and various models that aim to predict the impact of climate change also support these observations (Jena et al., 2016). For example, Shimla, the capital of Himachal Pradesh, has seen an annual decrease in monsoon precipitation of 3.71 millimeters per year since ? (Jaswal et al. 2015). Winter precipitation, on the other hand, is generally the result of western disturbances (WDs). WDs are weather systems that develop as air moves from west to east across the Himalayas, bringing heavy snowfall to the region (Kumar et al., 2015). Between 1977 and 2007, there were between two and five fewer WDs per month in December, January, February, and March. As a result, a decrease in overall winter precipitation in Himachal Pradesh was also exhibited. During the same time period, there was a 13 percent decrease in precipitation from the mean (based on what time period?) (Kumar et al., 2015). Although there has been an overall decrease in precipitation, in the past five decades, there has been an increase in the frequency of heavy rainfall episodes, likely due to surface warming (Kumar et al., 2015; Jena et al., 2016). Melting glaciers and mountain snowpack serve as a water source by providing water to nine river systems in the region (Asian Development Bank, 2010). However, rising temperatures due to anthropogenic activity have caused an increase in the annual glacial melt. This in turn is causing a year after year decrease in glacier size, thereby depleting freshwater resources in the province in the long-term (Asian Development Bank, 2010). While the Hindu Kush Himalaya hosts a wide range of temperatures due to highly variable elevations throughout the area, maximum temperatures throughout the region are rising as a result of anthropogenic activity (Asian Development Bank, 2010). Higher temperatures facilitate evaporation and thereby reducing soil moisture. These bio-physical changes have already had implications on communities within Himachal Pradesh. Reported implications include:

- Declining water availability for irrigation: Reduced soil moisture has led to an increasing demand for irrigation water. Residents obtain water for domestic and agricultural use from natural sources and from the government supply: the Department of Irrigation and Public Health. The government supply also relies on local rivers and springs for freshwater. The decrease in precipitation associated with the summer monsoon is causing the surface water resources to dry up (Asian Development Bank, 2010). This may cause the sources of the government provided water to dry up.

- Shifting agricultural land use: Rising temperatures have caused apple farmers to move to higher altitudes in order to achieve an appropriate chilling period required for high quality apples. Consequently, lower altitude lands are growing alternative crops in order to accommodate the rising temperatures (Rana et al., 2013; Basannagari and Kala, 2013; Kumari et al., 2012).

- Shifting agricultural productivity: Rising temperatures have caused a delay in sowing and harvesting times. Some fruits are ripening prematurely. There has also been an increase in the prevalence of disease among crops (Kumari et al., 2012).

Given that 90% of the nearly seven million inhabitants of Himachal Pradesh are dependent on agriculture, these negative implications have profound, detrimental effects on the state as a whole (Changing Trends of Monsoon, 2013). Additionally, while implications in and of themselves, declining water availability and shifting agricultural land use and productivity simultaneously threaten food security. It is likely that there are additional implications that are not as well recorded. The impact of climate on mountain communities extends beyond that which has been documented for Himachal Pradesh. One example is a case study of rural villages in the Lo-pa region of north western Nepal, which relies primarily on agriculture and animal husbandry for livelihood. Recently, the region has supported fewer animals, yet there is still not enough grass for them to graze (Devkota, 2013). In the village Dhe, there is a special festival called Dhimpuche. This festival involves one particular pine tree and is only celebrated in Dhe. If residents relocated they would be unable to observe this important holiday. As a result, many are hesitant or unwilling to relocate even if it is in their best interest. Migration is an example of a climate change adaptation policy, yet as demonstrated through the case study of Lo-pa, cultural factors and perceptions must be considered if they are to be successful.

Incorporating risk assessments and perceptions studies into adaptation efforts

The Intergovernmental Panel on Climate Change (IPCC) defines risk as a function of three factors: hazard, exposure, and vulnerability (IPCC, 2014). Hazard indicates of the potential for a specific event to occur in a given area that may have devastating consequences. Vulnerability is representative of the areas ability to respond to such an event. Exposure is the potential a hazardous event has of occuring. The relationship between risk and its three components is shown below in Figure 2.

Figure 2: Schematic Interaction Between Risk, Hazard, Exposure, and Vulnerability

Our study focuses on the exposure and vulnerability components of risk. Exposure is the amount of stress likely to be experienced by a community due to climate change and can be measured by considering either long-term changes to weather patterns or by considering the changes in the number and severity of extreme weather events (OBrien et al., 2004). Vulnerability is measuring both sensitivity and adaptive capacity. Sensitivity is the likelihood a entity has of experiencing negative impacts from exposure. Adaptive capacity is a communitys ability to counteract changes in climate based on various factors including wealth, technology, education, and skills (OBrien et al., 2004). Indices can be developed to measure exposure, sensitivity, and adaptive capacity (IPCC, 2014, OBrien et al., 2004, Sharma, J. et al., 2017), allowing differences in exposures and vulnerabilities to climate change throughout a region to be mapped, as shown in Figure 3.

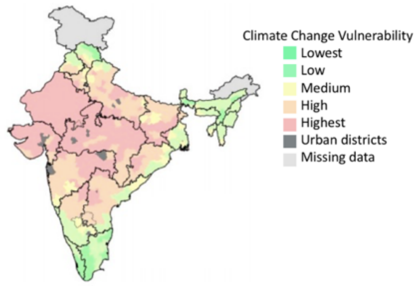

Figure 3: Vulnerability to Climate Change Across India (OBrien et al., 2004)

Understanding the exposure and vulnerability of an area to climate change is important information to have when taking action to mitigate or adapt to climate change. Government agencies such as the Department of Environment, Science, and Technology of the Government of Himachal Pradesh, are tasked with efforts to plan, coordinate, promote and oversee the environment conservation and enhancement programs through environmentally compatible management practices and technologies (Vision, Mission & Objectives, n.d.). One such directive is the Departments State Strategy and Action Plan of Climate Change, published in 2012 (Department of Environmental Science and Technology, 2012). The plan outlines specific goals for Himachal Pradesh and makes connections to the national action plan. These goals include, but are not limited to, a significant increase in solar energy production, improved habitat sustainability through improved energy efficient in buildings, conservation of water resources, and renewed focus on sustainable agriculture (Department of Environmental Science and Technology, 2012). Given that the missions of the National Action Plan on Climate Change and the Departments State Strategy and Action Plan of Climate Change are dependent on? the behaviors and livelihoods of the public, it is crucial that the missions align with public attitudes and perceptions. Public perception is just as important to the formation of effective policies as the scientific evidence that support the need for said policies (Besel et al., 2017). In fact, according to environmental scientist Anthony A. Leiserowitz, public support or opposition to climate policies ... will be greatly influenced by public perceptions of the risk and dangers inherent in climate change (Leiserowitz, 2005; Besel et al. 2017). This is because perceptions influence how people act and respond to climate change initiatives. There is some information about perceptions in India and in the Hindu Kush Himalaya, but it is limited and there is a need for more research in Himachal Pradesh. A study regarding climate change perceptions was recently conducted in Meghalaya, a state in northeastern India (Department of Science and Technology Centre for Excellence, 2017). It is one of the few states to receive national funding to combat climate change through the National Adaptation Fund for Climate Change. Through their study of Meghalaya, researchers highlighted the need to strengthen the adaptive capacity of communities in order to reduce their vulnerability to climate change. This can be accomplished by taking into consideration traditional knowledge in relation to climate (for example, how residents believe nesting behaviors of insects can predict flooding), impact studies, and vulnerability assessments. The vulnerability assessment itself is dependent on public perception regarding temperature and precipitation, extreme weather events, water availability, and forest cover. Researchers also evaluated how residents believed agriculture has been impacted by the climate (Department of Science and Technology Centre for Excellence, 2017). One way to understand vulnerabilities and risk is to Listening to the stories of residents has revealed how climate has affected their lives in the past and how its impact has changed over time. In 2017, researchers Besel et al. conducted a study on perceptions of risks related to global climate change. The team the of participants by obtaining what they referred to as limited life histories (Besel et al., 2017). The researchers prompted participants on the topic of climate change, after which the participants were able to freely reflect in writing. Examples of prompts include What is your earliest memory about global warming/climate change? and Do you remember when you decided climate change/global warming was or was not a real phenomenon, or are you still uncertain about the issue? (Besel et al., 2017). The research team determined that this method involving limited life histories provided useful insight on public perception and that this method overcomes limitations of the more traditional methods of analyzing the change in media content over time or conducting typical surveys and interviews (Besel et al., 2017). Similar studies may be useful in Himachal Pradesh in order to evaluate the vulnerability of the region and determine appropriate adaptive measures.

Methodology: Recording Experience and Perceptions

Here we provide an overview of the methods used to conduct our study. The goal of our project was to characterize perceptions of vulnerability to climate change among lifelong residents in Himachal Pradesh. Our goal, objectives, and associated tasks are summarized in Figure 4.

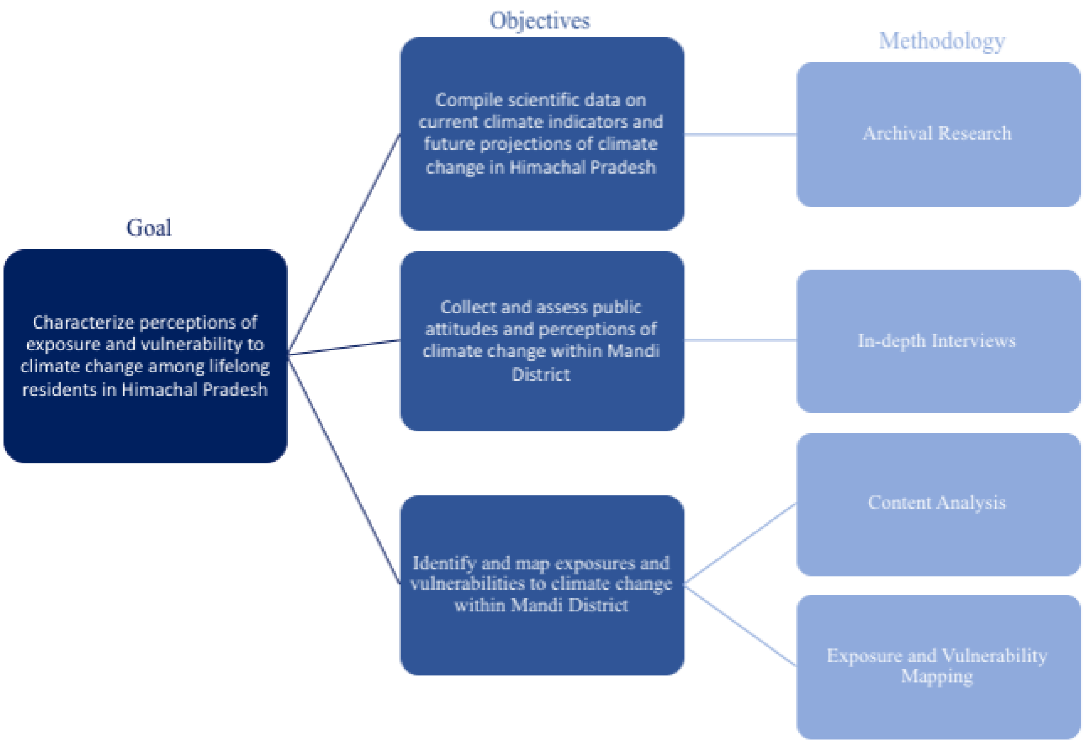

Figure 4: Goal, Objectives, and Associated Tasks

We describe each of the objectives, as well as the associated tasks for each, in more detail in the sections below.

Objective 1: Compile scientific data on current indicators and future projections of climate change in Himachal Pradesh

We compiled scientific data on current climate indicators and future projections of climate change in Himachal Pradesh. To do this, we analyzed rainfall data broken down by month over the past five years from the Shimla Meteorological Center. These data were used to identify whether a particular district seemed to have experienced any significant changes in rainfall. Next, we compiled temperature and precipitation data from 1901 to 2013 for a 100 square-kilometer grid encompassing Mandi District (shown in Figure 5 below).

Figure 5: 100 Square-Kilometer Grid Encompassing Mandi District (Google Maps, 2018)

These data shed light on climate change with relation to temperature and weather pattern changes in Mandi District.

Objective 2: Collect and assess public attitudes and perceptions of climate change within Mandi District of Himachal Pradesh

We accomplished our second objective through a modified ethnographic approach in eight rural villages within Mandi District: Arnehar, Bagi, Darlog, Khanahr, Kundak, Kutahar, Parashar, and Parnu. The location of these villages is shown below in Figure 6 (Sarkar, 2018).

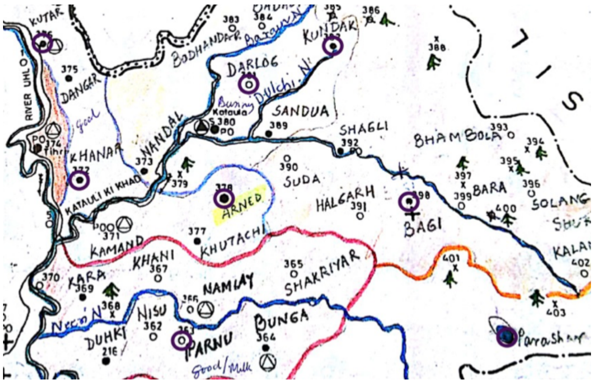

Figure 6: Villages for Interviews (Sarkar, 2018)

Ethnography is a field a research that involves understanding way of life from the native point of view (Berg, 2007, p. 171). Our approach sought to understand how climate change affects local residents by interviewing them in a semi-structured manner that allowed them to tell their story while also addressing key points that were crucial for our study. We prompted residents when necessary to obtain consistent information from each village in order to measure perception, adaptive capacity, sensitivity, and exposure, as highlighted below in Table 1.

Table 1: Interview Topics

Perception	Adaptive Capacity	Sensitivity	Exposure
Awareness of climate change	Ability to sell excess crops	Water availability	Threat of landslides
Relationship to human activity	Availability of work outside of the village	Number of crops	Threat of floods
	Education level	North/South facing	Changes in precipitation
			Changes in temperature
			Changes in length of seasons

These interview topics were determined based on our review of literature regarding exposure and vulnerability to climate stressors (e.g., OBrien et al., 2004; IPCC, 2014). They also relate to climate change awareness, beliefs, understanding, and misconceptions. Figure 7, below, illustrates the 2018 team conducting interviews in Arnehar, Mandi District, Himachal Pradesh. Figure 7: Interview in Arnehad (Kiehn, 2018)

Figure 7: Interview in Arnehar (Kiehn, 2018)

In addition to interacting with residents of eight villages in group settings, we also conducted interviews with 13 lifelong residents of more urban areas.

We reviewed the content of each in order to determine overarching similarities or contrasting themes between the qualitative and anecdotal reports for the local perceptions of climate change. The data were also used to identify vulnerabilities to climate change from the perspective of the residents.

Objective 3: Identify and map exposures and vulnerabilities to climate change within Mandi District

Our fieldwork from Objective 2, as well as our previous research, defined how we measured exposure, and two indices by which we could measure vulnerability: an adaptation index and a sensitivity index (OBrien, 2014). We used the sum of these indices to determine the current vulnerability of the community to future changes in climate. The components of exposure and the two indices of vulnerability are illustrated in Table 2. The sum of exposure and vulnerability were used to create a color scale that was incorporated into a map of the villages with relation to their exposure and vulnerability.

Results and Discussion

Results

To meet our first objective, we analyzed rainfall data over the past five years for the twelve districts of Himachal Pradesh obtained from the Shimla Meteorological Center (see Supplemental Materials). The data analysis was inconclusive. As a result, and as well as for convenience, we focused on Mandi District as the area for our study. we analyzed the average temperature and precipitation each month from 1901 through 2013 at the four corners of a 100 kilometer-square grid encompassing Mandi District. We constructed scatter plots of the data, then used linear regression analysis to produce the trend lines (see Supplemental Materials). The trend lines reveal the most prominent temperature increase in the months of February (0.0185C per year for 113 years) and March (0.0162C per year for 113 years). For precipitation, while there is much more variation in the data, there has been a significant decrease in precipitation during the months of July (-0.75985 mm per year for 113 years) and August (-0.65973 mm per year for 113 years) and also a decrease in precipitation during December (-0.14033 mm per year for 113 years) and January (-0.16798 mm per year for 113 years). Analysis confirms increasing temperatures during winter months and decreasing precipitation during both the monsoon season and the winter months, as suggested in our background research.

Perceptions about changes in climate

Following our analysis of local climate data, we conducted group interviews in the eight villages in Mandi District (refer to Figure 6). In these interviews, villagers shared stories that gave a more complete picture of climate change in Mandi District and how they view these changes. We also conducted individual interviews with 13 shop owners who are residents in Mandi Town in order to compare the perceptions of rural and urban residents (see Figure 8).

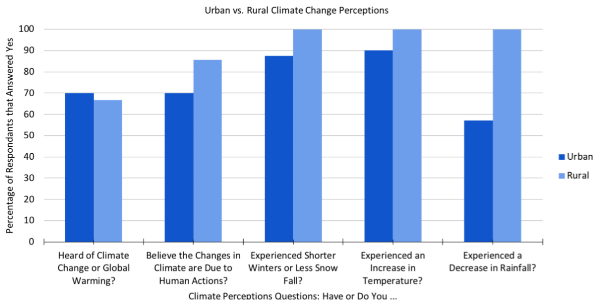

Figure 8: Contrasting Urban and Rural Climate Change Perceptions

Residents in all villages discussed a general increase in temperature and decrease in rainfall in recent years. This was reported in 100% of the villages we visited. They also all noted shorter winters with less snowfall. All villages except for Bagi and Kundak face issues of water scarcity. Bagi and Kundak both have larger natural streams close to their villages that provide water for drinking and irrigation. Most, though not all, of the residents of the more urban Mandi also noticed these same changes in the climate. They most often referenced the shorter winters and lack of snowfall as well as delays in the arrival of the monsoon.

Perceptions about causes of climate change

Although not all of the villagers were aware of the concept of climate change, most were still able to identify human activity to be the cause of the changes they have seen in their climate. They referenced projects such as the construction of IIT Mandi as contributing to the change. In other circumstances, villagers reported that they believed the gods were responsible for climate changes. Still, they could identify human activity as the primary cause due to the belief that people upsetting the gods brought about these detrimental changes. Though they were not generally aware of the scientific reasons for their observations, many correctly identified the causal link between people and climate change. Similarly, 70 percent of the residents of Mandi Town that were surveyed believed people were responsible for the changes in the

"There used to be small shops on the roadsides in circular way. But now they have moved all the shops from there to here. This is because of population growth and traffic issue ... Population is increasing so the number of vehicles is also increasing. Every family has 2-3 vehicles. They use vehicles wherever they go ... Even for a small task, we don't want to walk. Vehicles release carbon dioxide. We should plant the Peepal tree which is found only in India -- it absorbs most of the CO_2 and gives lots of oxygen. ... Environment was very good in the past. People are adapting individualism culture now. They don't care about others' problem. But in the past people used to solve the problems together."

Resident of Mandi Town

climate, and they were more slightly more likely than rural residents to be familiar with climate change as a concept. Urban residents tended to associate the changes in the climate with increased population in the area and the increased prevalence of motor vehicles.

Perceptions about the impacts of climate change

The changing climate has impacted both the residents of villages within Mandi District and the residents of Mandi Town. The residents of the rural villages reported reduced crop yield due to the lack of water. As a result, there is increased pressure to find an alternative source of income to pay for food that they are usually able to grow on their own. Some are also having to adjust their planting and harvesting cycles due to delay in the arrival of the monsoon (which is supported by climate data from the area). Similarly, clothing shop owners reported excess stock of winter clothes because fewer than expected were sold during the winter. Electronics shop owners have recently had an increase in the number of sales of fans and air conditioners. They also reported a shift in the timing of sales to earlier in the year. Overall, store owners within Mandi Town stated that their summer season is beginning up to a month earlier than in the past, thereby affecting their businesses.

"[Our work is] mostly agriculture, it's all that we do. Our whole households are dependent on that. If by God's grace there is good rain then we grow enough with our hard work to keep our family going and if not then we do some manual jobs as workers and earn 20-30 Rs so that we can get our family rations. We somehow make our ends meet, some of our people go to Manali, to Lahaul, to Leh, to Kullu for seasonal works and we somehow survive, what's to be done - we've got to feed ourselves right?"

Villagers of Kutahar

Perceptions about vulnerability to climate change

Though some urban residents were aware of the negative implications of climate change, climate change appears to be of greater concern to the rural residents. Urban residents did not mention concern for their livelihood in relation to climate change. while in contrast, climate change may threaten sources of food, water, and income for residents of rural areas. while the changes in climate affect what the shops in Mandi sell and when, it does not appear to threaten their businesses as a whole. In contrast, the survival of the rural villages is closely tied to the climate and as farmers they are very aware of this reality. When asked what they would do if these climate trends continued many of the rural residents did not have an answer. Our interviews with the residents of eight villages in Mandi District shed light on the exposures and vulnerabilities to climate change for each village. In order to measure the exposure of each village, we considered five factors: landslide threat, flood threat, shortened winter (or less snow), increased temperatures, and decreased rainfall. Each of these factors with respect to each village is shown below in Table 2.

Table 2: Exposure to Climate Change by Village

	Arnehar	Bagi	Darlog	Khanahar	Kundak	Kutahar	Parashar	Parnu
Landslide Threat	1	0	1	1	0	0	1	0
Flood Threat	1	0	1	0	1	1	1	1
Shorter or Drier Winter	0	0	0	0	0	0	0	0
Increased Temp.	0	0	0	0	0	0	0	0
Decreased Precip.	0	0	0	0	0	0	0	0
Exposure	**2**	**0**	**2**	**1**	**1**	**1**	**2**	**1**

We gave the villages a score of 1 for each of the threats that was present and a score of 0 for each threat that was not present. Therefore, Bagi is most exposed to climate change, while Arnehar, Darlog, and Parashar are least exposed. In order to measure vulnerability, both sensitivity and adaptive capacity need to be considered. Sensitivity for each village was measured by considering the availability of water and the number of different crops grown. A score of 1 for water availability signifies the presence of a significant source of water near the village. To ensure that the "number of crops" index was not disproportionately weighted the index had to be normalized. Normalization is a standard method of comparing indicators with different units. The normalized value of an indicator is found using the following equation: x-min/(max-min). The max and min are the maximum and minimum non-normalized values of the indicator. In our case, the maximum was four crops and the minimum was two crops. For the north or south facing index, 1 indicated that the village was north facing, 0 indicated that the village was south facing, and 0.5 indicated that the village was either east or west facing. According to our research, Arnehar and Bagi are least sensitive to climate change while Kutahar and Parnu are most sensitive. This information is displayed in Table 3.

Table 3: Adaptive Capacity to Climate Change by Village

	Arnehar	Bagi	Darlog	Khanahar	Kundak	Kutahar	Parashar	Parnu
Water availability	0	1	0	0	1	0	1	0
Number of crops	1	0.5	0	0.5	0.5	0	0	0
North or South facing	1	0.5	0.5	0	0	0	0.5	0
Sensitivity	**2**	**2**	**0.5**	**0.5**	**1.5**	**0**	**1.5**	**0**

Finally, table 4 illustrates the breakdown of the adaptive capacity index.This index is based on three factors: ability to sell extra crops, availability of external work, and education. For ability to sell extra crops, a score of 1 signifies that the village sells any excess crops at a market. A score of 0 indicates that the crops are for subsistence only. The same measurement system is used for availability of external work. For education, a score of 1 means there is a primary school in the village. Consequently, Bagi, Khanahar, Kundak, Kutahar, and Parashar are more adaptive to climate change than Arnehar, Darlog, and Parnu. It should be noted, however, that because Parashar does not have permanent residents, therefore the ability to sell extra crops was not applicable. Therefore, Parashars sensitivity score theoretically could have been one point higher.

Table 4: Sensitivity to Climate Change by Village

	Arnehar	Bagi	Darlog	Khanahar	Kundak	Kutahar	Parashar	Parnu
Able to sell extra crops	0	1	0	0	0	0	N/A	0
External work present	0	0	0	1	1	1	1	0
Education	1	1	1	1	1	1	1	1
Adaptive Capacity	**1**	**2**	**1**	**2**	**2**	**2**	**2**	**1**

The sum of the adaptive capacity index and the sensitivity index reveals the vulnerability for each village to climate change (see Table 5). A lower score represents a more vulnerable village.

Table 5: Vulnerability to Climate Change by Village

	Arnehar	Bagi	Darlog	Khanahar	Kundak	Kutahar	Parashar	Parnu
Sensitivity (Max: 3)	2	2	0.5	0.5	1.5	0	1.5	0
Adaptive Capacity (Max: 3)	1	2	1	2	2	2	2	1
Vulnerability (Max: 6)	**3**	**4**	**1.5**	**2.5**	**3.5**	**2**	**3.5**	**1**

We identified Parnu as the most vulnerable of the villages, though all the villages scored within two thirds of the highest possible (least vulnerable) score. We identified Bagi as the least vulnerable village.

Discussion

Our research, seeking to understand how people view climate change in the area, revealed three key points about climate change perceptions in Mandi District. First, despite relative lack of education, residents of the rural villages generally believe that humans and human actions are the reason for the changes in the climate. This is a major component of their perception of climate change. They understand that people are the cause of the changes to their climate even if they do not understand the mechanisms by which these changes occur. Second, people we interviewed reported that they were impacted by a changing climate. This includes farmers in remote, rural villages and shopkeepers in Mandi Town. However, those whose livelihoods depended on the climate seemed to be more aware of the types of changes that have already occurred. Still, it is clear climate change is affecting and will continue to affect all residents of Mandi District. Finally, the majority of residents (both rural and urban) that we interviewed believed people should be taking action to mitigate or adapt to climate change impacts and help prevent future change. When asked whether they would be willing to make personal changes to their lifestyle to help address the issue of climate change the majority said that they were. Similarly, these same people also expressed the belief that the government should implement policies to help mitigate the impacts of climate change. This indicates that people of Mandi District are potentially open to climate change mitigation policies.

"With rise in summers and if [water and waste water] areas are not properly cleaned, there would be rise in disease like malaria, dengue, typhoid etc. We rarely used to see these insects earlier but now there are a large amount of insects like mosquitoes even in winters ··· God knows what will happen and with hospitals very far from us, the situation will be very grave. People generally hesitate to go to doctors even if they have a slight fever. People would just not go to hospitals until the situation is very serious and sometimes things go out of hand. Sometimes blood test have to be done for such diseases and people ··· have to shell out 5000–10000 Rs of cash on this. This puts extra pressure on the lives of individuals who are already poor, who are already dependent on a source of income which is not regular and dependent on monsoon. A person with regular job can afford to be sick but a poor person can't be sick if he has to survive in these regions. Cleanliness drives need to be down to remove the dirt ridden areas."

Villagers of Khanahar

Our exposure and vulnerability indices reveal that some villages are at greater risk with respect to climate change than others. We found three factors to be most negatively impacting the vulnerability of the villages:

1. Availability of work outside of the villages
2. Ability to sell excess crops
3. Availability of consistent water resources

Only half of the villages reported that their residents were able to find work outside of their villages. This means that half of the villages visited are entirely dependent on their crops for food and income. Further, only one of the villages reported being able to sell excess crops at market. Therefore, the villages of Mandi District are primarily vulnerable due to lack of livelihood beyond subsistence farming and water scarcity. The exposure of the villages was more similar as all of the villages face the same long-term climate projections. The larger climate trends of the area (higher temperatures, less rain, shorter winters) are the same for all of the villages. The differences in exposure, therefore, come from exposure or lack of exposure to localized climate change related incidents like flooding or landslides. There are several limitations to this study. First, the sampling for the interviews was a sample of convenience, and the sample size as a whole was very small. As a result, the subjects interviewed may not accurately represent the perceptions of all of Mandi District and cannot be generalized to the larger state of Himachal Pradesh. Another issue with the sampling is that very few women were participants. All of the interviews conducted in Mandi were conducted with men. Though both men and women were present during the group interviews in the villages, the questions were primarily answered by men.

"People of our land are hard to anger and very calm and peace loving, and according to me one reason is that mostly we don't consume refined oils or artificial Dalda ··· Our elders used to tell us that if you eat pure, you will get not get angry very soon. They were calm and muscular and strong. They were resilient and used to lift 100–200 Kgs of weight but now this trend is disappearing. The curse of cigarettes, drugs and other such habits are slowly starting to be seen. [Youngsters] see people do it and the start doing it. These things give vigor on outside only make you hollow from inside."

Villagers of Kutahar

Concern for the future was a common theme in the responses from villagers. The interviewed residents can see their water resources decreasing and their crop yields suffering. Their source of food and income is at risk. As the climate trends are expected to continue into the future some of these villages may find themselves unable to sustain themselves or maintain their quality of life. As farming becomes more unreliable they will be forced to find other means of supporting themselves. This exposes villagers to some of the issues of modern living from which they were previously protected and threatens their culture and way of life. This region could benefit greatly from outside intervention to help them cope with climate change which is explicitly informed by the specific vulnerabilities and perceptions of the people that it seeks to help.

Project Outcomes and Recommendations

Project Outcomes

We coded villages based on their combined exposure and vulnerability indices to create a map that shows exposure and vulnerability rankings within the District (see Figure 9).

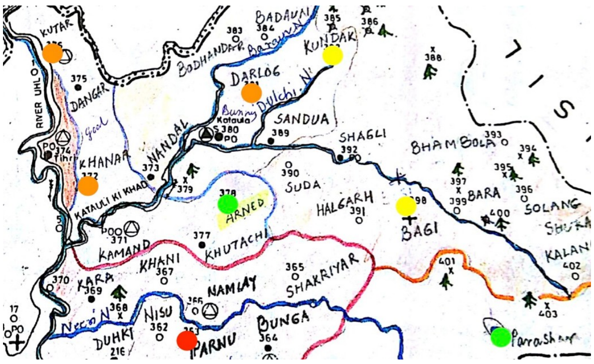

Table 6: Exposure and Vulnerability to Climate Change in Mandi District

Green represents the villages with the highest combined exposure and vulnerability score, with yellow as the next highest. In contrast, red indicates villages with the lowest score, with orange as the second lowest. This combined exposure and vulnerability score identifies communities at, potentially, the greatest risk due to climate change. This map may be used as a baseline by researchers for risk analyses studies in Mandi District in the future, as it identifies two of the components of risk (vulnerability and exposure). Additionally, it may be used, in conjunction with the rest of the results of our exposure and vulnerability study, by policymakers to identify communities in the most need of assistance as well as the ways in which they are vulnerable. This information can better inform adaptation and mitigation policies. We are currently developing a template for an interactive web page which will display village profiles and relevant information in conjunction with the map presented above. This would serve as the beginnings of a local climate perceptions and vulnerability database.

Recommendations

Our analysis of the Mandi Districts exposure and vulnerability to climate change has revealed that there are two significant factors contributing specifically to the rural communities vulnerability to climate change.

1. There is little work available to residents outside of their village
2. There is little (if any) income due to the fact that residents are unable to sell their excess crops

Of these two factors, addressing the first has the greatest potential to reduce the vulnerability of the villages. As the climate continues to change, agriculture will become increasingly unreliable source of income. Even if the second factor above was addressed, the residents would still be very reliant on the climate. As a result, adaptation policies in the area should instead focus on increasing the availability of occupations outside of subsistence agriculture. In some cases, policies may call for improved infrastructure (for example, improving the quality of roads) in order to facilitate access to jobs due to the remote locations of the villages. Another approach is to provide job training for residents. In either case, government interventions should be centered around creating work for the villagers that is not reliant on the increasingly unreliable climate. This approach, if successful would likely decrease the vulnerability of the villages. The above approach would require significant changes to the way of life of the rural residents of Mandi District. Remote villagers would likely have to travel for work outside of agriculture. This would dramatically change the day to day life of these villages. Facilitating work outside of the villages would result in fewer villagers that are available during the day to do any necessary tasks. Finally, although increased employment outside of the village may reduce vulnerability to climate change, it would increase vulnerability to economic fluctuations. Villagers that are largely farmers now would become susceptible to unemployment and other issues related to the larger economy of the region.

Another approach the government could take is addressing vulnerability through sensitivity. Only three of the villages had access to large and consistent natural water sources. The government supplied water is only enough for drinking not for irrigation. This water scarcity is a primary contributor to the vulnerability of the region. However, although one might consider the government providing additional water to support irrigation, this may not be a long-term solution as this water also comes from natural sources in Himachal Pradesh. These water sources are subject to the same strains from climate change. Instead of being susceptible to drought in their local area, villages would become susceptible to drought in other areas of Himachal Pradesh. Providing enough water for irrigation would also be a very large project for some of these remote villages. The population of the area may not be large enough for the government to consider implementing such a costly intervention. Increasing government water supply to rural villages does not solve a problem, at best it delays the impacts of climate change and masks the issue until it becomes dire. Finally, we recommend a combined approach. These villages need access to drinking water and water for irrigation. They cannot transition away from farming in a single season and probably will never do this entirely. This water would be provided by the government as an expansion of the current system. It is understood that this is not a permanent, long term solution to address the vulnerability of these villages, rather it is a short term solution that will reduce their sensitivity to the reduction in rainfall. Providing access to work outside of the villages will address vulnerability in the long term by creating a source of income that is not dependent on the climate.

Conclusion

As demonstrated throughout the course of this report, Mandi District, and likely similar regions in this part of the world are particularly exposed and vulnerable to climate change. This is due to its dependence on the southwestern monsoon, winter precipitation, and snow and glacial melt for freshwater, as well as the general climate conditions for sustaining local agriculture (Asian Development Bank, 2010; Pandey et al., 2016). Rising temperatures and decreasing amounts of precipitation have already begun to have negative social implications in the area, particularly with regard to freshwater resources (Jena et al., 2016). In order to implement policies to counteract these negative implications, it is important to take public perception, exposure, and vulnerability into consideration. Listening to the stories of these villagers revealed the ways in which these people understand their environment and the changes therein. Our research revealed that the residents of Mandi district are aware of the changes in their climate and that these changes are already impacting their lives. These residents are concerned about climate change and believe human action is necessary to address the issue. Further research is also required to more adequately map the vulnerability of the region. A continuation of this study or a similar study should be conducted to more completely assess the exposure and vulnerability of the region to climate change. Future studies may want to focus on more isolated communities. The villages in this study are all in relatively close proximity to IIT Mandi and most are reasonably close to roads. The study of communities with significantly less outside interaction would contribute greatly to the information on local perceptions of climate change and vulnerability. This information is best used to guide and focus adaptation efforts in order to address the concerns of the people. Our study provides a better understanding of climate change in Himachal Pradesh and its effect on the local community.

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The full report and Supplemental Materials for this project can be found at: http://www.wpi.edu/E-project-db/E-projectsearch/search using key words from the project title. Outcomes delivered after May 1 will appear on the IITs ISTP page at: http://www.iitmandi.ac.in/istp/projects.html

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All-Season Plant Nursery to Increase Food Security

Abstract

In the widely agrarian state of Himachal Pradesh, pests, temperature variation, weather and climate change are becoming more prevalent to farmers and villagers. The rapidly changing environment is damaging food security in this region which is driving many to more urbanized areas where food security is not an issue. Our team studied feasibility of an all-season plant nursery that would help to improve food security, preserving the traditional livelihood present in Himachal Pradesh. We approached this challenge with three objectives. First we learned about private and commercial farmer practices and needs by conducting on-site interviews with these individuals. Next we evaluated these sites using a defined set of evaluation determinants. Finally we built a small-scale nursery prototype designed to reflect the challenges these farmers face. We proposed a recommendation which outlined specific design considerations which would improve the nurserys self sufficiency. We also proposed a one-year nursery trial period for farmers who would want a nursery but are unable to afford the upfront costs of building one. With these proposals we aimed to preserve the culture and livelihood that makes this region of India so unique and wonderful.

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All-Season Plant Nursery for Improved Food Security

Food security is one of the worlds most pressing problems, affecting nearly one billion people globally. The United Nations recognizes this problem in its second sustainable development goal (UNHCR, March 2017). In rural states like Himachal Pradesh, the problem includes the complex challenges of the weather and terrain for dependable crop growth. Agriculture is a vitally important part of life, but the seasonal nature of food production can be problematic for consistent growing conditions. These communities rely on knowledge passed on by previous farmers and good weather to get them through each season . This region experiences a wide range of pests, temperatures, and weather. Additionally, increasing uncertainty resulting from climate change puts farmers at risk of losing their traditional way of living. The threat of climate change and increased difficulty of being a farmer can drive people away from farming to pursue a larger profit. As a result of this, farming becomes more difficult to make a profit, further repeating the cycle. An all-season nursery could potentially lengthen the growing season in order to minimize risks and increase the opportunity for agricultural stability and success.

There are several aspects of this northern region that make it particularly prone to growing season difficulties. The District of Mandi sits in the foothills of the Himalayas, in the heart of the state. Mandi is a mountainous region with elevations between 696 meters at its lowest and 2030 meters at its highest. The region has a humid subtropical climate in most areas and an alpine climate at higher elevations. The elevation and steep inclines make effective crop growth difficult. Temperatures in the summers can rise to over 38 degrees Celsius and fall to below -1 degrees Celsius during the winters. The seasonal nature of the weather makes it difficult for farms to be productive year-round. Mandi receives an average of 168 centimeters of rain every year and during July, the first month of monsoon season, the average rainfall is 48 centimeters (Climate: Mandi, 1982-2012). These weather conditions can be damaging to the primarily agrarian culture of the surrounding region.

Temperatures that are too hot or too cold can affect the growth of the seasonal crops. The inconsistent rainfall presents an issue of maintaining irrigation throughout the dry seasons or plants being drowned out by the heavy rainfall of monsoon. These are concerns for farmers who either need the money that their crops will bring in or need the food they are growing for themselves.

Despite the challenges of growing crops in this mountainous region, 71 percent of residents in the province are associated with agricultural livelihoods (Envis Centre: Himachal Pradesh, 2011). While some residents of Himachal Pradesh already use nurseries to protect and grow plants out of season, this practice is not being used to its full potential. This is evident by the low production of vegetables as seen from interviews conducted by the team. The ability for families or businesses to grow crops throughout the winter and other inclement weather such as during monsoon season may supplement food supplies or profits during a slow period.

The purpose of this project is to study the feasibility of enabling farmers to use plant nurseries and test a prototype for year-round production in Himachal Pradesh. If needed, an all-season plant nursery would allow for a more diverse and consistent food supply year-round and as a result improve food security in the region. The design of a structurally sound building could allow a maximum amount of sunlight while offering durability and effectiveness as well as protection from monkeys. Our goal for the design and materials of the project was to create an affordable nursery that could be easily constructed and maintained by anyone. As such, objectives of the project were to research current nursery and non-nursery farming practices as well as stakeholder needs, identify site and design specific parameters for nursery construction, and to join the best practices for the design and development of nurseries with the needs of the people of Mandi. We designed and built a prototype for an all-season plant nursery to assist in year-round crop growth in Mandi, India.

Nursery Challenges and Design

The weather conditions present in this region of Himachal Pradesh can provide a good environment for plant growth but can also be harsh for the many different types of plants grown. To give both commercial and sustenance crops a more controlled environment for both in and out of season growth, we investigated more deeply the constraints and requirements that could support farmers in Himachal Pradesh. What we learned is that adding equipment and infrastructure to traditional communities poses a financial risk and potential learning curve that may limit interest. The stakeholders for this project were small-scale farmers and commercial growers. Rain-fed farms account for 80 percent of all food for India, and selling these crops is the main source of income for residents of Himachal Pradesh.

Challenges of Introducing Nursery Technology

Although an all-season plant nursery seems like a logical solution for farmers trying to grow crops in the difficult climate, there are many challenges involved in introducing nurseries. Nurseries are expensive, and with the per capita income of Himachal Pradesh at 95,582 INR (approximately 1,461 USD) it would take a hefty loan to purchase a nursery (Baldi, 2016). Also, although Census data from 2011 proves Himachal Pradesh has one of the highest literacy rates in India with nearly 83 percent, only 3 percent of residents have access to internet (Biswas, 2012). Without access to internet, it is difficult for residents to research how nurseries work and how best to use them. Another challenge for farmers without access to internet is they cannot apply for government subsidies or research other agricultural extension benefits. There is a limited amount of help available for farmers, but they can contact the local Agricultural Extension Officer or the Directorate of Agriculture, located in Shimla (Department of Agriculture, 2001).

To help combat inconsistent growing conditions, assessing the viability and the need for a simple nursery with options for season extension and out of season crop growth could assist these farmers and households in producing enough food for their families or crops to be sold at local markets. In addition, an advanced prototype could benefit the agricultural research community and provide options for scientific or academic agricultural research for site specific conditions. Our motive was that the benefit of an adaptable plant nursery for growers, is that it has parameters that could be customized by stakeholders. Considerations included size, cost, portability, reparability of materials, and scalability. Simplicity was key; an intuitive design allows for easy maintenance as well as smooth use.

Site Specific Form and Function

The design for an adaptable plant nursery for use in Himachal Pradesh needs to consider a range of options for cost and local materials. A nursery is a structure where plants are grown from seedlings, whereas a greenhouse is a structure made from predominantly transparent material where plants are grown. Greenhouse temperature control techniques can be either passive or active, meaning they are either independent or dependent on electricity.

The user requirements for the space, the cost of building materials for the nursery, and other customized features add or subtract complexity. A summary of common design considerations can be seen below in Table 1.

Table 1: Design Features for Plant Nurseries

Feature	Considerations
Foundation	Material, cost, dimensions
Insulation	Material, cost, insulation ability
Ventilation	Style, heat loss, insulation ability
Cladding	Material, cost, durability, light penetration
Photovoltaic panels	Cost, dimension, energy output, maintenance
LED lights (Far Red)	Cost, light output, energy consumption, maintenance

Nursery structures are dependent on site-specific conditions such as climate and social considerations around usability. Standard modifications include shape and foundation quality. A standard peak structure, where the roof of the structure is a scalene triangle to maximize area exposed to light, is common in Himachal Pradesh. An outline for building greenhouse foundations is detailed in The Food and Heat Producing Solar Greenhouse by Rick Fisher (1976). One approach to building a foundation is to make a base from a solid substance such as concrete or masonry stones, and then surround this by an insulator such as Styrofoam (Fisher, 1976). Additionally, a case study conducted in Northwest Nepal in 2011 found that a mixture of mud brick and straw as a foundation proved to be strong and a great insulator (Fuller, 2012). This study demonstrates that simple solutions using locally obtained material can be exceedingly effective.

Greenhouse structures and shape are chosen for specific environments. The standard peak structure supports different types of pressure that can be put on a greenhouse such as snow load, wind load, dead load, and live load. Snow load and wind load are the stresses that are put on the greenhouse by their respective conditions, dead load is the weight of the structure itself and all of its attachments like pipes and lights, and live load is the weight of any person on the structure during maintenance (Ponce, 2015). The loads that the structure can bear are heavily dependent on the construction materials. A common building material is aluminum, which has the advantage of being lightweight and durable.

Cladding, the covering on a greenhouse, is most commonly glass or polyethylene. Insulation, durability, and transmittance of light and radiation into the greenhouse are important factors when considering what material to use. While glass transmits light extremely well and polyethylene is cheaper and lighter than glass, they are both expensive and hard to obtain. A third option for the cladding is polycarbonate. This material is often formed into two sheets of plastic with hollow channels running between them which serves as added structural support and also increases insulation, called twin wall cladding (Abdel-Ghany, 2012).

Passive methods of heating and ventilation are important for a self-sustaining nursery. Storing light energy will heat up the nursery while proper ventilation will allow cooling and humidity control. Proper micro-climate maintenance allows for the most efficient growth of crops in the nursery.

Maximizing light transmittance is important for photosynthesis and heat retention. A large surface area on a south facing wall maximizes the light and radiation that is able to pass through the cladding and into the greenhouse. Radiation that passes through cladding and becomes trapped causes the greenhouse effect which heats up the nursery. Multiple layers of cladding create air pockets between layers which increases insulation (McCullagh, 1978).

Approaches to Temperature Control

Just as in a residential home, insulation, heating, and ventilation are important and closely related in greenhouses. Without the proper insulation, trapped heat from the sun can be lost when temperatures decline, so minimizing heat loss is essential. A large internal volume gives the structure thermal inertia, a property of a structure which describes its ability to retain heat.

Keeping a nursery or greenhouse at an appropriate temperature for the plants presents a great challenge. There are two broad categories of solar energy collection: passive and active. A passive system uses a heat sink to absorb thermal energy during the day and then passively radiates it back out into the greenhouse at night. One common method for keeping the structure heated is storing heat from the sun in thermal masses. There are different materials used for this, mostly commonly ceramics or water. When added to a greenhouse, they absorb heat during the day and then release it at night. In contrast, active heating involves the use of a thermal mass and powered ventilation. A Ground-to-Air Heat Transfer system (GAHT) uses a fan to blow air through pipes running through the ground. In the summer it vents hot air through pipes in the ground, cooling it off and bringing it back into the nursery. During the winter it vents cool air through the ground that has been heated all summer to heat the nursery up (Schiller, 2017). This setup can be seen in Figure 1.

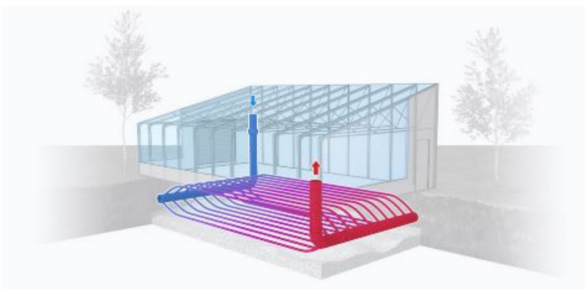

Figure 1: GAHT system in a greenhouse (Schiller, 2017).

Given the generation of carbon dioxide as well as humidity from enclosed spaces, a key aspect of greenhouse microclimate maintenance is its ventilation. An article written by John Worley of the Department of Poultry Science at the University of Georgia states that factors to consider when designing the ventilation system included local wind speed and direction, vent layout, vent area, and whether to use a forced or passive ventilation system (Worley, 2015). There are a number of commonly used ventilation layouts that are each chosen for specific purposes. The University of Thessaly, School of Agriculture, Crop and Animal Production produced a study on the effectiveness of four different layouts, one of which is shown in Figure 2.

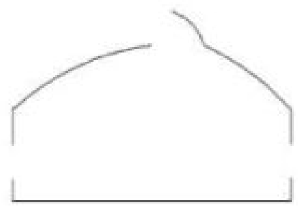

Figure 2: Geometry of side and roof openings configuration (Bartzanas et. al., 2004).

In this study researchers found this configuration that combined open side vents and a roof flap was the best vent layout since it allowed a large quantity of airflow to be circulated through the greenhouse while maintaining proper airflow inside (Bartzanas et. al., 2004). Another study, done by J. J. Hanan (1978) found that alternating roof vents on either side of a greenhouse employed the cross-flow strategy along with vents on the roof vented heat more efficiently than one single vent type.

Active ventilation is also an option when considering ventilation systems. A second study conducted by the University of Thessaly considered the viability of a system that circulated air using a fan. The researchers found that while there were large differences in microclimate conditions inside the greenhouse between an active and passive ventilation scheme, very little difference in plant transpiration rate was present (Kittas et. al., 2001). Regardless, active ventilation offers a good way to ensure proper rates of ventilation within the greenhouse. In a windy area such as Himachal Pradesh this is important since high winds can potentially be harmful to young or fragile crops.

Power and Supplementary Lighting

Features such as solar panels and LED lights are not necessary for the construction of a functional nursery, but they provide supplementary assistance in areas such as energy consumption or increasing plant growth. Passive methods of heating and cooling do not use electricity, but at the same time do not change conditions as quickly or as radically as active methods that use fossil fuels or coal. Introducing solar panels can decrease or negate the cost of air conditioning and heating each year (Carlini, 2011). By decreasing the cost of non-passive heating and cooling methods, more effective temperature control can be achieved while also keeping the cost of greenhouse maintenance low. Any solar energy produced will help mitigate efficiency losses in the nursery. Photovoltaic panels can be quite expensive and thus it is important to have a well-designed nursery to reduce the necessary size of the panels if affordability is to play a role in the nursery design.

During the winter months there are not enough hours of sunlight in a day to grow plants as efficiently as in the summer (McCullagh, 1978). Supplementation of light is necessary for continuing growth throughout the winter. A study done by Kai Cao in 2016 used Far Red LED lights to offset the light lost from shorter days. By using Far Red LED lights, the plants did not grow as tall but the overall mass of the plant, meaning the leaves and flowers, had increased in size (Cao, 2016). Increased leaf area allows plants to take in more light energy from the sun. The study also showed increased flowering from plants supplemented with Far Red LED light which correlated to increased crop yield.

Government Subsidies

For farmers who are willing to invest but still need some monetary assistance, there are government subsidies to help lessen the financial burden. We identified a number of government subsidies that incentivize farmers to switch to the use of nurseries to grow crops. The government schemes relevant to this project include: The Rural Infrastructure Development Fund (R.I.F.D.), The Ministry of New and Renewable Energy solar panel subsidy, the Dr. Y. S. Parmar Kisan Swarozgar Yojna and Japan International Cooperative Agency (J.I.C.A.) scheme, and the Rashtriya Krishi Vikas Yojana Scheme(Department of Agriculture, 2001). A description of these subsidies is presented below in Table 2.

Table 2: Government subsidy schemes

Name	What it subsidizes	Percent subsidy
R.I.F.D.	Drip irrigation and fogger systems up to 1 hectare in size	Up to 80%
Ministry of New and Renewable Energy	Solar Panels for rural farmers	up to 80%
J.I.C.A. & Dr. Y. S. Parmar Kisan Swarozgar Yojna Scheme	Nursery production	Aims to subsidize 100%
R.K.V.Y.	Yearly seed supply	Approximately 50%

Combining all of the considerations with the end user in mind gave us necessary insight into the structure and features of the nursery needed for our purposes. The challenges facing the introduction of nurseries in addition to combining structure, ventilation, and insulation come together in a way that considers who will be using it.

Approach: Interviews and Field Tests

Three objectives were identified in order to assess the feasibility of an all-season plant nursery in Himachal Pradesh. The three primary objectives can be found below in Figure 3.

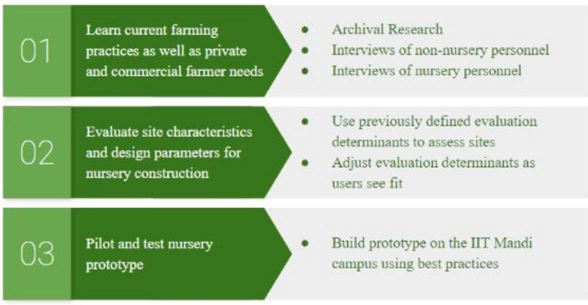

Figure 3: Outline of objectives

Objective 1: Learn Current Farming Practices as well as Private and Commercial Farmer Needs

Growing crops in Himachal Pradesh is a major source of food and income for its citizens. To learn about how both private and commercial farmers function in this economy, we conducted archival research and interviews with farmers who grow crops with and without nurseries.

We identified Government subsidies from nursery personnel and from our own research that would make building and sustaining nurseries more affordable for farmers attempting to start their own. Each of these programs work to subsidize the cost of nurseries for farmers in rural Himachal Pradesh to increase the number of nurseries in the region.

To engage directly with users of the potential nursery, we located farms in Arnehar, Kataula, and Kamand and interviewed farmers who did not use nurseries. We used an interview guide found in Appendix A. We interviewed them on the types of crops they grow each season, if they sell their crops or keep them, water and electricity availability, and any other problems that they face. The interviews were conducted in Hindi. Photographs and videos of the interviews were taken with the farmers permission for documentation purposes.

We located farms in Chail and Kataula that do use nurseries and interviewed farmers and government workers using an interview guide found in Appendix B. We interviewed them on what types of crops can be grown in nurseries, the structure and size, the materials used, and internal climate control. Interviews were conducted in Hindi. Photographs and videos were taken of the nurseries with permission from the owners for documentation purposes. The group can be seen visiting a nursery in Figure 4.

Figure 4: Research in nursery practices

Objective 2: Evaluate Characteristics of Sites and Design Parameters for Nursery Construction

To further evaluate potential nursery sites and the current nurseries in Himachal Pradesh, we conducted site evaluations with documentation and observation, as well as

After interviewing the farmers, we visited their farmland and took photographs documenting the site conditions, being sure to capture qualities of the farms which might be useful later during the evaluation stage. We also took into consideration different areas of their farmland where a nursery might be effectively placed. We evaluated the farmland based on the amenities in Appendix C.

For greenhouse and nursery operators we followed a similar approach. We asked additional specific questions regarding the greenhouses and took pictures of the various structures for documentation purposes. Later, we evaluated the greenhouses based on the determinants in Appendix D. Photographs of farms without nurseries were taken for documentation purposes and later evaluated based on determinants in Appendix C.

Interviews with experts in related fields were conducted. We contacted Mr. Jagdish and Mr. Hidev from the medicinal plant department at the IIT. They are horticulturists who maintain the medicinal garden and labs on the IIT campus. They provided useful information regarding seasonal plant growth and best practices for farming year-round in Himachal Pradesh. We later visited the Model Floriculture Center in Chail and met with supervisor Dr. Kashop as well as a few other farmers working in an nearby floracultural reserve. This government run farm is primarily operated in greenhouses. We spoke with Dr. Kashop in order to gain practical knowledge of greenhouse operation in Himachal Pradesh. We learned some very valuable information speaking to her and the greenhouse workers here and much of it influenced our greenhouse prototype design.

Objective 3: Pilot and Test Nursery Prototype

In order to build the prototype on the IIT Mandi campus, we discussed a variety of potential build sites to evaluate. Ultimately, the site chosen was by Maple Mess Hall between two walkways. This site was chosen due to its longest access to light and close proximity to the final presentation area.

The design for the prototype was created based on the results of the research done in the first two objectives. Combining this with our previous research, we came up with a design that seemed like it would be able to address the problem. From here the next step to begin the construction of the prototype was to acquire all the necessary components. These came from various sources, primarily online retail and accessible gardening stores in Mandi. The aluminum for the frame came from a hardware store in Mandi Town.

The first step of the actual construction was to assemble the frame. The prototype is small enough that it would be possible to move the frame after being assembled. This was accomplished using the IIT machine shop tools and the aluminum beams. The next aspect of the construction was to dig a foundation. This serves two purposes, first to allow for a more solid base that would not be blown away or knocked over, and second to give a place for a GAHT system. The tubes act as a way to turn the earth beneath the nursery into a thermal battery. Next we installed the piping for this system, reburying it in the soil. The final step of construction was to place the nursery on the foundation and secure it to the ground using stakes.

In order to actually test out the prototype and see potential results, we planted various seedlings to be tended to over the next few months. We made observations and monitored the temperature and humidity. This information was to give both quantitative and qualitative analysis of how effectively the nursery is functioning. Although monitoring the growth of the plants through to harvest is not within the scope of this project it will be useful to include the plants to facilitate future observations.

Results

Current Farming Practices and Needs

The following section includes the results and discussion that follow our teams methodology as outlined above.

Design Parameters and Site Characteristics for Nursery Construction

We interviewed eleven farmers who grew crops without the use of nurseries and operated in a range of elevations. Without the use of nurseries, both private and commercial farmers are limited to growing a relatively small range of crops. The most common crops sowing and harvesting patterns can be found below in Figure 5.

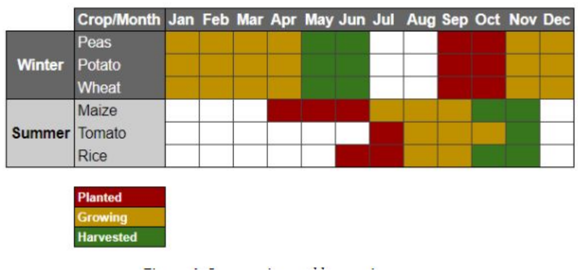

Figure 5: Crop sowing and harvesting seasons

Our initial intent was to interview farmers and record specific needs they might have based on challenges they commonly face. However, we found that interviewing them on their challenges was a more effective approach as many of them did not see any issue with the way they farm or did not have sufficient knowledge of alternative farming methods such as nurseries. In terms of challenges faced, most farmers that we interviewed noted that due to lack of water, as well as the destruction of crops from monkeys, they can only grow wheat and maize. Monkeys will not eat wheat and maize because they prefer to eat softer crops like fruits and vegetables. Farmers who faced crop destruction from monkeys were forced to travel into town to buy produce. Some farmers also expressed a desire for a reliable water collection system for irrigation because many used rainwater as their main source of water for irrigation.

To learn about commercial practices, we interviewed nursery and greenhouse personnel and identified how greenhouses are operated and maintained. We also learned about nuances in the greenhouse structure and function. In Chail, we visited a government-run floriculture center as well as a farmer owned flower nursery. We also visited a farmer owned nursery in Kataula who built his nursery using government subsidy.

Each site had its own technique for maintaining temperature and humidity. At the Model Floriculture Center in Chail, the workers manually opened the vents at 9:00 am in the summer and at 11:00 am in the winter while the vents were closed at 5:00 pm each season. The Floriculture Center also used thermometers and barometers to measure temperature and humidity respectively. For extra ventilation, a nursery made from hard sheet polycarbonate in the Floriculture Center used a honeycombed cardboard structure on one wall so that when wet, cool air was drawn in and hot air was pushed out. At other sites, such as Chail village and Kataula, workers used their own intuition and experience of the internal conditions when deciding to use the vents and the foggers, which can be seen below in figure 6.

Figure 6: Foggers installed in a greenhouse

We asked workers about the price of different types of nurseries as well as the materials and temperature control methods nurseries use. Dr. Kashop from the Floriculture Center informed us that standard peak structures have a higher construction cost compared to arched structures. Comparatively, with a common size of 250 square meters, standard peak structures cost around 800,000 INR to build while the arched structures only cost around 400,000 INR. We also learned that twin wall polycarbonate is more expensive per unit than polycarbonate film but did not need to be replaced. Conversely the film needed to be replaced every 5 years due to inevitable physical wear.

Design Parameters and Site Characteristics for Nursery Construction

We conducted site assessments to learn how nursery structure and design responds to local conditions. The Model Floriculture Center and nurseries we visited followed two types of structures: standard peak and arched. Each nursery used side and roof vents made from mesh screen. Active ventilation was not used at any of the locations we visited. Both polycarbonate film and twin wall polycarbonate were used as a cladding material but polycarbonate film was used in all but one of the nurseries seen. Every nursery also used foggers to maintain the internal humidity. Table 3 below shows basic amenities shared by the nurseries we visited.

Table 3: Nursery site evaluations

Amenity	Findings from evaluation
Lighting	Naturally lit
Type of ventilation	Passive: side and roof ventilation
Insulation	None (besides polycarbonate sheets)
Maintainability	*Polycarbonate film:* needs to be replaced every few years due to natural degradation and destruction from monkeys *Hard polycarbonate sheet:* can go more than 8 years before being replaced
Irrigation system	Drip irrigation
Internal temperature regulation	Passive, manually regulated
Microclimate regulation	Manually regulated
Structure Shape	Arched

Although these features were adapted from features of nurseries found in research, construction, we found these amenities to be successful in each of the nurseries we visited. As such, we implemented a mix of both into our design of the nursery.

In our site evaluations we considered aspects of the local terrain that could challenge the design, or limit building and maintaining a nursery in that area. Some of these key site parameters included physical accessibility, water, electricity, and crop use. These characteristics are presented per village on the next page in Table 4.

Table 4: Farmland evaluation by town

	Arnehar	Shegli	Kataula
Village accessibility by vehicle	Very difficult	Very difficult	Easy Access
Water availability	Water delivered with difficulty	Water delivered with difficulty	Locally sourced by river
Electricity availability	Available	Available	Not available outside of main village
Crop usage	Personal consumption only	Most for personal consumption, some for profit	Plenty of crops for profit

Accessibility for each village was included as a measure of how easily materials and goods can enter and leave the village. Factors such as terrain and exposure to sunlight were not included in the table. They were not included because any place where crops are able to be grown then it can be assumed the terrain and sunlight are sufficient for the placement of a nursery. Ultimately, there was little to no variation in farmland characteristics with only some variation in village characteristics which include accessibility by vehicle as well as water availability.

What we did find while interviewing farmers, was an association between elevation and accessibility to water for growing crops. Farmers at higher altitudes were limited by the water they could pump up to their villages. Most collected rainwater to supplement the water they used to irrigate their crops or they exclusively used rainwater to water their crops because they did not have enough water to spare between their daily use. Only wheat and maize was grown in these villages as they do not require as much water as vegetables and cash crops. The high elevation farmers were more interested in water collection than obtaining a nursery. They seemed interested in the prospect of a nursery if a water collection system was added, making it self-irrigating. Farmers at lower elevations had little problem with irrigation water but they were prevented from growing crops that require large amounts of water because of monkeys. Monkeys like to pick at and eat soft foods, like fruits and vegetables, so farmers were reduced to growing only hard crops like cereals. These farmers were interested in nurseries as they could grow vegetables without fear of monkeys destroying them.

Piloting and Testing an Improved Nursery Prototype

After taking the results of the prior two objectives into account we modeled the structure of the prototype using CAD software, as shown above in Figure 7.

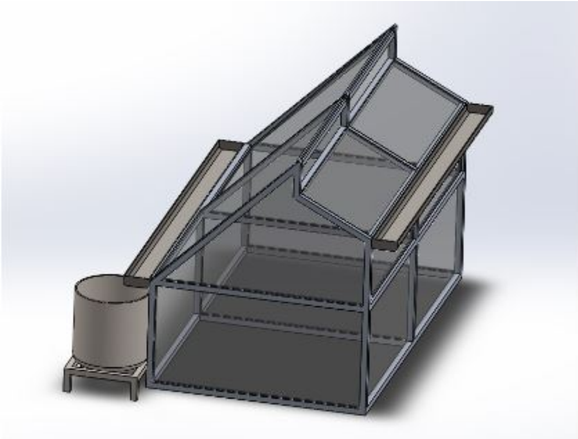

Figure 7: Nursery prototype model using CAD software

This design was based on the research into similar projects, such as Robert Fuller and Alex Zands paper Solar Greenhouse Technology for Food Security, published in 2012 and conducted in Northwest Nepal. We added amenities to address the challenges described by our stakeholders. The key features are highlighted below in Table 5.

Table 5: Key Features

Nursery Feature	Solution
Ventilation	Roof vents, exhaust fans
Heating	Thermal mass, solar insulation
Structure	Standard peak
Irrigation system	Gravity fed drip irrigation
Water collection	Gutters, water storage tank

We built the prototype frame out of aluminum in a standard peak shape. The prototype contains two separate sections divided by twin wall polycarbonate. One section is cladded with twin wall polycarbonate and one with polycarbonate film. Having two differently cladded sections was done to compare their insulating properties with each other.

Discussion

Nurseries have been used very successfully in the region to both expand and diversify crop yield. Farmers who used nurseries were able to grow for both personal use and profit. Some farmers even produced enough so they did not have the need to buy produce from other farms. This success was very encouraging for our study as it validates the hypothesis that nurseries positively impact farmers in Himachal Pradesh. Unfortunately, the farmers who would benefit most from this project were also those who were least likely to install a nursery. We found during our interviews that poorer and less accessible farms grew fewer types of crops and for a shorter season. An improved nursery could potentially solve these issues, but we found several reasons these farmers were not using them. The most important factor was the up-front cost of construction and materials. Most farmers were not aware of the subsidies available to them. Even with government subsidy the money spent building the nursery is not refunded until sometime after the construction has been completed. The second reason was that farmers with no experience in greenhouses were unsure if they would make returns from the investment. The final factor that kept farmers from using a greenhouse-style nursery was that they felt they would not have enough water to supply the needs of the plants. The farmers felt this way because they used government water on tap for daily use but collected rainwater for their crops. Rain water is scarce during certain seasons so some farmers believed that they did not have enough water to grow crops other than wheat and maize.

There are government schemes for nursery subsidies, but these must be applied to separately. Since there are many different subsidies to apply for, this may cause some confusion amongst the farmers about the application process. However, each application is separate, meaning that if one application is rejected there are others that farmers can apply to. The applications can be found on the website listed in Recommendations.

Project Outcomes

To promote and expand farming in Himachal Pradesh, we propose two recommendations that will make the use of improved plant nurseries feasible for interested growers.

First, a nursery designed for conditions found in Himachal Pradesh should be improved with important amenities. Based on the farmers need for more water for crops, gutters and a small water tank should be added to assist in self-sufficiency and water collection. Farmers at higher altitudes primarily use rainwater to water their crops, so a system for harvesting rainwater would assist farmers in obtaining water for their crops. The gutters would run water to the storage tank, which will sit on a small table that folds out of the main structure. A valve connecting the tank to a hose runs into the structure. When the plants need to be watered, turning a valve would open the pipe up into a drip irrigation system. This water collection system would would allow the design to be viable in more locations including those where water is scarce. Additionally, the design would use an aluminum frame, which is light and allows the structure to be moved around easily if need be. Hinges and pins as opposed to fixed corners would be used so the nursery can be folded to help ease the stress of transportation.

We also propose a trial period for farmers who cannot afford to pay out of pocket immediately or for farmers who wish to learn more about how a nursery works before investing. During an interview, Parwata and Disha, two women in Kataula, said that they did not know how to properly use a nursery to justify the purchase. Jogender Singh, a man from Arnehar Village, told us he did not have enough money to afford a nursery. To address these problems we created a table outlining issues expressed by farmers and our proposed solution to their problem which can be seen on the next page in Figure 8.

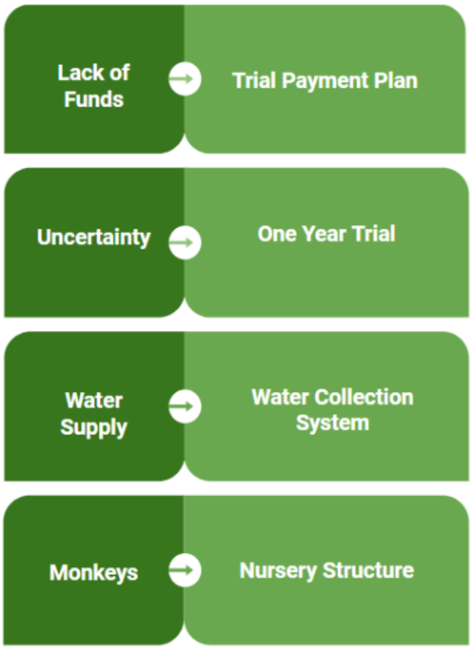

Figure 8: Summary of farmer concerns and ways to address them

Farmers participating in the program would receive a physical nursery on trial for one year. After the year is over, the farmers determine if a nursery is worth the investment. If the farmers decide they want to keep the nursery, they pay off the price as they continue to use it. On the other hand, if farmers decide they do not want to keep the nursery, it would be returned and loaned to another farmer. For larger farms it would also be possible to purchase more nurseries but they would be responsible for covering the upfront cost of additional systems.

This solution addresses the issues faced by the farmers who are not already using nurseries and attempts to overcome them. There will not be an upfront cost for the farmers because it will be covered by a sponsoring organization. This will also cover the issues of the wait time for subsidies. If after the year that a farmer is given to use a nursery they are interested in keeping it, the profits from the increased production provided by the nursery would cover the payments. Since the farmer would be making payments on the subsidy-reduced cost it will not take very long for this project to be paid off. This also helps farmers who are afraid of the commitment to a nursery due to lack of knowledge. This proposal would give farmers a comfortable way to assess if this would be a good fit for their needs.

We recommend that the prototype be put through a year of rigorous testing, during which a wide variety of crops are tested and shown to be viable under most conditions. Throughout this trial year, farmers can visit the prototype model to learn more about how to use the improved nursery.

Conclusion

Farmers in Himachal Pradesh, India, face difficult growing conditions, and in turn deal with lack of crop variation and short growing seasons. This problem manifests in unsustainable local practices and farmers needing to import other produce to supplement their diet. The goal of our improved plant nursery was to assist in off-season plant growth, add variation to crop growth, and support food security in rural regions. This project could introduce a relatively simple technology to address what we have identified to be the primary problems these farmers are facing. It also aims to preserve the local knowledge of farming and food production in a world which is becoming more urbanized.

From our interviews, we have seen that farmers are more accepting of nurseries if there are no upfront costs , and if there are added benefits such as water harvesting and prevention of crop destruction from monkeys. In fact, while the climate presented some difficulties to the farmers, water deprivation and monkeys were a bigger issue than originally thought. Those without nurseries expressed concern about the limited supply of irrigation water and about monkeys stealing any vegetables they might decide to grow. The concept of a portable nursery loan system will allow a noncommittal learning experience with nurseries to Himachal Pradesh.

The full report and Supplemental Materials for this project can be found at: http://www.wpi.edu/E-project-db/E-projectsearch/search using key words from the project title. Outcomes delivered after May 1 will appear on the IITs ISTP page at:http://www. iit-mandi.ac.in/istp/projects.html

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Investigating Smart City Initiatives in Mandi Town, Himachal Pradesh

Abstract

The growing population in Mandi has ladened its surrounding environment and infrastructure. This project identified Smart City features present in Mandi and determined potential future initiatives. We created a map of the local amenities and engaged local residents and officials to highlight areas that would benefit from further development. The field work identified potential for improvement in waste management and collection, parking spaces, road networks, and business centers. We proposed that (1) waste be organized and collected categorically, (2) develop areas and processes of waste management, and (3) a multistory complex to alleviate congestion.

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The Pressures of Urbanization

Urban populations in developing countries are increasing more rapidly, relative to developed nations, due to their dynamic rural-urban migration. Consequently, rural-urban migration outpaces urban job creation and the development of social services (Todaro, 1980). Furthermore, higher population growth is occurring in developing nations due to their limited access to information and contraceptives (Pakhomov, n.d.). To combat the burden placed on cities and the environment from growing populations, demographic changes and urban migration, the UN has introduced Smart City initiatives to enhance the ability of a country to create urban ecosystems that can alleviate these vulnerability stressors while improving the residents quality of life (United Nations, n.d.).

The world's largest democracy, India, is projected to surpass China as the most populous nation by 2030. The growing population coupled with urban migration, stemming from recent economic growth, have resulted in globally reoccurring urban pressures in overcrowded Indian cities (Pakhomov, n.d.). In response to a growing metropolitan population, Indian Prime Minister Modi's administration created India's first national urban planning initiative called the Smart City Mission, with the goal to develop 100 Indian Smart Cities in the coming years. The Indian government has tailored Smart City approaches utilized internationally to focus on the development of four pillars to mitigate the strain of urbanization. These four pillars highlight institutional infrastructure, physical infrastructure, social infrastructure, and economic infrastructure (The Republic of India, n.d.)

Steady growth in population, an increased demand on its infrastructure, and degradation of its environmental surroundings have made Mandi an ideal candidate for Smart City initiatives. Located in the heart of Himachal Pradesh, Mandi is an ancient, agrarian city at the intersection of key tourism and cultural hubs for travelers heading through on north-south journeys (see Figure 1, below).

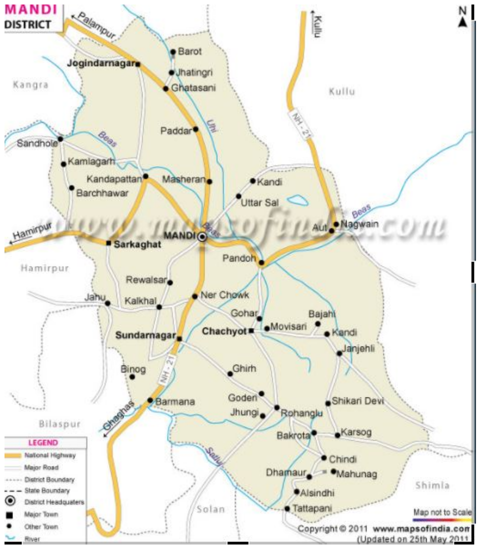

Figure 1: Map of Mandi District (District of Mandi Map, 2015)

Serving as the district headquarters, Mandi is the base for rural-urban interaction within the district as farmers and residents from surrounding villages congregate. In 2011, the population of Mandi town exceeded 26,000 (Ministry of Home Affairs Mandi, 2011). The addition of the Indian Institute of Technology outside of the city is expected to bring thousands of new students, faculty, and jobs to the region. These factors have culminated into a crowded, bustling city depicted below in Figure 2.

Figure 2: Mandi Town (Top view of Mandi Town, Himachal Pradesh, 2007)

The goal of this project was to identify Smart City features present within Mandi and determine potential Smart City initiatives to improve quality of life within the city. To accomplish this goal, we completed three objectives. First, we assessed the current state of Mandi by identifying and mapping its amenities and services. Next, we engaged with local stakeholders, an important aspect of the Smart City Mission, to gain their insight on Mandi's current state and their future aspirations. Finally, our team piloted a Smart City recommendation for a sector of Mandi. Initiatives to help Mandi become a Smart City may promote its future sustainability, development, and community growth in the coming years

India's Solution

Three Models

The Smart City Mission is a two-stage competition between 100 Indian cities. Started in 2015, the initiative led by the Indian government aims to be completed by 2020 and could potentially be renewed after its culmination. To create a more sustainable urban environment, the cities' proposals must utilize one of three models that provide smart solutions to proportionately improve four aspects of a city, which are described as 4 pillars of smart cities: social, institutional, economic, and physical infrastructure. Smart solutions would address each pillar by resolving issues such as providing adequate water and energy supply, public transportation, education, citizen participation, and e-Governance (What is Smart City, n.d.). Table 1 below summarizes the three different methods of implementing smart solutions according to the Indian government: retrofitting, redevelopment, and greenfield development.

Table 1: Methods for Smart City Initiative Development ("Strategy", n.d.)

Retrofitting	Redevelopment	Greenfield Development
- "City Improvement" - Implements services and smart applications to build upon existing infrastructure	- "City Renewal" - Completely replaces existing infrastructure with new/enhanced infrastructure	- "City Expansion" - Develops new infrastructure in vacant areas of cities

The Four Pillars

The four pillars chosen to be highlighted by the Smart City Mission are summarized in Table 2 below. Each pillar can be assessed by the 5 stages of development using a rubric. The stages are nonexistent, unstable, unreliable, high-quality, and fail-proof (Kumar, 2012, p.214).

The four pillars of Smart City development are interwoven to form a complex web. From an economic development perspective, social infrastructure can be defined as the resources used to "improve the efficiency and skills of manpower" (Kumari & Sharma, 2017, para. 1). However, even though these methods the community would improve their quality of life and increase their social capital, while building up their economy. For governmental institutions or institutional infrastructure to be most effective, they require the trust of the community. Trust in institutions is strengthened by the social capital and infrastructure provided to communities by those very institutions. Effectual governments are then able to allocate resources and proper regulations to develop economic infrastructure.

Table 2: The 4 Smart City Pillars

Social Infrastructure	- Builds a sense of community within the city - Unites societal groups that don't usually interact - Requires transparency between government and its people - If underdeveloped it isolates certain minority groups
Institutional Infrastructure	- Initiatives and services of regulatory organizations in a city - Provides political, financial and environmental administration/stability - Stresses corporate responsibility - These institutions must equally represent all stakeholders in the city
Economic Infrastructure	- Networks and facilities that make varying business activities possible - Reduces expenses and improves production in the city - Utilizes capital goods to produce consumer goods - Could persuade large businesses to seek settlement in cities
Physical Infrastructure	- Services and systems that are necessary to maintain a city - Focuses more on physical resources in the 3 other pillars - The foundation and base that other pillars build upon

Methodology

The goal of this project is to identify the Smart City features already present within Mandi and determine possible future actions to increase Smart City Initiatives within the city. We completed the three objectives in Table 3 below to accomplish this goal.

Table 3: Methodology

Objective	Tasks
Assessed the current state of the city by identifying and mapping its amenities and services.	-GIS Mapping of Mandi's Amenities
Engaged with local stakeholders to gain their insight on Mandi's current state and its future aspirations as a Smart City.	-Survey Mandi Residents
	-Interview Government Officials
Develop a pilot Smart City recommendation for a sector of Mandi.	-SWOT Analysis Assessment
	-Comparative Case Study

Assess Physical Amenities

Our team created a GIS map of various amenities and services within Mandi to accomplish this objective. An amenity was defined as any shop, restaurant, service, school, and so forth, located inside of the city. The map of the amenities and services available in Mandi Town was created using ArcGIS software.

To create this map, team members walked around Mandi with a GPS unit and a camera. Our team focused on a small sector of the city along NH 21 and the Indira Market Square. At each location the amenitys: name, category, GPS coordinates, address, phone number, and photo were collected. To streamline the data collection process, the phone app, CAMCARD, was utilized. This app scans business cards and was used to collect and store basic information for the amenity or service. The area of focus for the map are sections of Ward: 1, 3, 6, and 9 circled in the map below (see Figure 3).

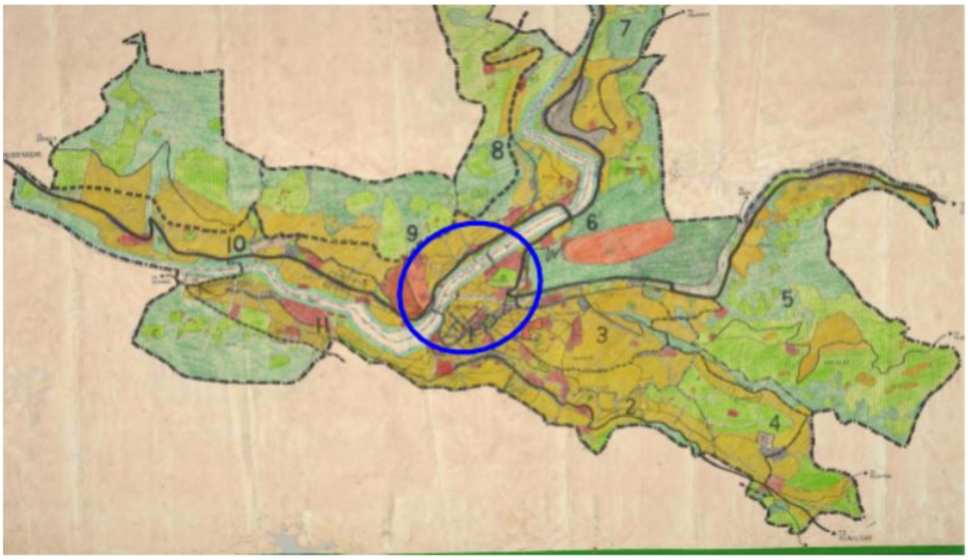

Figure 3: Map of Mandi Town

The collected data was then uploaded into a Microsoft Excel spreadsheet. This spreadsheet was used to compile and organize all the data our team collected which was then uploaded into the GIS software. The software was used to display the coordinates of the various amenities and also display all of the shops contact information when users interact with it.

Collect Stakeholder Insights

Survey Residents

We gained quantitative and qualitative observations from 170 residents by having them complete surveys regarding the current state of Mandi's amenities and infrastructure and their future aspirations for the city. The survey, in both English and Hindi, that we used to engage the residents is in Appendix B and C. We surveyed the residents of Mandi focusing on the same section of NH 21 and the Indira Market Square as our first objective. We collected our data utilizing a sample of convenience. To avoid communication issues the IIT team members took a more active role with surveying the residents since they were able to communicate to the locals in Hindi. If an IIT team member was not available to survey on any given day, the teams TA accompanied the WPI teammates in the city to aid with communicating. Figure 4 below depicts two of our team members: Mayuresh Gupta and Yasmeen Logan interacting with the business owner of Komals World in Mandi Town.

Figure 4: Interviewing Mandi Business Owners

Interview Officials

The group of individuals most privy and knowledgeable of Mandis current state and future aspirations are its city officials. With the help of our well-connected sponsors, Professors Shukla and Sharma, we secured meetings with some of local officials in Mandi. The officials our team met with included Mr. Lavan Thakur and Dr. I.D. Sharma. We conducted semi-structured, formal interviews, altering questions to focus on the expertise of the interviewees. These interviews were conducted in English or Hindi depending on the preference of the official. With the consent of the interviewee we recorded the entirety of the interview then transcribed and translate the interview. Interview guides can be found in Appendix D.

Develop Smart Recommendation

Smart City initiatives can help Mandi in its future growth and development in the coming years. To improve the current infrastructure within Mandi, our team developed a pilot Smart City recommendation that addressed a weakness discovered during our first two objectives. Our team utilized a comparative case study used on a similar urban problem in another city to tailor a solution. First, we completed SWOT Analysis to identify the city's strengths, weaknesses, opportunities, and threats. The SWOT analysis utilized the data collected during our first two objectives. We compared the current physical amenities of Mandi to the responses on Mandi's current condition and future aspirations from residents. This allowed us to see where there was disparity between the two sets of data and identify the disparities as weaknesses for the city. The SWOT Analysis can be found in Appendix E. Second, after completing our SWOT analysis our team utilized a comparative case study to choose one of these weaknesses or opportunities and performed more research on how to improve that aspect of the city. The comparative case study required our team to research similar problem and solution in another city, preferably in India. From this research, we developed a similar solution for Mandi based on the other citys solution. By analyzing how other areas addressed these problems we were able to tailor a solution more relevant to Mandi.

Results

To meet our first objective, we collected information for 641 shops and amenities along NH 21 and inside the Indira Market. These amenities include over 25 banks and ATMs, 31 medical shops, and 85 restaurants spread across the focus areas. A majority of these stores were centrally located in and around Mandi Town's Indira Market. These amenities are categorized into 21 major sectors (listed in the legend of Figure 6 below) so that users can easily sort and locate amenities they are interested in. They were also categorized by the type of smart city infrastructure. For example, the banks and ATMs fall under Economic Infrastructure.

The information for this set of amenities was uploaded into an Excel workbook and then exported into the ArcGIS software which can be used to display contact information for the amenities. Filtered searches for each pillar of infrastructure are displayed in Figure 5 below.

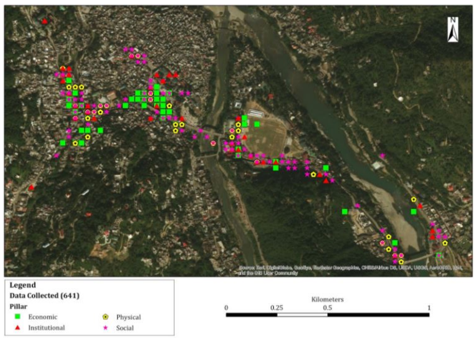

Figure 5: GIS Map of Mandi Town Smart City Pillars

Our second objective focused on engaging local stakeholders to gain their insights on the state of the infrastructure in Mandi. We surveyed 170 residents near Indira Market and the adjacent regions of NH 21 mapped in our first objective. We retroactively stratified a sample of convenience to gather data to represent the demographics more proportionally. Table A1 in Appendix A displays the age ranges and genders of the stakeholders which completed our survey.

Our survey contained 4 parts, each corresponding to the four pillars of Indian Smart City Infrastructure. Each quantitative question required the respondent to rank the condition of certain aspects of each pillar from 1-5 (with 1 being the lowest rating and 5 being the highest rating). We calculated the mean rating of each pillar, displayed in Figure 6 below. More detailed graphs on averages by demographics and for individual questions can be found in our index of Supplementary Materials. More detailed graphs on rankings by different demographics and means for individual questions are in the Appendix A.

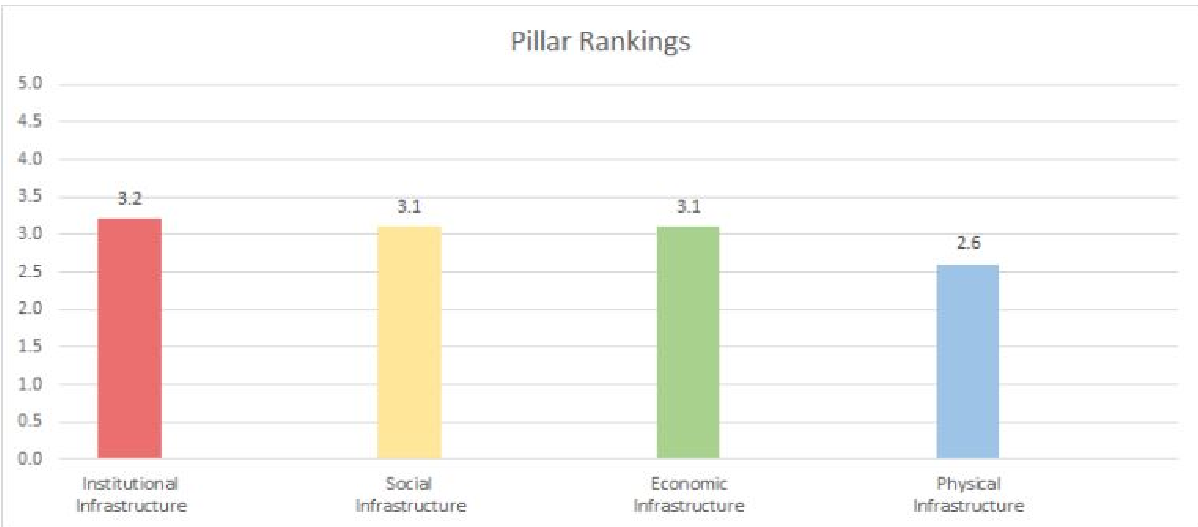

Figure 6: Relative Conditions of the Smart City pillars According to Residents

From our team's observations, we developed a list of strengths, weaknesses, opportunities, and threats to assess needs and opportunities for Mandi's smart future development. These four categories are represented in the SWOT analysis below in Table 4.

Table 4: Mandi Smart City SWOT Analysis

Strengths	Weaknesses
- Medical stores - Mandi temples - Safety and security - Local shops	- Parks & green spaces - Narrow roads - Parking centers
Opportunities	**Threats**
- Surrounding greenspace - Business centers - IIT Mandi development - India Smart City Mission	- Congestion in Mandi - Future population growth - Waste management - Other major Himachal cities

Discussion

Creating the Arc GIS Map of Mandi and engaging with the residents through surveys and interviews enabled our team to identify areas Smart City Initiatives would be valuable in Mandi Town. The ArcGIS Map provided our team an assessment of the current amenities and services in offered within Mandi Town. Meanwhile, our interactions with residents allowed us to understand the residents perception of their city and potential improvements they would like to see implemented.

The Final Arc GIS Map (previously displayed in Figure 5) presents the current amenities of the featured sector of Mandi Town. From this map a couple of conclusions about the current state of Mandi can be determined. The map itself can also be sorted sorted by the 4 main pillars of the Indian Smart City mission. This allowed our team to focus on one key observation for each of the smart city pillars.

In terms of the social infrastructure in Mandi, there appears to be a lack of sit down restaurants and greenspaces for its citizens to enjoy. Our map displays the locations for 85 different amenities under the category of eateries. However, over 90% of these dining amenities are smaller juice bars, tea stalls or dhabas. There are only a few sit down restaurants where a group of friends or family can sit down together and enjoy a full meal in our highlighted section of the city. Some of these sit down restaurants include: The House of Ming, Copacabana Bar & Restaurant, the Regent Palms Hotel, and Domino's. Also we located only two green spaces in the mapped sections of the city. These were the Indra Market Square and Paddal stadium. Both restaurants and greenspaces allow citizens of a city to interact and build strong social connections. To achieve a more successful level of social infrastructure within the city the number of restaurants and green spaces could be increased within Mandi.

With regard to the Institutional Infrastructure in Mandi we found that there are many medical stores and pharmacies, but an overall lack of Hospitals and clinics to treat citizens. Both of these types of amenities are categorized as medical in the ArcGIS map. In total there are 31 total amenities categorized under this category, with medical stores and pharmacies totaling 29 stores and only two hospitals and clinics. The 29 medical stores and pharmacies are spread relatively equally across the city of Mandi. These medical stores allow citizens to pick up prescriptions, medication, and other medical supplies. However, there are only two hospitals in the sector of Mandi which we surveyed. These were the main Zonal Hospital and the smaller Sri Harihar Hospital. These two hospitals are typically overcrowded and the addition of another medical center could help alleviate some of this pressure from Mandi's citizens.

The Economic Infrastructure assessment showed a lack of business centers inside of Mandi Town. Many of the amenities that were listed as shops inside of the city were small shops that sold goods such as clothing or food items such as snacks in a general store. There were very few larger industries present within the city. Large industries within cities are very important since they help boost the economy, which in turn aids in future development of the city. A larger business center district inside of Mandi could aid in developing Mandi Town's economy and aid in future development.

Finally, the assessment for Physical Infrastructure indicated a lack of parking space inside the city and an overall congestion of Mandi's amenities and services. While mapping the city our team found that there are 5 parking centers in our sector of Mandi. All of these parking centers were not very large and could only accommodate a relatively small number of vehicles. From walking in Mandi Town it is apparent there are many more people driving through the city than the parking spaces available to them. This lack of parking makes it almost impossible for residents who live far away from central places such as the Indira Market to drive there on their own to enjoy one of the citys few greenspaces. More and larger parking centers within Mandi could help transportation within Mandi.

One challenge our team faced while creating the map stemmed from the congestion of amenities and services in Mandi town. While it was easy for our team to walk from shop to shop, record GPS coordinates, and talk to business owners to get contact information for their shop, in many cases these shops were located so close to one another that it made plotting the location of the shops very difficult. Our team used GPS coordinates from the Compass app on our smartphones to track coordinates. The close proximity of amenities paired with the inaccuracy of the smartphone GPS app caused many shops to be mapped onto the same coordinates. This caused the map to overlap in some sectors. However, once our team received a more accurate GPS unit, the accuracy of the coordinate mapping was improved.

From the point of view of the residents, there were supporting responses. Table 5 below expresses the inferences concluded from our surveys and interviews.

Table 5: Comments from interviews and surveys

SOCIAL INFRASTRUCTURE	• Social infrastructure is adequate, but underdeveloped • Religious temples were ranked as the most developed aspect of the city • Religion is the cultural identity and binding factor between diverse social groups • Younger groups ranked the pillar relatively higher even though it lacks sources of entertainment, means of communication, and greenspaces • Social capital may be tailored to be more accessible for younger generations
PHYSICAL INFRASTRUCTURE	• This infrastructure requires the most development • Various rivers, riverlets, and streams provide access to water and are potential sources of energy creation • Geographic features of the region limit available land for development resulting in narrow, single laned roads • Poor road networks lead to traffic congestion and magnifies the lack of pedestrian walkways and vehicle free roads • Congestion impedes waste collection as residential areas are harder to traverse
INSTITUTIONAL INFRASTRUCTURE	• Government institutions work methodically but complete their tasks. • Sufficient source of electrical infrastructure reduces instances of power outages. Ample police presence provides the safety and security of the residents. • Judicial and intentional utilization and redevelopment of private and public property to build efficient infrastructure. • Lacks an outlined area and facility to treat waste resulting in practices that are not sustainable or environmentally friendly.
ECONOMIC INFRASTRUCTURE	• The strength of the economy is the opportunities for local stores, promoting entrepreneurship. • Local shops are inclined to sell or provide a similar array of goods and services, limiting the diversification of industries present.

A proportionate split between genders ensured sentiments representative of the population. However, surveying the vicinity around Indira Market presented a sample concentrated with younger respondents, skewing the data. Overall, residents ranked the services and amenities within the city's pillars as adequate, suggesting it is functional but could use development or improvement. The insights from the interviews and surveys expressed two courses of action, expanding to undeveloped areas (Greenfield development) or improving the existing structures (retrofitting).

Overall, our sense of the data is that we realize Mandi does have potential to increase smart city initiatives within the city. The experience of the town blends old with new, youth with an aging population, and the potential for many newcomers to settle here. Mandi already has strong infrastructure in temples, local shops, and their citizens safety and security. However, the city has very weak infrastructure in waste management, waste collection, parking, and congestion. To improve smart city initiatives within Mandi the gap between the quality of its good and bad infrastructure must be narrowed.

Deliverables

ArcGIS Map of amenities

The first main deliverable our team completed for this project is an interactive GIS map of Mandi Town's amenities. This map allows users to filter all of the amenities by major category and find basic contact information. The full map is displayed in Figure 7 below:

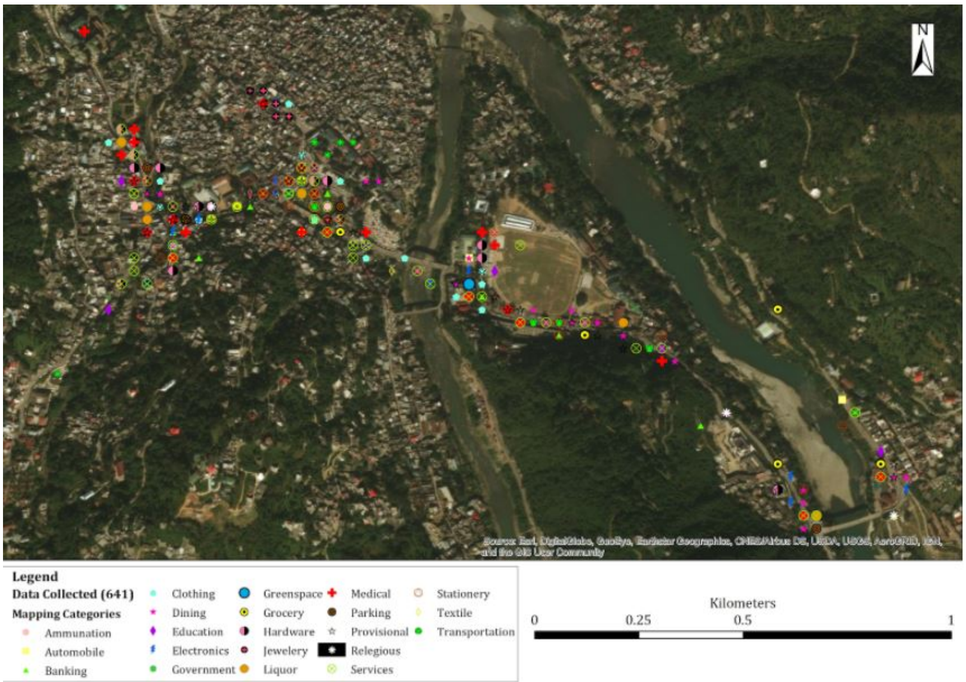

Figure 7: Complete Amenity Map of Mandi Town

Smart City Initiative

There are many ways in which Mandi could move forward towards Smart City status. However, after our 7 weeks of research onsite, we have developed three fundamental recommendations for the city of Mandi organized by increasing levels of complexity. These recommendations may help alleviate some of the city-wide weaknesses found while conducting our research, and concern the most basic amenities of waste collection, waste management, parking, and congestion.

Short Term

1. Improve the methods for the collection of waste from Mandi residents. The waste collection in Mandi was rated as a 2.5/5 from their citizens. Currently, all of the waste from home residents in Mandi is collected all together into one garbage truck all mixed together. However a growing trend across cities and even on the IIT Mandi campus is separating waste into three categories: recyclables, biodegradables, and other solid waste. Cities often color code personal garbage bins for residents while also color coding public waste bins across the city. Obviously, having color coded trash bins for Mandi residents is not feasible with the limited sidewalk space and street narrowness in the residential districts of Mandi. However a more feasible solution for Mandi would be to first educate their residents on how to properly dispose of waste so that pick up will be more efficient. Also a new city wide system where the three different types of waste are collected in colored coded trucks would likewise increase efficiency in waste collection.

2. Improve overall waste management across the city. Mandi residents rated waste management in Mandi town as a 2.3/5. Currently, after waste is collected in Mandi it is transported to Pandoh 14 km away from Mandi. There it is dumped into a valley to be left out in the open. This is very unhealthy for the environment, and ultimately the waste management for the growing city can be improved to stop these poor practices. We recommend that the city develop a plan to build a waste management plant outside of Mandi for all waste collected in the city. This would first cut down on the trash dumped within the city and also the trash dumped into the nearby Pandoh Valley.

Long Term

3. Improve the quality of three of the lowest ranking amenities in the city: parking, road congestion, and business centers. Pushing the community towards significant growth may mean modernizing aspects of how welcoming the city is to visitor traffic. Complying with the sentiment of local stakeholders calling for the effective use of land, our sponsors, Dr. Derricks Shukla and Dr. Rajneesh Sharma, have designed a 10-story complex. This complex will be built between Victoria Bridge and Bhulli Bridge over the Beas River. On one wing, the structure will contain a multistory parking lot, office buildings, and spaces for stores and the other wing would house a new hospital. This design would add parking and business spaces, while its location on the outside of town would relocate the traffic and congestion found in the town center.

Conclusion

The heavy burden placed on Mandi due to its growing population and regional cultural appeal prompted it to be the ideal beneficiary of Smart City initiatives. The data collected was modeled around the four pillars of the government-led Smart City Mission. After identifying key areas for development, by comparing the map of local amenities to the insights of residents, we can see that the city has tremendous potential to invest in Smart City projects. With improvements coming to nearby highways and with the development of IIT Mandi, the city is poised to be an important hub hosting young people, ancient traditions, and visitors passing through. We hope that our recommendations provide a solid base for re-visioning the city provide a solid baseline for the future development of Mandi into becoming a leading city in Himachal Pradesh.

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- The residents and business owners who were insightful, cooperative, and hospitable during our surveying and mapping of Mandi

The full report and Supplemental Materials for this project can be found at: http://www.wpi.edu/E-project-db/E-projectsearch/search using key words from the project title.

Outcomes delivered after May 1 will appear on the IIT's ISTP page at: http://www.iitmandi.ac.in/istp/projects.html

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Designing a Water Filter to Remove Iron and Biological Contamination in Mandi District

Abstract

Water quality reports over multiple years in Mandi District have revealed high levels of iron contamination in many villages that may put residents at risk of negative long-term health effects. Our goal was to create a filtration technology to address the drinking water needs of residents living within Mandi District. To realize this goal we assessed drinking water perceptions, behaviors, and water quality in areas of Himachal Pradesh with known concerns regarding water contamination. With knowledge of which contaminants exist in the drinking water of villages in the Sundernagar area, we designed a filtration device to remove iron and biological contamination. We have created a filter prototype that can be further tested, refined, and potentially implemented in affected communities.

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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, borewells and tubewells. 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.

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 ones 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 byproduct 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 thus 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 Chemical and Heavy Metal 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 1, along with their acceptable limits in milligrams per liter.

Substance	Accepted Limit (mg/L)
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

Table 1: Common Metals and Chemicals Found in Water Supplies (Kumar & Puri, 2012).

When levels of any of these substances are above these limits and that water is consumed by any person, it can have very negative effects on their health. 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 (GHC, 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 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 that 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. Some examples of common filtration materials can be seen in the Figures 1, 2, and 3.

Activated Charcoal Filters

Applying extreme heat and reducing oxygen levels to charcoal results in highly-dense activated charcoal. This media is porous resulting in an increased surface area and increased absorption capacity. These characteristics give activated charcoal 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 1: Activated Charcoal Powder

Activated charcoal 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 usually ranges 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.

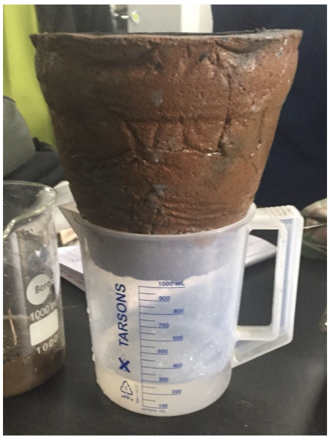

Figure 2: Ceramic Filter

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 3: 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 worlds 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:

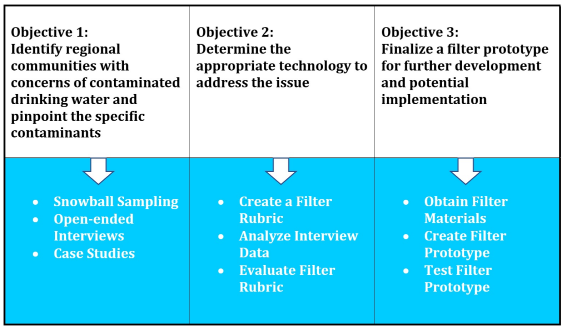

Figure 4: Outline of Objectives and Steps

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 that 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 chemical 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 5.

Figure 5: 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.

Results and Discussion

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 6, appears to be highly contaminated with dirt, salt, and iron, given the orange coloring.

Figure 6: 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 2).

Village Name	Source Type	Test Date	Conc. of Iron (mg/L)
Bharari	Tubewell	Feb. 2018	0.330
Chambi	Tubewell	Apr. 2017	2.400
Kaned	Tubewell	Mar. 2018	0.820
Ghangal	Tubewell	Mar. 2018	0.420
Ghangal	Tubewell	Mar. 2018	0.730
Mahadev	Tubewell	Jun. 2017	0.680
Mahadev	Tubewell	Apr. 2017	0.730
Khatarwar	Tubewell	Mar. 2018	2.030

Table 2: Villages in Sundernagar with high iron content in water supply (MDWS, 2018).

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). Officials from the Himachal Pradesh IPH department also provided us with six water sample evaluations, which can be found in Appendix D. All of 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 an overall 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 as follows:

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 Navlaya 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 to understanding. We interviewed two older men in Navlaya 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 Figures 7-9. 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 in Figure 7. Individuals in Mandi were also seen using the water directly from the tap to bathe and wash dishes and clothing.

Figure 7: Government Water Taps in Mandi Town

Figure 8: Government Well in Bhadyal Village

Figure 9: Government Hand Pump in Navlaya Village

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 2100 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 3, 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 amount of potential contaminants. Notably, many residents boil their water during rainy seasons to remove possible bacterial contamination.

Table 3: Current Small Scale Methods of Water 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 4, all of these contaminants have different origins, but all have negative health impacts on humans when consumed.

Table 4: Effects, Origin, and Removal of Iron and Biological Contamination

Contaminant	Health Effects	Origin of Substance	Methods for Removal
Iron	• Hemorrhagic necrosis • Causes sloughing of areas of mucus in the stomach (WHO, 1996).	• Naturally occurring • Construction material • Leaches into water via iron pipes (WHO, 1996).	• Ion exchange • Zeolites (Lenntech, n.d.[b]).
Micro-biological	• Diarrhea • Nausea • Vomiting (WHO, n.d.[b]).	• Fecal contamination • E. Coli (WHO, n.d.[b]).	• Slow sand filtration • Boiling water • Reverse osmosis • UV radiation • Ceramic filtration • Activated charcoal (limited potential) (WHO, n.d.[b]).

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 must take cost into account when 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 (Figures 10 and 11). This design removes iron, turbidity, and bacteria from contaminated water samples, which were the main contaminants of concern. Our filter design 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 could retrieve water from their desired source and pour the water into the top bucket. Water would then be 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.

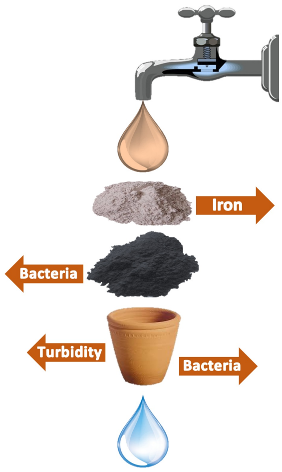

Figure 10: Prototype Components

Figure 11: Built 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. All of 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.

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 5 illustrates the general needs expressed by residents, as well as if and how our filter meets that need.

Table 5: 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 charcoal, 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 rate 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 would provide 6 liters of filtered water the next morning, which could sustain multiple peoples' drinking water needs for the day. Activated charcoal and zeolites, which we obtained in powdered form, are able to remove iron and other chemical contaminants. Further testing of the prototype for percent of iron removal will be necessary to prove the effectiveness and functionality of the filter. These trials will be performed and recorded in the final submission of this project to Worcester Polytechnic Institute. A link to this submission is noted after the conclusion of this report.

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. As a case in point, 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 very prone to pollute waterways, and have brought havoc to 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.

Conclusion and Recommendations

Outcomes and Recommendations

While limited in time and budget, we have laid the groundwork for streamlining our prototype. Given the size of the sawdust we obtained and the available equipment, we were only able to achieve a 425-micron pore size in the ceramic base. Ideally, the pore size needs to be 0.2-3.0 microns to allow for removal of viruses and protozoa. Additionally, the clay to create the ceramic base was provided to our group in blocks, which needed to be broken down before being sieved. In the future, locating clay for the filter that is ready-made will save about two hours of manual labor. Sawdust, the burn-off material in the ceramic, was also provided in a raw form, but locating a finer version of the material or other finite particles would save time and decrease pore size.

Similarly, the process to form the ceramic base of our prototype demanded hours of lab time for each mold and led to imperfect shapes. We had a few of the ceramic pieces break in the kiln so we had to reform the ceramic several times. Creating a mold where the components can be added and simply pressed into the filter shape would save time and likely prevent cracking. A mold for the filter could also allow for larger-scale production of the water filter prototype. If a mold was built then replication of the filter would be feasible.

Moreover, through our research and fieldwork, we are now aware of the lack of data available on water quality in many areas of Himachal Pradesh. The IPH Department and other organizations have not tested all local water sources, especially small rivers in very rural areas where people may retrieve water. We recommend that organizations, like the IPH Department, increase their efforts to test water quality. As industry expands in this area, the strain on water sources will only increase. It is important that organizations make an effort to test and monitor the water quality throughout villages in Himachal Pradesh. If this is not done, changes in water quality may go unnoticed in the following years. We recommend that a systematic way to test the water sources is put into place, such as tri-monthly water testing of natural and government sources to ensure the safety of water provided to these villages.

We also recommend that organizations including the IPH Department and NGOs, like the one we worked with, continue to collaborate on the issue of drinking water contamination. These groups are comprised of passionate people who want to improve the lives of residents in Himachal Pradesh. Often education is the best method to create awareness and begin inspiring change. From our fieldwork, we know that individuals are overall curious and, to some degree, have had concerns surrounding their drinking water. The sooner people become aware of the potential dangers in their drinking water, the sooner they will be willing to take necessary measures to prevent risks. We think that education and public awareness on water quality would be a catalyst for all residents to desire a water filtration device.

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

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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 time to participate in the study and answer our questions.

The full report and Supplemental Materials for this project can be found at:

http://www.wpi.edu/E-project-db/E-projectsearch/search using key words from the project title.

Outcomes delivered after May 1st will appear on the IITs ISTP page at:

http://www.iitmandi.ac.in/istp/projects.html

All Appendices can be found at the end of the report found in the first link above.

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Onsite Treatment of Organic Waste

Abstract

The goal of our project is onsite treatment of waste water and solid waste on household level. To achieve this goal we interviewed and surveyed 2 village mukhiyas and residents of 2 gram panchayats (Navlay and Katindi) of Himachal Pradesh, regarding current treatment methods and practices. We determined lack of awareness among the residents and panchayat members regarding waste disposal and water treatment methods. To assist this we set up an onsite treatment method at the household level. We developed a prototype of a Biogas plant (on a small scale to cater to needs of individual households) and a Bio Filter (which aims to treat waste household water).

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Introduction

India is one of the largest producer of solid waste in world and stands among the top 10 countries generating municipal solid waste. Annually, India produces 1.2 billion tons of solid waste, which is projected to increase to 2.6 billion tons in the near future. Boom in urbanization, increasing population, high consumption lifestyle are a few major contributors for increasing solid waste. MoEF (Ministry of Environment and Forest) has passed MSW (Municipal Solid Waste) Rules 2000 for better solid waste management in Indian municipalities. There is immediate need for disposal and treatment on smaller scale, on household or community level. Our prototype treats solid organic waste on a smaller scale.

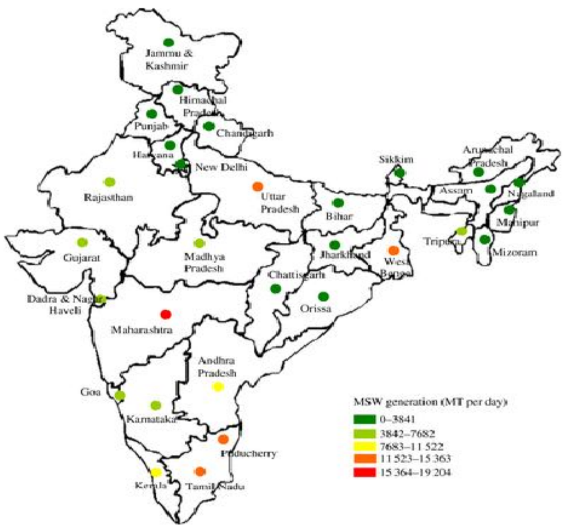


Figure 1: Waste generated in different states in India

Growth of mega-cities due to globalization of economy has led to generation of waste. In Himachal Pradesh, nearly 304 MT of Solid waste is generated daily of which 51 MT is generated from the capital Shimla (Himachal Pradesh, Waste Management by Saptrashi Dutta,2017) Waste management is unable to cope with the amount of solid waste generated. The diagram above is of solid waste generated in various states in India on a daily basis, and shows that Southern states take the lead.

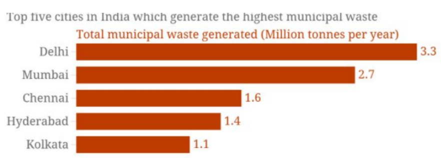


Figure 2: Top 5 Cities

What people are currently doing in Himachal?

In our survey, we covered 16 people in Navlay, Katindi, and Mandi town.

Residents of villages Himachal often burn the solid waste generated in households in open air which results in toxic fumes in air as the waste contains plastic waste and others waste. Even in towns people dont segregate the waste at household level and dump into a single bin. In Mandi town, solid waste is collected by municipality on daily basis. Often municipalities collect the waste from Households in Himachal and dump at dumping sites. The transportation often results in leakage waste on the road leading to discomfort of pedestrians and motorcyclists. The waste is dumped on roads and in to rivers alongside. More than 70% of waste is biodegradable and recyclable. Per capita of waste generated in 2011 is 0.413 (kg/day) in Himachal (Central Pollution Control Board, 2012).

In case of waste water, in Mandi the waste water in households goes in to canals alongside roads and is discharged into river. The untreated water pollutes the river. In Navlay village the water is discharged in to rivers or else pits are made for water to seep into. The water from households can be reused rather than being released into rivers, thus polluting them. In few villages of higher altitude which face scarcity of water, the reusable water can be reused for other daily activities. People arent aware of consequences of the future water shortage and stubborn to change. Rather than discharging the water into rivers and burning the waste or landfilling the waste, better ways of treatment can be done. Organic waste which constitutes more than 50% of waste in Himachal can be treated at household level. Waste water which can reusable can be reused as in few of the areas where there is scarcity of water can be reused. To asses this issues we came up with Biogas plant on smaller scale which produce Methane from organic waste. This biogas plant is integrated with the Bio filter which filterers the waste water from Households which can be used gardening and other similar uses.

Figure 3: Water being discharged into river in Mandi Town

Methodology

The aim of our project was to provide methods to treat organic solid and liquid waste at site and also research the existing methods of waste treatment and their limitations regarding onsite disposal. To complete our aim we:

1. Explored the advantages and disadvantages of various methods.
2. Selected few methods.
3. Completed field visits.
4. Finalized 2 prototypes for treating both liquid and solid waste.

Methods of onsite treatment

There are various methods by which we can treat waste at our home without transporting it to treatment sites. We studied various methods and their pros and cons according to the availability of resources and their working in the areas that we are considering (rural). Some of the methods that we read are landfilling, recycling, incineration, soak pits, bio filter, and biogas plant.

Landfilling

It is the term used to describe the process by which waste is placed in the landfill. Landfill need not be an engineered site when the waste is mostly inert at final disposal. **In rural area**s waste contain large proportion of soil and dirt. The practice of disposal of such waste is called as **non-engineered disposal method**. This can be done at individual household level but we did not consider it in our project because it require **large space** and also there are threats of various **diseases** due to open disposal and growth of **microorganisms**. In villages, large space at individual level is not readily available but this method can be useful at community level. The purpose of landfilling is to **bury** the waste to alter the chemical composition of the waste. Capacity and design life of a new landfill depend on size, topography of site, rate of waste generation.

(a) Land Filling (b) Recycling

Figure 4: Methods of treatment of waste

Recycling

In this waste materials are treated in a way that they can be used again. It is a key component of modern waste management and it is the third component of 3 Rs i.e. Reduce, Reuse, And Recycle. Recyclable materials include many kinds of glass, paper, metal, plastics, electronics, etc. Although organic wastes cannot be recycled but this can be a solution of onsite disposal of waste. But this method is not useful in rural area as it requires a collection process which is not possible in villages they have to go to some shops. But it is very common in cities people sell their stuffs for money and then they are recycled by the buyer at large scales.

INCINERATION

It involves the combustion of organic substances contained in waste materials. Incineration of waste materials converts the waste into **ash, flue gas** and heat. The ash is mostly formed by the **inorganic** constituents of the waste, and may take the form of solid lumps. Heat generated during this process can be used to generate electric power. After the burning process the left out product can be used as aggregate for low grade concrete, also used as road metal. Ash is used for making bricks or block manufacturing. In Indian cities, incineration is not very much practiced. The first large-scale MSW incineration plant was constructed at Timarpur, New Delhi, in 1987. We are not adopting this method for our project because it will not be economical at household level also it require knowledge and other reasons are not all waste can be burned, release hundreds of toxic chemicals

SOAK PITS

Also known as a soak away or leach pit, is a covered, porous-walled chamber that allows water

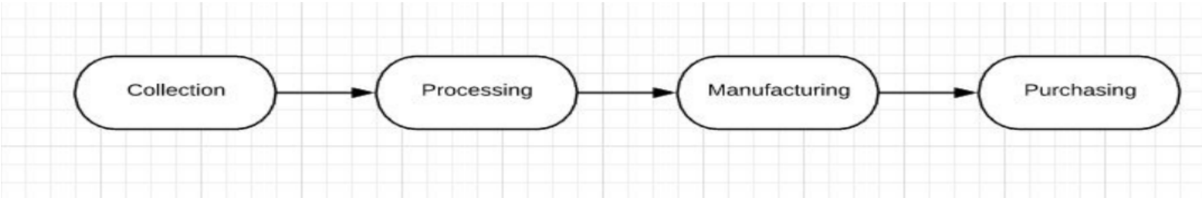


Figure 5: Flow chart of recycling

to slowly soak into the ground. Pre-settled effluent from a collection is discharged to the underground chamber from which it infiltrates into the surrounding soil. Is should be between 1.5 and 4m deep, but never less than 2m above the groundwater table. It should be kept away from heavy traffic area so that soil above it is not much compacted.

Figure 6: Soak pit in Katindi

It can be built and repaired with locally available materials, small land area is required and it is very economic. But it has some advantages also like it requires primary treatment to prevent clogging. Himachal government launched a scheme according to which in rural areas every house will be funded by the government for constructing its own soak pit.

Finalized solution on which we have worked

Bio Filter

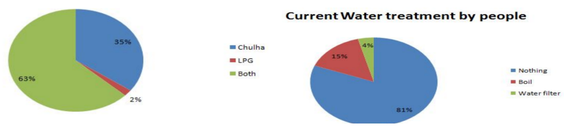
This is the method by which we can treat our waste bathroom water and make it clean up to a level that it can be reused for cattle feeding after adding some disinfectants. The treated water can also be used for gardening purpose. We have made a prototype of this. It is a layer wise separation of waste water. It can be used in rural as well as urban areas. Its more detail is given in the later section of this report.

Bio gas plant

This method is adopted for treatment of solid organic waste, this method is an old method but usually it is made on large scale but it can be built on household level. The details of this are mentioned in the later section of report.

Field work

Peoples opinions that we gathered during our field work changed our methodology several times. We got to know about several government schemes, current treatment process that they are following. We have conducted 3 field trips i.e. Navlay, Mandi, and Katindi. In Navlay people dont have water scarcity as a problem and hence they are unaware of the consequences. They have natural sources of water, for backup they have a large reservoir from which water is circulated to houses. There is a scheme named Teel Tukara according to which water is circulated from Parashar Lake to Navlay. They discharge their waste water directly into the fields and river. Also they collect all their solid waste (including plastics) for manure. Sometimes they burn plastic also as they are unaware of organic and inorganic wastes. They are interested in idea of biogas plant as conversion of their waste into gas and manure is beneficial to them. They also following vermicomposting technique for manure formation. In Katindi village, we met with the Pradhan, Mr. Manohar Lal, along with other villagers. We get to know that they are getting very limited supply of water and they have to use same water for cattle. They released their waste water into the fields. Bio filter can be a useful onsite treatment method as the treated water can be used for their cattle. Pradhan of village told us about a government scheme according to which every house will be funded by the government to make soak pits. When we told them about mini biogas plant they are very curious although some of them already heard about it.



(a) Percentage of people using chulha, LPG or both based on our surveys

(b) Current Water Treatment by People

Figure 8: Current Water treatment by people

Place	No. Of people surveyed	Identified sources of water
Navlay	16	• Government distribution system from natural springs • Hand pump • Teel tukara govt. Scheme from parashar lake.
Katindi	11	• Uthao Payjal Yojana (Govt. Scheme) • Dodunu Naala (2km away from Katindi)
Mandi	42	• Submersible pump • Government distribution system from uhl river • Hand pump

Figure 7: survey by our ISTP team

In Mandi, our respondents filled the survey forms. People of Mandi are educated but still they directly said that when they need 1 glass of water they use 4 glass because they have plenty of it. They discharge their waste water into the sewer lines or directly into the rivers also. The people of Mandi are interested in both the ideas, i.e. biogas and water filter.

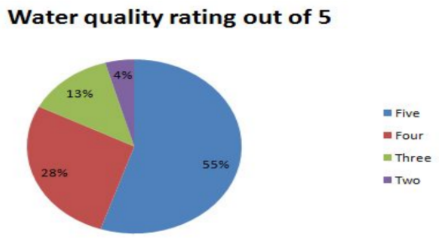


Figure 9: Water Quality Rating out of 5

We will visit few of the places again after making our prototype and estimate the cost of final product.

Biogas Plant

A biogas plant uses organic wastes like food waste and cow dung to produce biogas after performing a series of processes on it called as anaerobic digestion. The biogas consists mostly of methane (60%-70%), carbon dioxide (30%-40%) and some other gases like hydrogen, nitrogen and some oxygen also. The biogas produced can be used for various processes because it can be burnt, so it has same potential uses as any other combustible gas. Some applications of biogas include cooking and production of electricity. To make a biogas plant and implement it at a household level the parts used by us are:

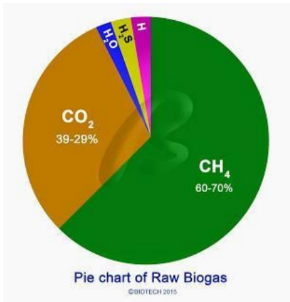


Figure 10: Pie chart of raw biogas

The process which takes place inside the digester tank is called anaerobic digestion. This process is a collection of other processes by which microorganisms breakdown biodegradable materials in the absence of oxygen. The various stages of Anaerobic Digestion are:

1. **Hydrolysis**: Biomass is made up of large organic polymers. For the bacteria in anaerobic digesters to access the energy potential of the material, these chains must first be broken down into their smaller constituent parts. These constituent parts, or monomers, such as sugars, are readily available to other bacteria. The process of breaking these chains and dissolving the smaller molecules into solution is called hydrolysis. Through hydrolysis the complex organic molecules are broken down into simple sugars, amino acids, and fatty acids.
2. **Acidogenesis**: This process results in further breakdown of the remaining components by fermentative bacteria
3. **Acetogenesis**: In this process, the simple molecules created from previous processes are further digested by acetogens to produce CO2 and Hydrogen
4. **Methanogenesis**: This is the last stage of the digestion process. In this stage, methanogens use the intermediate products

of the previous stages and convert them to Methane, carbon dioxide and water. Methane makes up majority of the biogas emitted.

The overall process of anaerobic digestion can be represented by the following chemical reaction.

$$C_6H_{12}O_6 \longrightarrow 3\,CO_2 + 3\,CH_4$$

Glucose is digested into methane and carbon dioxide by anaerobic microorganisms. When feeding organic waste to the digester tank, the food waste should be broken down to small pieces and mixed with water The inside of the biogas digester tank should be 50% of water and remaining 50% should be organic waste. To ensure efficient working of our biogas plant some preventive measures are taken

1. The digester tank should be kept air tight because the process is anaerobic. After the food waste is fed into the tank through the inlet, the inlet pipe should be covered. And the outlet pipe should also be covered until the gas is produced.

2. The digester tank should be painted all black because if it is not black then sunlight can enter the tank which will allow the algae to grow inside and if the algae is grown, oxygen will be produced.

Bio Filter

Filtration is one of the most important treatment processes used in water and wastewater treatment. In water treatment, it is used to purify the surface water for potable use whereas in wastewater treatment, the main purpose of filtration is to produce effluent of high quality so that it can be reused for various purposes. Any type of filter with attached biomass on the filter-media can be defined as a bio filter. Originally, bio filter was developed using rock or slag as filter media, however at present, several types and shapes of plastic media are also used. There are a number of small package treatment plants with different brand names currently available in the market in which different shaped plastic materials are packed as filter media and are mainly used for treating small amount of wastewater (e.g. from household or hotel). Irrespective of its different names usually given based on operational mode, the basic principle in a bio filter is the same: biodegradation of pollutants by the microorganisms attached onto the filter media.

Our System

Any debris and gunk that is present in the wastewater settles down at the can. It also contains bio balls which provide biological filtration and the finished product is the filtered water which can be used for gardening and other similar uses.

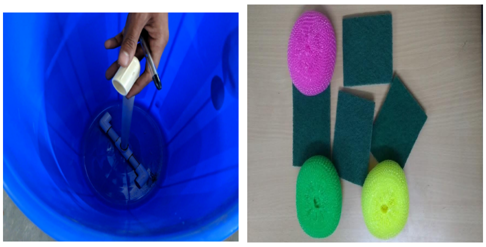
Fortunately, naturally occurring bacteria oxidize the ammonia, use it to grow, and convert it to nitrite (NO2-). This is an aerobic process that needs oxygen to occur. The bacteria that convert ammonia to nitrite are known collectively by their genus name Nitrosomonas. Like ammonia, the nitrite produced by the Nitrosomonas bacteria is toxic to aquatic organisms and must be oxidized further to a less toxic form of nitrogen. This is accomplished by another naturally occurring genus of bacteria referred to as Nitrobacteria. These bacteria metabolize and oxidize the nitrite (NO2-) produced by Nitrosomonas and convert it to nitrate (NO3). Oxygen is also consumed in the creation of nitrate.

$$NH_3 \xrightarrow{\text{Nitrosomonas}} {NO_2}^- \xrightarrow{\text{Nitrobacter}} NO_3$$

The purpose of this prototype in our project is to provide water, clean enough so that it can be used as an input in our Biogas prototype.

Assembly

Waste water is pumped into the can and the centrifugal motion separates liquid and solid materials. The debris settles down at the bottom, then there is a layer of scrubbers which filter any remaining impurity. Next layer is of Bio Balls which provide biological filtration.



(a) Inlet Pipe (b) Scrubber layer of bio filter

Figure 12: Layers of Bio Filter

Bio Balls

These are typically used in aquariums to transform harmful ammonia into nitrates. They work well when the water is passing over them so they are perfect for this setup.

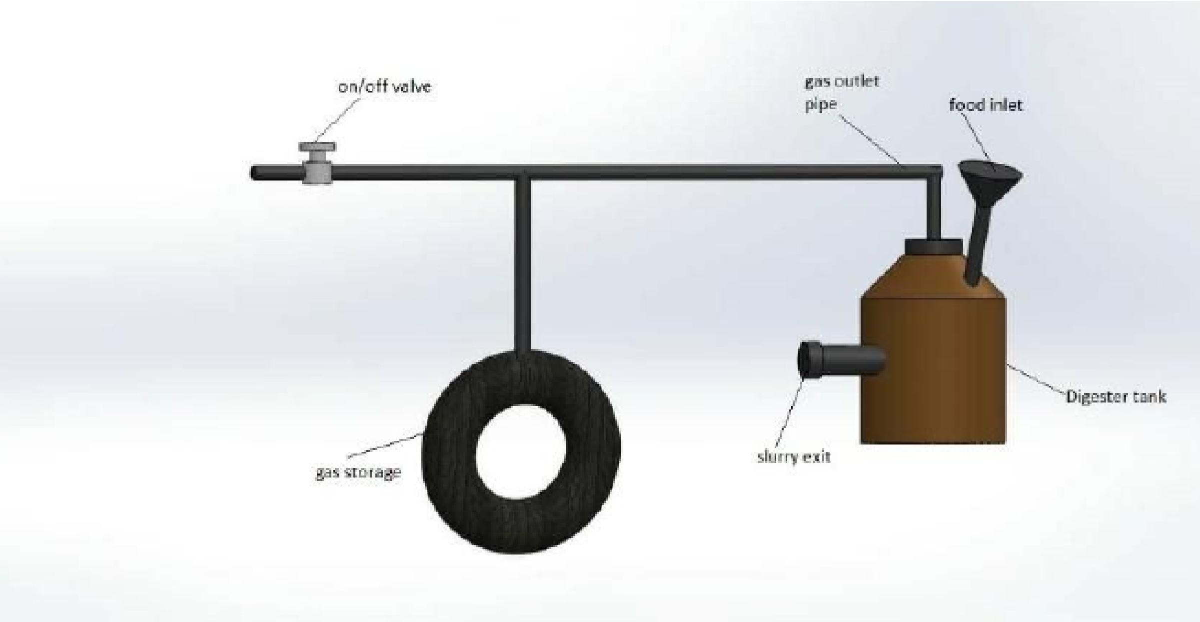


Figure 11: CAD Model of our system

Figure 13: Bio Balls

There is another layer of scrubbers and on the top of the whole system there are pebbles which put pressure onto the whole system so that the sponges dont float around because of water pressure.

Results and Discussion

Results

For our solid waste treatment, we fed food waste and cow dung mixed with water to the biogas plant to produce biogas. The bio filter is used to treat waste water, and that filtered water can be used in biogas plant by a secondary treatment because bio filter is a primary filtration apparatus. To meet the temperature conditions for efficient working of biogas plant, we kept the plant outdoors to keep it warm and painted it black to so that sunlight does not enter. Out of 40 liters capacity, 30 liters was filled with food waste, cow dung and water.

Limitation

Though the purpose of this prototype is not to provide potable water but to be an addition to the biogas prototype, potable water can be obtained through a secondary treatment measure as bio filter is a primary filtration apparatus.

Project Outcomes and Recommendations

While limited by time and budgetary constraints, we have laid the groundwork for streamlining our prototype. We could only obtain the parts which are locally available and in budgets. We were able to get 40L bucket for our storage tank same as in Bio Filter which limits the production of gas. We made a prototype of bio gas plant integrated to Bio Filter. Water filtered through bio filter is then used in Bio Gas Plant for production of bio gas as 50% of input of Bio Gas Plant is water. So we were able to generate bio gas from organic waste and waste water. All the input is coming from daily waste which is major achievement for our project. We have limitation and time of time so we have made our prototype very simple. But there are modification we would like to propose. In Bio Gas Plant we are using bacteria for the production of methane gas through anaerobic process. We have used a simple storage tank painted black to maximize the temperature. In place of simple bucket we could have a temperature controlled tank with temperature sensors. In cold places like Himachal Pradesh, it would be very much difficult to produces gas through anaerobic reaction. So we

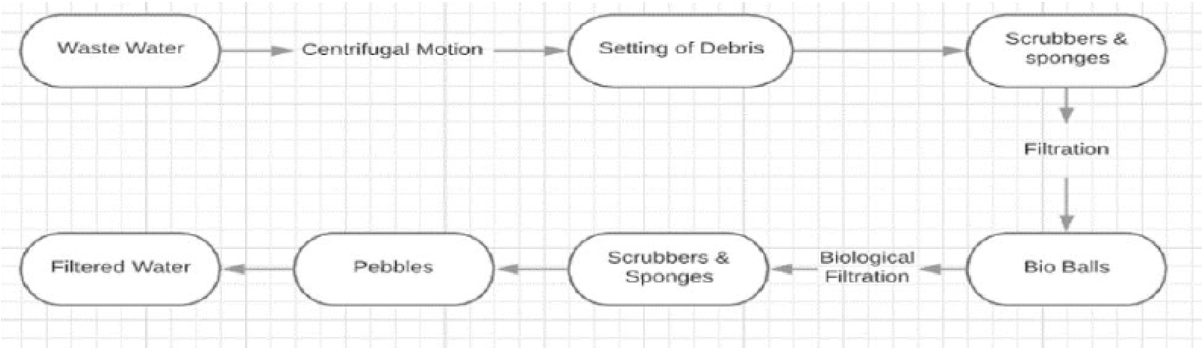


Figure 14: Flow Chart of Working of Bio Filter

need to artificially maintain the temperature. In Bio Filter we are using Bio balls to treat ammonia in waste water. These bio balls needs to be changed after certain time. In our prototype, we didnt add any feature to remove bio balls and refill it. This would be the modification that we would like to recommend in Bio Filter prototype. Further size of the tank could be made as per requirement. Currently in our integrated system of Bio Gas Plant and Bio Filter, we are manually adding water which are coming out from Bio Filter to Bio Gas Plant for production of methane gas but instead we add controlled mechanism which would regulate the water from Bio Filter to Bio Gas Plant as per its requirement. Then it would be more reliable and easy to use for common people.

Conclusion

We have studied various methods of onsite waste and water disposal and through the survey of nearby villages and the campus itself, we came up with our solution of solid waste and water treatment which involves production of biogas from a modified bio gas plant and the treatment of water from bio filter. The treated water coming out from bio filter is used for gas production. This solution would be very useful in places like Himachal and also at other places, where access to water is a problem. The impact of our prototype of biogas is too early to show, but schools and villagers have all expressed interest, citing the limited energy sources as a major challenge. Interest ranged from using the gas for cooking, powering a generator to produce electricity, to larger scale like providing energy for cooking. Although biogas technology in is quite an expensive enterprise, it is a one time investment, and the returns are beneficial for people as well as the environment. It is a viable alternate energy source.

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2. Dr. Rinki Sarkar for helping us in our survey
3. Manohar Lal, Pradhan of Katindi Village, who co-operated us during our survey to Katindi.

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Water Purifier using Solar Thermal Energy

Abstract

Water connects every aspect of life[1]. Today, 1 in 9 people lack access to the clean water in the world. The goal of our project is to design a cheap solar water purifier which uses sunlight to purify the water with provisions of mineralization. The current methods of purifying the water using the solar energy are inefficient and time-consuming. We accelerated the process by using other renewable energy systems like small wind turbines which perform reasonably fast, efficiently and effectively. We focused on identifying the hindrances and shortcomings in using the solar thermal based system by the general public, which prevent its effective acceptability in society. It can also be used for industrial applications which requires the highest quality purified water.

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Introduction

There has been significant growth in renewable energy resources sector in India, even for electricity generation from renewable sources. Compelling findings on climate change have brought drawn our attention to its effect on our lives. Hence, new applications of renewable energy are being developed to build a sustainable ecosystem. Solar energy is harnessed to develop ever-emerging technologies such as solar cooker, solar heater, and photovoltaics. A Solar Thermal Energy (STE) system uses the suns energy, rather than electricity or fossil fuels, to generate low-cost, environmentally friendly thermal energy. They help to provide cleaner fuel, reduce carbon footprint and electricity bill. It can be utilized to develop devices to address global challenges.

With 1 in 9 people lacking access to safe water, people have raised concern over water crisis[0] all around the world. Open defecation and untreated sewage are leading causes of this major environmental issues in India. Rise in water-borne diseases has been observed in Himachal Pradesh in the last decade [10]. Many Himachal Pradesh villages lack infrastructure to monitor and maintain drinking water quality. With the increasing concerns related to the quality of water consumed by drinking and cooking, it is important to understand the perception of people living in rural and semi-urban areas of Himachal Pradesh and, if possible, the other parts of India. Feasible methods of water purification to achieve standard drinking water quality is still in contemplation. Remarkable development of low cost and high quality products is still needed to be achieved to solve rural household problems.

The objective of the project is to understand the need of a water purification in rural households. The survey helped us to understand the perception of people living in many villages of Himachal Pradesh towards the quality of water they consume for drinking and cooking. This task shaped our approach to develop and implement water purifier that is affordable and can be built with readily available material.

Background

Perception of Indians of safe water

According to IIMC report[9], majority of Indians consider the water they use for drinking and cooking as clean and safe. The water considered clean by 89 percent and safe by 81 percent. Subtle distinction between clean and safe is noticed states like Manipur and Assam, where most of the people are depended on river or pond water. Tastes good was considered as an attribute of safe water by 30 percent especially in Punjab, Rajasthan, Orissa, Maharashtra, Tamil Nadu, Andhra Pradesh and Karnataka than other states. 20 percent people consider that water as safe, which is free from germs. This perception is very poor in Punjab, Haryana, Himachal Pradesh, Bihar, Uttar Pradesh, Madhya Pradesh, Orissa, Maharashtra, Tamil Nadu, Andhra Pradesh and Karnataka. In North Eastern States, Goa and Kerala respondents mentioned more often that water should be free from germs as an important attribute of safe water. In some states like Punjab,Haryana,Jammu & Kashmir, Uttar Pradesh, Madhya Pradesh, Orissa, Gujarat,and Karnataka more than 9 percent people perceive water as safe that cooks well.

Traditional water sources are quite prominent in many regions of Himachal Pradesh, especially in weaker sections of the society[6]. It can be used for many purposes along with consumption of water. They may include springs, Khuls, Baories, Taalab, Khaties and ditches. For years, people have been using it without any kind of water treatment. Government data from IPH suggests that drinking water quality for local regions is of good quality, but it fails to monitor untreated natural sources on which the people are heavily depended on for generations. They give an incomplete and inaccurate representation of water quality.

There are many rural villages in the Mandi district of Himachal Pradesh that currently lack the infrastructure to monitor and maintain drinking water quality. The Irrigation and Public Health department (IPH) is responsible for testing and monitoring for twelve potential water contaminants annually or biannually. With only one to two yearly tests, it is not feasible to get a clear and consistent view of the overall water quality in these villages.

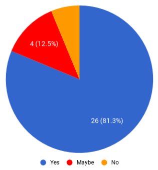
Methodology

Our aim is to develop an efficient and cheap water purifier that uses the sunlight to purify the water. Following objectives were identified in order to reach the goal

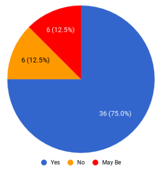
1. Assessing peoples perception regarding water quality.
2. Analysing the current solutions.
3. Testing and implementing the proposed solution.

Fieldwork and Prototype Development

To assess peoples view on the quality of the water, we conducted two different sets of interviews. One was conducted offline, for which we have interviewed 48 people in 4 villages. The other one was conducted through a google form and an online survey, with 33 respondents.



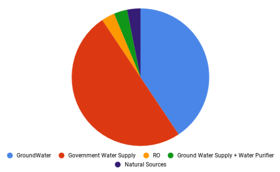
(a) Water Taste Analysis (Urban)



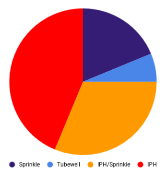
(b) Water Taste Analysis (Rural)

Figure 2: Water purification products available in the market (Source: Google Images)

For the first interview, locations were chosen on the basis of the distance from water resources, number of water resources and altitudes. In order to assess water quality, samples were taken from these villages and physical tests were done onsite. Chemical tests and other results for the water quality were taken from the ISTP 2017 report titled Improving Water Quality Treatment and Monitoring Techniques in Rural Himachal Pradesh Villages, and from IPH reports.



(a) Water Sources for different families (Urban)



(b) Water Sources for different families (Rural)

Figure 3: Assessing peoples perception regarding water quality.In the above Pi chart we can see that situation in urban sector is much better than in the rural sector. More than 50% people use water supplied by government, which is generally treated water.

We interviewed 2 doctors, Dr Nupur Garg and Dr Chander Singh, at the IIT Mandi Medical Clinic and the Community Health Centre at Kataula. They gave information about frequency of people suffering the from water borne diseases in the region. The interview with the doctors also helped us understand the water quality and its effects. The above information helped us identifying the relationship between the water quality and regional health. Apart from interviews various cases studies also provide insights about water quality. The villages which were chosen are Arnehar, Kataula, Salgi and Padhar (Mandi district).

For the online interviews, the questionnaire was shared on the internet and all the sets of the answers were studied thoroughly. We assessed the answers by the interviewee on the basis of their geographic location, views about their water, their perception on the system based on the solar energy etc.

Analysing the Current Solutions

Our second objective was to analyse existing products available in the market and filtration methods followed in Indian households. This helped us not only to learn about Indian lifestyle, affordability and their perception but it helped us to draw inspiration and improve our prototype.

Boiling of water is a common method of disinfection of water all over India. It is done before drinking or cooking, often given to a sick person. Simmering is common technique for food preparation.[8] This is a good method to treat water but over-boiling can lead to formation of metal oxides of metal traces present in water that are harmful for our body. Also, it does not remove turbidity, chemicals, taste, smell, colour from water. Villagers often use wood to boil water. In our survey, we learned that 12.5% of villagers boil water before use.

Figure 4: Water purification products available in the market (Source: Google Images)

Bleaching is a chemical method to disinfect water for safe use. A weak solution is used otherwise excess amount of bleach is toxic to our body. It is used especially in the summers, when filtration using clay vessels and Fitkari (Alum) are also common.

RO water purifier is a water purification device that uses electricity for Reverse Osmosis process. It is quite common in Indian households but in our survey, we met only one person who uses it at home. It removes ions, molecules and large particles. It is widely used in semi-urban and urban households. UV treatment is often used to kill pathogens. In recent years, researchers found that this water is unfit for drinking as it lacks nutrients. It overcome this problem, the water is further treated by water enrichment methods which adds to its cost (approx. Rs.12,000/-), making it unaffordable to poorer section of society. Another problem is that a large amount of untreated water is given out as output. Therefore, we need an affordable water purification method that does not lead to wastage of water.

Solar water still is device that uses renewable solar energy to purify water. It involves evaporation and condensation of water. We get distilled water as output. There are various multiple variations of the model but the underlying science is the same. A major problem is that is requires sunlight and daily output is very low. One would need a large still or a grid of small stills for everyday consumption. Also, distilled water has no nutritional values therefore, unfit for direct consumption. That is why it is used for laboratory and limited medical uses (eg. oxygen humidification).

Ceramic candle filter is a device which is used to filter drinking/tap water in order to remove suspended particles and pathogens. It involves material trapping mechanism and adsorption on the ceramic candles. The water is passed through candles and then it is collected in a separate container. The filters are easy to assemble and requires no energy. A less frequent maintenance includes frequent cleaning using brush. They can be constructed with locally available materials making it easy for rural residents to use. It does a good job to remote impurities but it has low flow rate and it does not remove all pathogens and chemicals in water.

The Problem with Solar Thermal Energy

An advantage of STE systems is that the solar energy can be directly converted to a usable form of energy without the evolvement of electrical energy. This helps to reduce energy loss. But, the major problem for small to medium level applications is about effectiveness in applications. These systems are very sluggish and also dependent on suns availability. One way is to involve other renewable energy (such as wind energy) conversion methods to accelerate the system.

Methods of Water Enrichment

According to a 2009 WHO report, Calcium and Magnesium in water may provide upto 20% of the required total daily intake[7]. We learnt that common purification methods that treat water but they also remove nutrients that are important for our body. Therefore, we need to look into different ways of water enrichment.

Copper in water:

It is an old Indian tradition to put water in a copper vessel, leave it overnight and then drinking a glass of it in the morning. It improves digestive system, kills harmful bacteria and many other health benefits. Instead of using a pure copper container which is quite expensive, a galvanized utensil can be used for the same.

Himalayan salt:

Unlike sea salt, Himalayan salt is uncontaminated and it provides more than 60 different minerals. One way to use it is preparing a salt water sole and then using a teaspoon of it meets daily nutritional requirements.

We used these enrichment methods in our water purifier prototype.

Testing and implementing the proposed solution

Based on the research conducted on already available products we came up with our proposed prototype.

Three levels of testing were done to evaluate the designed prototype. First level testing of the proposed design was done to estimate average outcome of the prototype which came out to be 340ml. Then the second level testing was done for chemical testing of output water. Third level tests aimed at checking the acceptability of the designed prototype. For this, surveys in four different villages of Himachal Pradesh were conducted. The interviews were conducted in three parts. In the first part, questions regarding water resources people use and their perception of water quality were asked. Then in the second part, brochure of our proposed prototype was showed, which consisted of specification of its features and comparison with available solutions in market. At last, questions were asked regarding their views on our solution and how much they are willing to pay for the prototype. Based on the feedback, possible modifications were made to improve output, both in terms of quality as well as efficiency, and thus an attempt was made to improve the acceptability of the product.

Results and Discussion

Following are the findings from our survey:-

1. Many villagers are still dependent on traditional water sources.

2. The available water is left untreated and consumed directly.

Figure 5: Water Tanker at Arnehar village

3. They have strong satisfaction with the drinking water quality.
4. Many villagers agreed on need for a water purifier but were expecting more output.

Case Study of Arnehar

Our visit to Arnehar brought our attention to the urgency of an alternative method of water filtration. An elderly woman gave us an insight into the current sources of water and sources used in the past. The villagers addressed the change in the taste of water over the years. The villagers mentioned that the taste is significantly different in comparison to their pleasant experience in urban cities like Mandi and Shimla. Currently, they are dependent on unregulated water system which consists of tank where water from hot spring is collected and then distributed to homes through taps. The storage tank is cleaned on weekly basis. Multiple filters were attached to the pipes that trap large particles in the stored water. The filtered water is distributed untreated which is not only used for irrigation and other general purposes but it also consumed in daily life. There is no monitoring system established in the village. According to the Narendra Singh (government servant), this is also the same situation in nearly villages like Suhara, Sandoa and Sakaryar. This visit instigated us to work on this project.

Water contamination levels

From the ISTP 2017 report on assessment of water quality in two villages, namely Salgi and Neri, we learnt that 74% of villagers depend on untreated natural sources from drinking water and cooking. The team observed strong satisfaction with the quality of water in both villages. They seemed to take no other measures for purification. The 2017 ISTP team found that the IPH is not monitoring an important source of drinking water. Bacteriological testing for E. coli and total bacteria indicated harmful contamination for natural water sources in Salgi and Neri. While the study was limited to five coliform and five E. coli tests, the results show an alarming and significant difference between the levels contamination in natural sources from the levels of contamination in government and groundwater sources. Chemical testing results indicated soft water with potential iron and nitrate contamination.

Survey Insight

46.2 % of people in Kataula use natural sources of water for drinking purpose. People believe that water coming from natural sources is more pure than the treated water provided by IPH. Among these people 84.6% people find the taste of their water above average. Sunima (aged 20, Kataula) told us during the survey, that in recent years she has started boiling water for drinking purpose due to increase in diseases caused due to untreated water. 75% of people were aware of basic water borne diseases.

Proposed solution

Shown in the figure below is our proposed solution. Our prototype consider two steps.

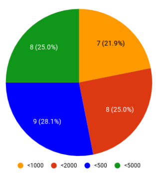
1. Water distillation
2. Water mineralisation

The first step takes place in a container with slant glass on top of it as shown in the figure. Container has impure water. Water evaporates due to solar energy and gets trapped in the glass case. We have used a black container so that water gets more solar energy and efficiency become high (since black color absorbs higher solar energy than other any color) Due to the inclination of glass, water is collected in the container, where the mineralisation process takes place. The container is made up of copper (copper is an essential metal of drinkable water) so that copper can added into the water. For adding the rest of the minerals to the water, we used Himalayan salt. We put Himalayan salt rocks in porous bags so as to add it in small amounts (the same amount as in a tea bag).

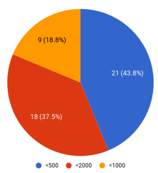
Here, most of the solar energy is wasted to heat up the whole vessel. We wanted to increase the efficiency. We found that if we can use the solar energy to evaporate the top surface only, than efficiency can be increased. Most of the materials that we are using in this process and also in the whole prototype are locally available and cheap. For this process we need Fabric Rich Carbon Coated Paper and Foam (that can float over the water).

The Carbon coated paper is in small square shapes and has four legs so that we can dip these legs into the foam and in this way we attached many carbon coated papers to get the arrangement as shown in the figure. The foam will float over the water and when these square shape papers get wet they will evaporate the water which was the top surface. This foam also acts as insulation which ends the need to heat up the whole container, thus increasing the rate of evaporation and in turn the output. Using this method we are getting one litre water by one meter square (container size) in one hour according to research done by others.[12] We have added small wind turbines to generate electricity in which load registers are heated up and then this energy is used to heat up the container. This increased output by mere 2% but is significant in terms of long term result. Another modification that we added to increase output is a laminated internal surface with aluminum foil which will reflect the absorbed heat, and thus will increase the absorption coefficient of the container. This increased output by 12%, according to our experiment.

Perception of proposed solution



(a) Willingness to pay for solar based water purifier (Urban)



(b) Willingness to pay for solar based water purifier (Rural)

Figure 6: In the above Pi Chart we can see that relatively people in rural areas are less willing to pay for solar based water purifier.

Even though 58% of our respondents agreed on need for a solar water purifier but out of those 86% felt that for the cost of proposed prototype is more compared to the promised output. 73% liked the idea that the proposed solution can be made using locally available material.

Discussion

Business Model

Distilled water has many industrial and medical use cases. Our enhanced water distillation prototype can produce significant amount of distilled water at low cost and then, it can be used for other purposes. For example, oxygen humidifiers in hospitals require this water for patients. Our low-cost high efficient model can be distributed in remote medical centres in Himachal Pradesh and other parts of India. By manufacturing tie-up with solar heating solution companies such as UNISOL (Steelhacks Industries), we can expand distribution of our prototype at large scale. Automobile industry use distilled water for applications ranging from engine cooler and cleaner to lead acid batteries used in cars and trucks.

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Our team would like to thank the following for their assistance and guidance during the course of our project:

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3. Our teaching assistant Pawan Panday for his assistance during the project. Dr Nupur Garg and Dr Chander Singh for their valuable time to participate in this survey.
4. The villagers of Arnehar, Kataula, Salgi and Padahar who generously donated their time to participate in this study.

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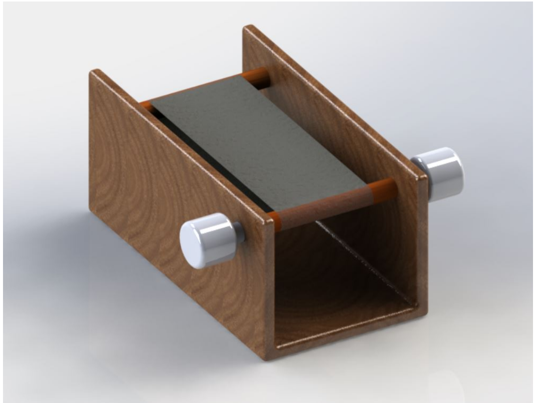
From waste to resource: E-waste management practice in Mandi



Abstract

The electronics industry is the world's largest and fastest growing manufacturing industry in the world and so is it's waste. E-waste refers to electrical and electronic products nearing the end of their 'useful life'. With latest developments in technology pushing through new e-products almost every month and a great influx of students and professionals in Mandi due to the impact of the recently established IIT, it's expected that soon the e-waste generation will skyrocket in the town. Against this backdrop the proposed project aims to understand the e-waste disposal behavior of individuals as well as the community as a whole, to build a low-cost prototype for material recovery from e-waste and to estimate the value of resources that can be generated from e-waste.

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Introduction

E-waste has many synonyms and pseudonyms across the world such as WEEE (Waste Electrical and Electronic Equipment), electronic waste or e-scrap. The most acceptable definition is WEEE. EEE(electrical and electronic equipment) is defined as "any household or business item with circuitry or electrical components with power or battery supply". [Huisman, 2012]. E-Waste is a term used to cover items of all types of electrical and electronic equipment (EEE) and its parts that have been discarded by the owner as waste without the intention of re-use.[Global e-waste Monitor 2017]. As on record, 44.6 Million tonnes of e-waste was generated in 2016 [GEM-2017] which averages out to 6.1 kg per inhabitant. Of this India produces 2 Million tonnes [HT,2016], 70% of which is generated by ten states of the country [Vats. C, Singh Santosh 2014]. E-waste in India is growing at 30% annually[HBL,2016] owing to the CAGR(Compounded Annual Growth Rate) of 27% of the electronic market.[Yourstory,2017].

All these trends and data project in terms of current wastes and the average growth rate of sector producing the same, there's a local diversity that is left unaddressed in such analyses which is the effect of some local event of a major change in the landscape. One of such affairs is the opening of a prestigious institute such as an IIT in the region viz. (IIT Mandi in Mandi). This has resulted in the flow of more tech-savvy individuals in the region and hence along with perennial advancement in technology has boosted the market for electronic and electrical items. As little to no data (both qualitative and quantitative) pertaining to Mandi's electronic waste context is available, this project serves as a crucial launchpad of all such attempts to understand the e-waste disposal behavior of individuals and the state's attempt to deal with the same.

A major roadblock for dealing with e-waste is the lack of adequate infrastructure to manage wastes safely. This leads to these wastes being buried, burnt in the open air or dumped into surface water bodies[Nnorom et.al 2008] All this is extremely harmful to the environment and consequently human body. Therefore our project also aims at assessing and demonstrating a process development which aims at material segregation from an e-waste component. This is entailed in building up of a prototype which highlights the important features of this approach.

Almost 95% of e-waste is recyclable[Hossain et. al 2015] and has potentially recoverable materials amounting to 55 billion euros[Statistia 2016]. On account of such economic opportunities, we aim to estimate the value of materials that can be recovered from the e-waste generated.

The study is proposed to be carried out in the IIT Campus and in Mandi town. The specific objectives and plan of execution are as follows:

1. What is the e-waste disposal behavior of the community residing inside IIT Mandi Campus and in Mandi town?
2. What is the estimated volume of e-waste generated today and what will be the projected volume for coming decades? [These two will base on a structured random sample survey at the household level]
3. Low cost prototype or process development to demonstrate e-waste recycling
4. What is the estimated value of recovered materials in the process? [This will based on the results obtained from material segregation and the projected volume of different types of e-waste]

Background

Mandi is a largely rural district of Himachal Pradesh with the central town rapidly urbanizing as local levels of education and income gradually rise as the town gains more significance in India's educational and tourism landscape. An estimated population of 1088366 generates 342.35 TPD(tonnes per day) of solid wastes of which e-waste is considered as an integral but small part.[Action Plan, municipal solid waste, HP,] This treatment to e-waste projects a lack of awareness and thus concern for e-waste and its management in the region. The GSDP of Himachal Pradesh[Wikipedia 2017] is growing at 14.45% of which Shimla, Mandi and Manali are major contributors. This means higher purchasing power which in turn implies people buying more electronic and electrical commodities. In light of this, we can ascertain that e-waste volumes are expected to grow exponentially in times to come in the region.

Sources of e-waste

As per [Hossain et. al 2015], some identified major sources of e-waste are:

1. Individuals and Businesses: As the useful span of electronic and electrical equipment has come down due to improved versions being launched about every few months, customers are forced as well as lured to buy new products.

2. Original Equipment Manufacturers (OEMs): Generate e-waste when units coming off the production line do not meet quality standards and the run-offs of the manufacturing process.

Classification

In general electronic and electrical equipment have been classified as follows[Hossain et. al 2015]:

1. Large household appliances: These generate high volumes of e-wastes after a relatively larger period of use. Examples include: Refrigerator and washing machine.
2. IT and Telecom: These are equipment used for communication or related activities such as education, research, etc. The rate of e-waste generation for them is closely bound to technological advancements. Examples are PCs and peripherals, large automated machines.
3. Consumer equipment: These are appliances other than those in the first category, which are found in households and industries. The e-waste generation period for these is moderately bound to the rate of technological advancement.

E-waste Composition and their hazardous nature

The processes of dismantling and disposing of electronic waste in developing countries led to a number of environmental impacts as illustrated in the graphic. Liquid and atmospheric releases end up in bodies of water, groundwater, soil, and air and therefore in land and sea animals both domesticated and wild, in crops eaten by both animals and human, and in drinking water.[Babu, 2016] E-waste contains a number of materials, many of which are hazardous such as Mercury which causes brain damage, lead which can result in instant death. Further hormonal imbalance and fetus malformation are also common in places where there is a prolonged exposure to e-waste. The following diagram brings about some of the hazardous materials in e-waste whereas the table following it lists their health hazards.[Hossain et. al 2015]

Figure 1: Hazardous Materials found in e-waste.(Uddin, Jalal, 2012)

Elements	Impact	Sources
Brominated flame retardants (BFRs)	Hormonal disorder	Used in plastic and textiles. PCB's
Cadium	Respiratory disorder, kidney damage , lung cancer	Respiration on burning of e-waste and via food
CFCs (Chlorofluor-ocarbons)	Accumulates in Ozone layer causes skin cancer, genetic damage in living organisms	Cooling unit,insulation foam
Dioxins & Furans	Malformation of fetus, decreased reproduction, impairment of immune system	Unwanted by products on combustions of plastics
Lead	Vomiting , diarrhea, convulsions, coma or even death	Solder, lead acid batteries, cable sheathing,
Mercury	Liver damage ,brain damage	batteries, switches and thermostats and fluorescent lamps [13]
Polychlorinated biphenyls (PCBs)	Cancer in animals, reproductive and immune system and nervous system	Dielectric fluids for capacitors, heat transfer fluids and as additives in adhesives and plastics
Polyviny-lchloride	Contains 56% chlorine, on burning release HCL. On inhalation effects Respiratory system	Plastic , pipes
Selenium	Sclerosis- hair loss, nail brittleness , neurological abnormalities	

Figure 2: Diseases caused by e-waste(Uddin, Jalal, 2012)

E-waste recycling and regulations

In developed countries, e-waste treatment plants are coming up which deal with some of their e-waste. They dispose off the rest of their e-waste by exporting used goods to developing countries in an attempt to bridge the so-called digital divide.[Nnorom, I.C., Osibanjo, O.,2008] These are used by refurbishing or repackaging with names similar to larger brands. In developing countries per se there exists little to no infrastructure to deal with e-waste.[Nnorom, I.C., Osibanjo, O.,2008] Furthermore waste is misplaced wealth is very apt for e-waste since it's composition shows that its recycling can result in some gainful material recovery.[Uddin, Jalal, 2012] Apathy from local governments means that these activities are mostly carried out by the informal sector which doesn't follow any standardized practices and causes loads of pollution. One such case in point which serves as a reminder of hazards of crude recycling of e-waste is he Guiyu town in Chaozhou region, Southeastern Guangdong province of China[documentary: BAN, Greenpeace]. In this town primitive recycling processes/techniques used include open burning of plastics (to reduce waste volume), and copper wires (to salvage valuable metals, e.g. copper), strong acid leaching of printed wiring boards, PWBs (to recover precious metals) from which the waste acid were discharged into nearby streams, and grilling of PWBs over honeycombcoal fires to melt solder (to allow collection of electronic components, e.g. diodes and resistors). Due to ground water pollution, Guiyus drinking water has been delivered from a nearby town for over a decade now.[Wong et al., 2007; Liu et al., 2006;Roman and Puckett, 2002]. There are also case reports of increasing respiratory tract infections, kidney stones, and the incidence of these health problems are higher among the migrant workers [Hicks et al., 2005; Liu et al., 2006]. Thus there's a need to have regulations regarding recycling of e-waste. Also crude methods should be avoided. The e-waste management regulations in India came into effect from 1st day of October, 2016. These include both the definition of e-waste as well as the idea f EPR(Extended Producer Responsibility), which tries to ingrain disposal and recovery costs in the cost of the products the waste originated from.[G.S.R. 338(E), March 2016]

Methodology

Given the complexity of our project, the sheer size of our goals and time constraints, we decided to sub-divide our objectives into more qualified subtasks and performed them as meticulously as possible.

Understanding the e-waste disposal behavior of the community

This objective requires intensive interaction with people and attempts to understand both their incentives and deterrents which proliferate in their behavior to e-waste. We found the following subtasks to be rather very useful in getting this into practice:

1. Assessing Local Perceptions and Behaviors Regarding E-Waste production and management in Mandi:

   (a) Mandi: For this aspect of the project we conducted household surveys. Our initial motivation was to conduct a completely random survey. We generated a random list of house-numbers which we had obtained through the 2017 election voter list and proceeded to conduct the surveys door-to-door. This proved to be daunting and unaccomplishable for we didn't understand the pattern houses were numbered by within the wards and number of available contact hours were limited. So we fell back to a systematic random sample. In this approach we would visit one house out of a cluster of 5-10 houses and then would hop off to another cluster. Following our back-up plan we succeeded in surveying 93 households consisting of 324 individuals. We covered all 11 out of 13 wards for the survey. The questionnaire we prepared was very extensive with questions which assessed the responders awareness regarding waste segregation, e-waste, its harmful impacts, local disposal mechanism, their attitude to old/out of use electronics and electrical items. Furthermore we enquired about their current number of EEE they are using at their home. This was for a further objective which will be mentioned thereon.

Figure 3: Wards visited for the survey (Source: Google Maps)

   (b) IIT Mandi: In IIT Mandi as well we conducted household surveys visiting as many as 30 Faculty and staff houses. The questionnaire and strategy were almost the same. These households had 78 individuals. Further, we surveyed 47 students in IIT Mandi hostels out of which 19 were from 3 seater rooms, 16 from 2 seater rooms and 12 from one-seater ones.

2. Assessing the Government Approach to E-Waste Management: For this aspect, we performed three face-to-face interviews. The first one of these was a cleanliness worker in Mandi Nagar Parishad, the second person was a Junior Engineer in Nagar Parishad, the third person being Secretary Mrs. Urvashi Walia. The questions were mostly regarding waste dumping and e-waste management, handling and disposal attempts (if any).

Estimating the volume of e-waste

: This objective aimed at estimating the volume of e-waste generated today and predicting volumes for the coming decades. The first part of this task proved to be extremely unprogressive. There was no official data regarding e-waste: the reason for which we will uncover in our findings. Additionally, no NGOs had undertaken any such studies as well. Attempts at learning the same from households also seemed futile as most people didn't seem to recall what e-waste they had thrown a month, a week or a year prior. For the second part which required us to estimate e-waste in coming decades, we added specific tables in our questionnaire which would record volumes of 19 different items usually found in households which come under EEE.[Global E-waste Monitor, 2017] For factoring in the damage they may have incurred already we also recorded how old these items were and if they had any repair history. The idea of projection was based on a simplifying assumption that e-waste generation per person will remain the same in the coming decades. This was made for two reasons:

1. Lack of any computable metric which would tell us how the consumption volume may increase per person.

2. As items keep on becoming lighter and multi-functional, the effect of any increase in the number of items would be equally outweighed by the corresponding light-weightedness.

Once we had the above data about e-waste generation per person, we computed the expected compounded growth in the population of the areas involved (Mandi town, IIT Mandi Faculty Blocs, IIT Mandi student numbers). The two multiplied together gave us our estimates about the wastes which would be generated in the coming years.

Prototype development to demonstrate recovery of materials from e-waste

The following image describes the standard procedure of handling e-waste.

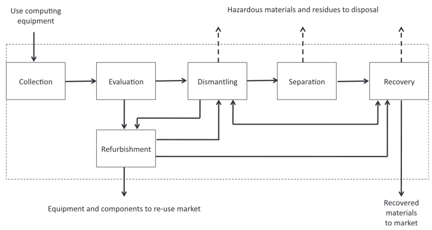

Figure 4: E-waste handling(Uddin, Jalal, 2012)

As the schema is very extensive and requires a lot of labor, most of which would be easily available once the requisite infrastructure develops. Also, the technical aspect of the schema which appealed most to us and appeared achievable was the recovery part. So we developed our prototype after taking motivations from [Tiwari, S., Kishore, S., et al, 2017]. Our prototype basically involves density separation, magnetic separation and eddy current separation after dismantling e-waste components.Our prototype employs physical method of separation and no use of chemical whatsoever. It is based on simple principles like density difference, behavior of materials towards magnet and how metal interacts with eddy currents. From the output of our prototype, electrochemical methods can be used to achieve better grade of metals. Our prototype is easily scalable and can be employed locally as well as commercially. In its current state, the prototype can separate the fine-grained scraps of PCBs(Printed Circuit Boards) into polymers, ferrous metals and non-ferrous metal particles. We have chosen PCBs because their contribution to e-waste is on all-time rise."The global printed circuit board market is expected to reach an estimated \$72.6 billion by 2022 and is forecast to grow at a CAGR of 3.2% from 2017 to 2022." [Research and Markets, PCB].

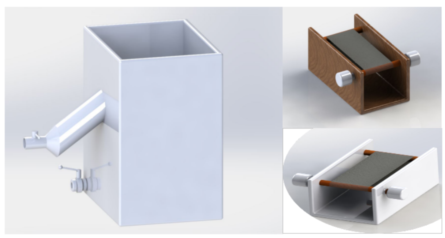

Figure 5: CAD Models of components of our prototype

Estimated value of recovered materials in the process

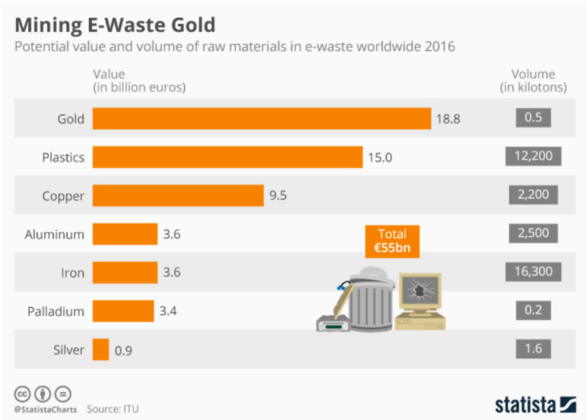

Figure 6: Value that can be generated from e-waste(Statistia)

As much as 55 billion euros of wealth is projected to be recoverable from e-waste as in 2016. Even if we reduce this number by one-fourth it would dwarf a number of small economies. Thus, recovery is one arena where e-waste handling giants must invest in. Our prototype recovers materials from a PCBs. For one PCB, extracted from a mouse which costs about rupees 110 to manufacture, we calculated the value of the recovered material using some estimates on cost of Alumunium, Copper, Iron, Ceramic in PCBs and iron. Also, this does not include the reduction in cost incurred for recovering metals in pure forms. On the other hand, this prevents PCBs from their eventual (more harmful) disposal mode of incineration reducing pollution. On the economic side of things, our hunch is that the value recovered may be lower than expected.

Results and Discussion

After this extensive project of 12 weeks, we obtained results which ranged from expected to alarming with some consequences instilling in us the hope that e-waste management, although a daunting task facing the world may be handled just well-enough in the future.

Results

We obtained some great insights into how technologies and their counter-effects interact with people in general. Here are our results viewed in light of our objectives:

1. Comprehending the e-waste disposal behaviour of the surrounding community and the data on generation of e-waste:

   (a) Although the literacy rate in Himachal is one of the highest among states with relatively larger size, at 83.78%, we were surprised to see that as much as 59% of our responders in the Mandi town didn't know about e-waste. Digging deeper we found that many people had the following notions about it:

      i. After being dumped e-waste may emit radiations leading to a plethora of diseases.

      ii. Items such as battery may blast under pressure which may then cause a rippling effect on the dumping site.

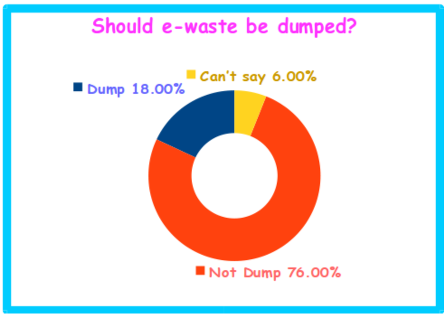

Figure 7: Should e-waste be dumped?

      iii. Some professed it smokes the air when incinerated, a phenomenon Mandi is actually witnessing with many a weekend evenings feeling ashy.

      iv. The populace was single-minded about some aspects though:

         A. All the e-waste collection, recovery and disposal is handled solely by the informal sector. 'Kabadiwalas' are a daily service, although people need them either monthly or quarterly.

         B. There's no e-waste disposal or collection centre around.

         C. The solid waste collection infrastructure of the town is in great shape and the dirt wagon makes its appearance regularly.

         D. Most people were more than happy to tie in with the current system a collection schedule for e-waste. The most preferable frequency being between 30 - 60 days.

      v. Source segregation seems to have taken a hit as only 68% actual indulged in the practice.

vi. 87.5% of the respondents believed e-waste causes/could cause pollution whereas only half of them could actually materialize about the specifics.

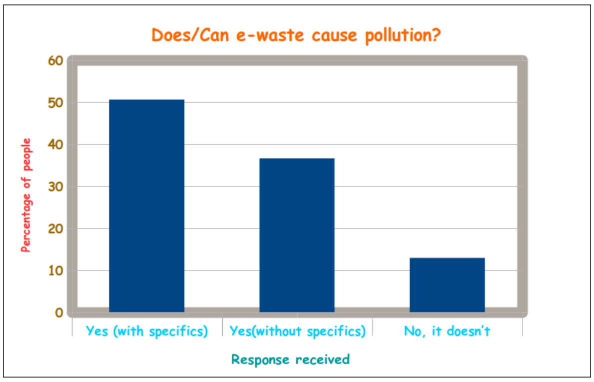

Figure 8: E-waste causes pollution?

vii. When asked about what they do with their defunct e-items, we got a mixed response with options ranging from throwing them in trash, storing at home, getting repaired to giving them to others.

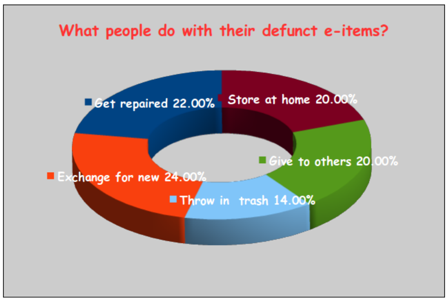

Figure 9: Dealing with defunct e-items.

viii. For the 324 people surveyed in Mandi, the estimated potential e-waste is 1388.62 kg. For the entire Urban population which sums up to 68,190, this potential e-waste comes up to 292.25 tonnes. In 2028 the number would swell up to at least 329.9 tonnes.

ix. Most people did not know of the new provision of EPR(Extended Producer Responsibility) under which the producers are responsible for dealing with the e-waste that their products generate.

(b) In order to get a complete picture, we performed the survey in both the south as well as north campus of IIT Mandi. For student surveys we had the following guiding philosophy: mostly awareness questions and some idea regarding the e-items they consume. Most of our findings tied in with what was found in the town, here are those which contrasted with our findings in Mandi:

i. 90% people we interviewed on campus had some inkling of what e-waste is and what its harmful impacts on environment are, what diseases it can cause.

ii. Source segregation was practised in all houses.

iii. Dealing with defunct items mostly involved storing them at homes. Since most items were relatively new so there wasn't so much defunct items or items with repair history reported.

iv. Awareness regarding EPR is low even in Faculty members and students, with only about 5% knowing about the provision.

v. As much as 505 kgs of potential e-waste is currently present. As the number households increase to this value is estimated to reach 8400 kgs in 2028.

vi. As far as potential e-waste per student is concerned, considering an average of 1000 individuals now, this sums up to 1749 kgs. This is expected to rise to 8745 kgs in 2028 with an expected number of 5000 students then.

(c) Although the current solid waste management of Mandi is top-notch, given that it is the cleanest city in India, the e-waste handling situation hasn't dawned on the authority as of this study. There's no treatment plant or plan reported, neither do they collect the e-waste themselves (as confirmed in the interviews we performed). In light of the fact that the new e-waste regulations came into force just two years ago it would be too early to conclude that e-waste management will be a problem for the city.

2. The prototype and the value of material recovered:

(a) Given finely grinded PCB scrap (the collection and crushing of which we outsourced), our prototype can separate it into polymers, ferrous, non-ferrous metals and ceramics.

(b) There is some overlap across categories since some ceramics also have magnetic properties.

(c) Before switching from the density separator apparatus to the belts, we need to dry the slurry.

(d) After some fine-tuning of locations required for the collection boxes under the belt, we got some overlap between magnetic and non-magnetic particles.

(e) The eddy current separator does a decent job of getting the non-ferrous (also the most valuable part) metals separated from the scrap powder.

(f) The results of our calculation:
The cost of raw materials for one PCB = Rs. 29.19[PCB Prdouction profile, 2012] The cost recovered by us, for one PCB = Rs. 6.59 Efficiency = $(6.59/29.19)X100 = 23\%$

(g) The efficiency observed above may not seem significant. There's a catch though. As a society, we mostly tie gains to monetary benefits but there's a cost we have mostly neglected. This is the cost of the harm to the environment that we do when these PCBs are burned out in the open. Additionally, this is in fact the cost of the material saved from getting wasted.

Discussion

There are multiple points of discussion:

1. A majority of people are unaware of the threats to the environment that e-waste presents and the damages it can do to human body. This is in stark contrast to the fact that most have been using the items for quite some time.

2. Even though people are unaware of the specifics of e-waste, most still believe that it causes pollution. This will work as propelling factor to any project such as these hoping to efficiently manage e-waste.

3. The implementation of guidelines dealing with e-waste are very lax and almost non-existent.

4. Most people are ready to hand over their e-waste for disposal which unlike similar studies which have indicate people's unwillingness to handout their EoL(End of Life) goods. Although some of the e-waste hoarded up in the household are due to emotional attachments yet most individuals were ready get rid of them.

5. There's also little-to-no use of refurbished e-items imported from other countries. This is a welcome sight since such items have lesser life and higher failure rates which would exponentially increase e-waste generation.

6. Overall the awareness level among people is not optimal but still stands out in developing country like India.

7. One area of major concern that this project unearths is the management of e-waste by the informal sector: (investigated as part of our interview with one such professional[name withheld])

   (a) They involve minimal use of technology with crude procedures carried out in poorer parts of the city.

   (b) The recycling drill involves involves physically breaking down components often without any protective gear.

   (c) They burn poly vinyl chloride (PVC) wires to retrieve copper and melt lead and mercury-laden parts.

   (d) The workforce: the urban poor with low literacy lacking awareness of the hazards of the toxic e- wastes.

   (e) None of this is regulated. Some of the material recovered as well as e-waste finds its way Chandigarh.

8. EPR is unknown to people and thus may not utilize it when required.

9. IIT Mandi community is better informed yet poorly equipped with dealing with the malice since there's no plant for the same. Although the situation may change given that we have already taken the first step.

10. Our prototype is far from perfect but it sums up both the issues that any such plant is expected to face. The design can be improved by:

    (a) It is not fully automated but it uses the standard conveyer belt philosophy so it can be automated with minimum effort.

    (b) More fine-grained separation is possible in case we also go the next level of treatment where we use chemicals for separation.

    (c) The choice of liquid for density separation is water. This is both practical and scalable.

Conclusion and Recommendations

Conclusion

We have drawn a few conclusions from the fieldwork and technical rigour we have put in the project:

1. The implementation of the guidelines for e-waste management are not in practice. There's no documented collection system, or a treatment plant nearby. This falls in the line of reasoning that e-waste is a slow poison and shows its effects only after long exposure. Thus the e-waste generated today will show its wrath 5-10 years from now. Thus the community has not taken many steps to keep this stream of waste in check.

2. The general awareness level in both the town as well as the IIT Mandi community is above average whereas the knowledge of the specifics has been mostly non-existent or unfounded (eg. the belief that e-waste can cause radiation when dumped).

3. Consumers are unaware of the EPR(Extended Producer Responsibility) clause that keeps the responsibility of e-waste management in the producers. This when implemented in full effect will make the entire process more transparent and assessable.

4. Our prototype describes a workflow of the process that can help in recovery of materials from e-waste. The process however is not really very economically viable. This could prove to be a deterrent for the initial adoption of the technology. Although there are more sophisticated practices mentioned in the literature and also in practice in the developed countries.

5. The volumes of potential e-waste present in the various households as well as inside the campus is sizeable and comparable to one of tier-two towns in China. That is not very alarming yet a significant value.

6. Material recovery and recycling are the way to go if we want to truly manage e-waste. Disposal has mostly proved to be disastrous unless performed extremely meticulously.

Recommendations

After careful thought and considering the effects of all the variables involved in the problem we have the following recommendations:

1. Collection: The most dreary aspect of any waste management process is the collection part. Segregation and directed collection can go a great way in dealing with the hazards and implications that e-waste produces. An effective collection system enables the channelization of the e-waste to appropriate recycling facilities and increases reuse of certain components. Since under the EPR system, the producer is responsible for his/her products. A take-back system could be established. This could be either individual where producers can have direct contact with dismantlers or recyclers which allows them to get back the re-usable components from their obsolete equipment. Or it can be a collective system where the producer would enter into a contractual agreement with a collection agency which would be responsible for the collection of the waste from the generator.[Uddin, Jalal, 2012] Factoring in that the solid waste door-to-door collection mechanism in Mandi is in good health. The collective model would cater better to this use case. Although people have seemed to be highly receptive and supportive of this initiative of treating e-waste and have agreed to handing over their defunct items once the collection mechanism comes into full force we suggest take back system provide some discount on the purchase of new items to those who readily cooperate.

2. Storage: As volume of e-waste generation can be erratic, at least in the initial years of a such an initiative. Therefore we require covered areas for storage of e-waste till such time that the waste is recycled or treated. This would have a weatherproof covering minimizing any contamination that could escape from the facility. Appropriate spillage collection facilities would make the storage more beneficial to the environment.

3. Establishment of more facilities for recovery and recycling of e-waste. This could begin with the model followed by e-waste recyclers present in Delhi and then adopted as seen fit.

4. In such establishments which deal with e-waste collection and treatment the informal sector workforce should be employeed. This is so because by formalizing these processes we are taking away their major(and possibly only) source of income.

5. Proper implementation of EPR so that the emphasis shifts from the consumer to the producer to handle the e-waste. This can then help in achieving an arrangement whereby

those who produce goods share the responsibility for the environmental impacts throughout the whole of their life cycle, from resource extraction to recycling, reuse and disposal (Nnorom et.al, 2008). This would also add the cost of recovery and recycling in the retail price of such products, thus actually factoring in management and treatment costs in the market.

6. Accentuated awareness and coordinated effort of the local self-government in materializing the guidelines envisioned in 2016. This would help us achieve a better environment and save us from the ill-effects that e-waste causes.

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