Purification of Sediment Contaminated Water Using *Opuntia basilaris* and its Possible Implementation in Developing Countries

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ABSTRACT

Water pollution has escalated into a large problem across the globe, estimated to impact the lives of millions of people each year. Natural ways of water purification have been studied more extensively recently due to secondary contamination from previous cleaning mechanisms being identified in the "purified" water, including metal particles from water filtration though decaying pipes in water treatment plants, and metal substances from the ground that did not get filtered (Runnels 1992). The *Opuntia* species, also known as prickly pear cactus, possesses characteristics within its mucilage that allow it to filter water and collect harmful metals. Evaluating the possible implementation of mucilage from this specific cacti to filter water of harmful contaminants is the goal of this research project. Mucilage is a gel like substance that is found within a variety of plants. (Matsuhiro al et. 2006). With natural methods of water purification starting to be implemented more widely, discovering an improved technique can alter current standards. This species of cactus is a widely available renewable resource in many areas of the world, and if implemented effectively, has the potential to offer great benefits. The benefits of cacti use has already been demonstrated cleaning water in developing countries to remove hazardous waste from emergency spills and disasters. In 2011, Opuntia Basilaris (prickly pear), was used to clean up an oil spill by absorbing the oil and breaking it up into smaller droplets, allowing the oil to break down faster (Alcantar 2012). This type of cactus has also demonstrated the ability to filter arsenic, which could support its implementation in water filtration systems to remove harmful heavy metal-type substances and to reduce the residual risk

of diarrhea, cancer and keratosis caused by arsenic contamination that is not addressed by many current filtration systems, particularly in developing countries.

INTRODUCTION

Pollution of all types is present in water sources around the globe, and due to the extensive list of often fatal medical concerns that can be caused by water pollution, it is important to make every effort to fully filter harmful contaminants before people are exposed to it. Beginning during the industrial revolution of the eighteenth century when factories began dumping waste into rivers, lakes and other water supplies, water pollution started to be recognized as affecting the health of people in cities and towns (Merchant, 2002). A problem discovered, however, was that while water pollution can be equally present in the water supplies in both rich and poor areas of the world, it primarily affects the poor who can't afford to cleanup the source of pollution. Additionally, the people in poor areas of the world that can't afford life saving medications and medical practices often suffer more as these countries death toll increases at a greater rate as water pollution rises (WHO 2016). In these poor urban areas where pollution causes the most problem, there have been 3,000,000 documented cases of premature deaths recorded every year throughout China, India, and Bangladesh (Dennis 2016).

Pollution is a vast and broad topic so the most efficient way start with helping address the pollution problem is to narrow the focus to the type of pollution that we as humans can control and contain. Looking at the types of pollution that impact the earth and the atmosphere above us, we have noise pollution, light pollution, radioactive pollution, soil pollution, thermal pollution, air pollution, and water pollution. Of these, soil, air and water pollution play the biggest role in affecting people's health and the health of the environment around us. Better technologies and more restrictive policies have significantly improved control of pollution in these three areas in wealthy nations such as the United States and have led to methods to record pollution patterns in a complex database (Tainio 2015). While this works as a solution for countries that can afford to closely monitor and collect data on it's countries pollution statistics, this hope is cut short due to lack in ability to fund in the areas that suffer the worst (Bascom 1998).

Monitored by a series of national and international organizations whose goal is to improve the health of people in all communities throughout the world, pollution is treated as a serious threat. When pollutions levels rise above the level set by these organizations that reality of the situation comes into play. In America, we fall under under the legal power of the Environmental Protection Agency, also known as the EPA. The EPA was established in 1970 under the order of President Richard Nixon to keep Americans safe and healthy because during that time, pollution had reached a level of significant concern for the country. The mission for this agency was to gather together the best researchers in the fields of identifying and mitigating pollutions that had previously been individually working toward the goal of environmental conditions improvement (Nelson 1980). Another very well known organization that does research in benefit for the people of various countries is the WHO, or the World Health Organization. WHO is the official environmental protection agency of the United Nations. Founded in 1948, it serves as the first organization that focused on the health and welfare of all of those peoples represented by the United Nations (Roemer 2008). Every year, the WHO develops and releases numerous reports on multiple aspects of health issues that are considered a primary concern for that year. Most common in those reports is the data collected tracking impacts of pollution. Figure (1) presents one of these statistics, the death rate of over 1.7 million children under the age of five per year that are linked to the environment. It is these reports that have provided a focus for my research as they highlight the the many critical issues caused by the pollution problem.

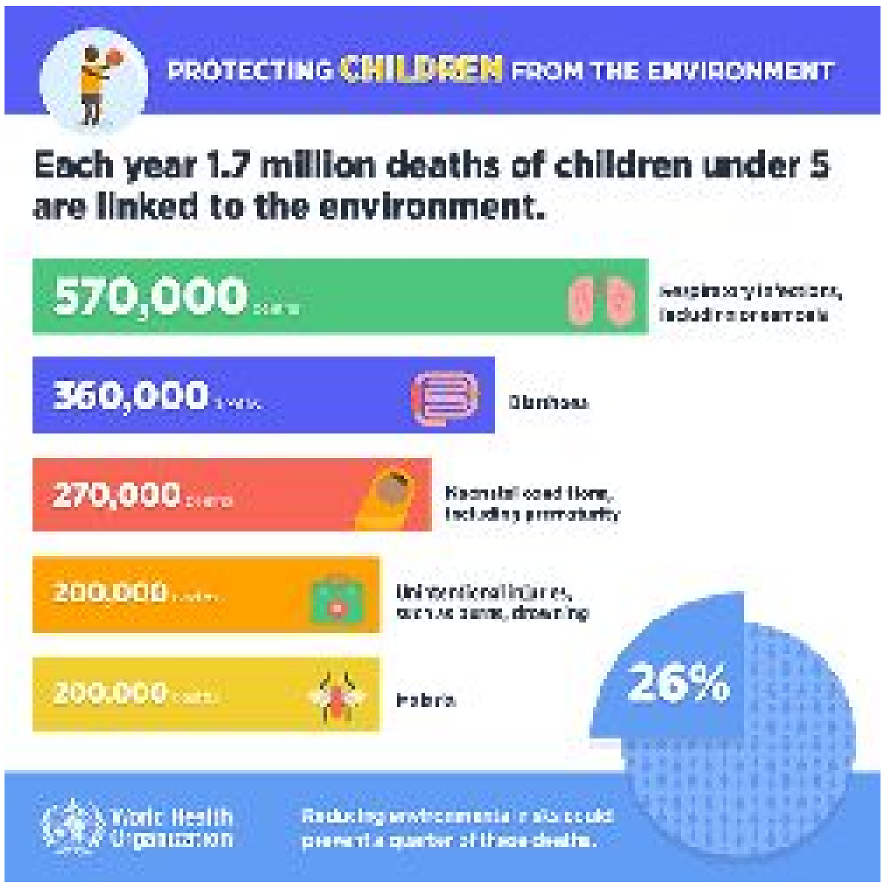


Figure 1. Effects of Pollution on Children Under the Age of Five, WHO 2017

Proving themselves as legitimate organizations that have the utmost interest in keeping us safe, they have established standards regarding safe toxin levels in the environment and operational requirements and processes to keep an environment is safe. Upon review of a sample of these standards, it appears many are not adhered to around the world. An estimated 98 percent of poorer countries, particularly within urban areas, have an unsafe levels of pollution related contaminants per the international standards, including violations of the regulations documenting how much pollutants are allowed in the air and water (WHO 2015). Focusing the research to matters that can be easiest addressed within the main pollution areas of air and water contamination, air pollution has proven difficult to monitor and make better due to the rapid and dynamic way air pollution gets transferred around the globe by winds, so this paper will focus on the water pollution which tends to be more isolated to the site of contamination. As depicted in figure (2), there are still extremely high rates of death, over 1000 per million people, in many of the underdeveloped countries in the world.

Figure 2. Deaths from Unsafe Water, Sanitation and Hygiene

Water pollution is not a new concept. While the identification of the need to clean up water and improve sanitation dates back to at least 2000 B.C when the Greeks and Romans started the practice of boiling water to purify it and make it drinkable (Crittenden 2005), it is the transformation of our society in the past 200-250 years that has taken water pollution levels to new heights (Merchant, 2002). What was this change dependent on? The primary answer is the industrial revolution of eighteenth century. The industrial revolution was much needed during its time, it improved many aspects of life for the people and benefited the economy. However, with this rapid increase in the use of steel, metals and chemicals in large factories, cautions regarding waste products and their effects had not been assessed.

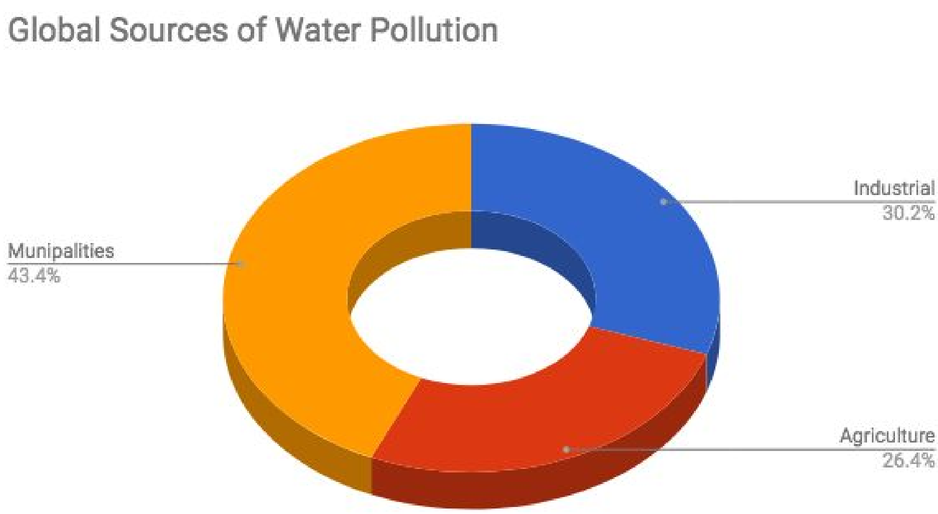


Figure 3. Global Source of Water Pollution.

As depicted in figure (3), analyzation of different areas and the factors and components that make up global water pollution show that industrial sources of waste caused 30.2% of all water pollution. Water pollution from agriculture has also increased in the wake of the industrial revolution as more production is being forced out of farms through the use of chemical fertilizers and pesticides to feed the large city populations. Additionally, waste removal from the population-dense cities and urban areas that grew up during the industrial revolution and after have contributed significantly to the overall global water pollution problem.

While the industrial revolution introduced the global problem of water pollution as a large scale issue without much awareness of the the problems they were creating, since that time, researchers have been able to specify what sediments are the most contaminating and which are causing the largest health problems among people. These sediments are heavy metals, put into the cycle of life primarily through waste dumped by big industrial companies (Baker 1981). Often transported away from the factories they were produced in, the waste metal sediments will either be picked up by runoff water and takens to streams and lakes, or soaked up into ground aquifers only to reappear later to affect those whose primary source of water is wells. The majority of these industrial wastes are toxic to humans due to their heavy metal content. Lead, mercury, chromium, and arsenic are the most toxic when it comes to effects on the human body. Arsenic (As) specific toxicity levels are so high that in order for water to be safe it must have no more than 10 micrograms per liter (Environmental Protection agency 2004). Arsenic (As) is also common type of metal found in rocks and stones in the ground (Fox 2012), so natural arsenic can contribute to the industrial waste arsenic as it travels via water run off and transportation underground (Pichler 2012). Arsenic when ingested at high amounts can be very dangerous, and acts as poison that can cause diarrhea, cancer, keratosis (Yeh 2012)

Arsenic (As) can also get to people through food sources watered by polluted sources, as well as directly from the water. Many rice paddies are now inundated with toxic wastewater that gets transferred into the plants as they grow. This is caused by farmers, particularly in poorer countries, unknowingly using this arsenic-contaminated water, so it is critical to to get rid of it throughout all primary water sources and not just drinking water (Alcantar 2012). Another example of water sediment contamination of food sources is through fish stocks. Fisherman, and particularly fish farmers, need a water source that is free of arsenic. This requires a large scale purification system based on an economically feasible method that can be used even by low-income inhabitants of rural communities, and these purification systems need to be sensitive to existing economic, social and cultural patterns if they are to be successfully implemented by the local population.

Arsenic has different forms, and is considered to be the most toxic form of heavy metal, followed by the arsenates and other organic arsenic compounds (Karim 1999). Lethal doses in humans intake of Arsenic range from 1.5 mg/kg of body weight to 500 mg/kg of body weight (WHO, 2012). Many countries suffer from water-based arsenic poisoning, including North America, as seen in figure (4), Taiwan, Mexico, Mongolia, Argentina, India, Chile, and Bangladesh. About 80 million people have been recorded to date that suffer from arsenic poisoning as well as other sediment poisoning (Karim 1999). Bangladesh's garment and textile industries have contributed heavily to what many experts describe as a water pollution disaster, especially in the large industrial area of the capital Dhaka, showing again how industrialization is impacting water pollution still to this day (Tribune 2015). In Bangladesh alone, arsenic-contaminated groundwater effects between 35 and 75 million people (Alcanter 2012). About 6 million people are at risk in West Bengal in India , and other regions of concern include the highly populated river deltas in Cambodia and Vietnam (Egli 2010).

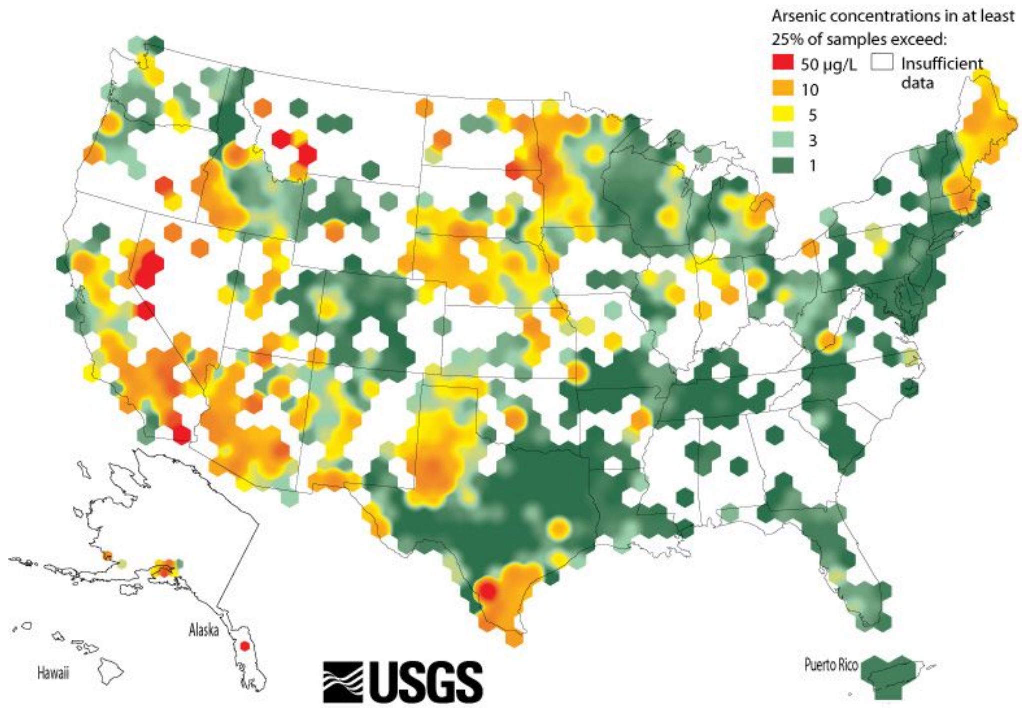


Figure 4. United States Geological Survey (USGS) Arsenic (As) Levels

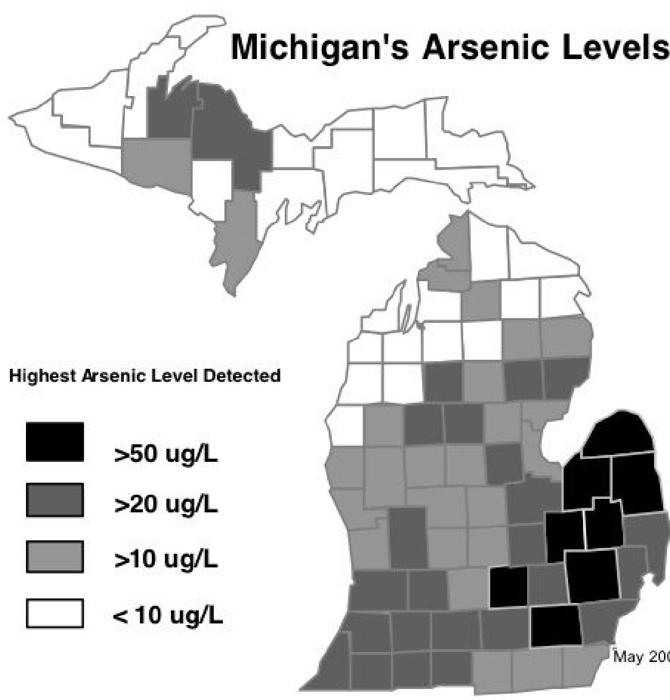


Figure 5. Michigan Arsenic Levels, 2003 Study

Looking at one area within the United States in more detail, figure (5) highlights the toxic arsenic levels recorded in water supplies in Michigan in 2003 which is believed to be caused by a combination of industrial dumping by the auto industry, secondary transfer from aging metal pipes, and naturally occuring arsenic in the soil and rocks. Any while almost all countries in the world have some level of arsenic contamination, Bangladesh is currently recognized as the most impacted with arsenic contamination reported to affect more than a quarter of the nation, figure (6).

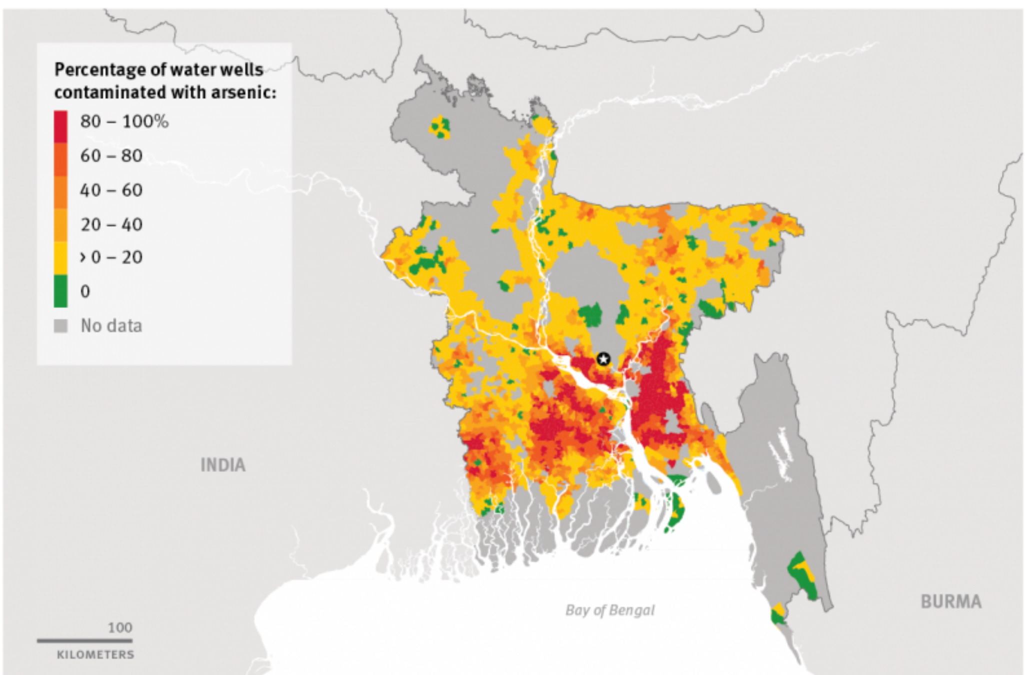


Figure 6. Bangladesh Water Wells Contamination Levels

BACKGROUND FOR THE USE OF CACTUS MUCILAGE AS A FILTRATION MEDIUM

What started as a tradition in a Mexican household has grown into a new method of water filtration, the use of the mucilage from the prickly pear cactus. Also known as the gum (Edward 2010), this method of using prickly pear cactus mucilage to filter water has been studied extensively at the University of South Florida (USF), where it's effectiveness as a water filtration medium has been demonstrated. In addition to the scientific research which has demonstrated the mucilage effectiveness, the mucilage from the prickly pear, or *Opuntia Basilaris,* as seen in figures (7) and (8), has been utilized effectively as a filter in several practical applications. Originating and most prosperous along the western coast of the Americas, the *Opuntia Basilaris (OP Basiaris)* runs from southern Canada down to southern Mexico, varieties can also be found in cold weather locations such as Michigan and throughout the world. Commonly known as the Prickly Pear cactus, this specific species of cacti lives in sandy, high elevation, and dry places, while also residing in other climates such as valley conditions and often can be found near streams (Matsuhiro, enz, Zá rate, O., 2006).

Figure 7/Figure 8. Visual Representations of *Opuntia Basilaris (OP Basiaris)*

The most common research being done on OP Basiaris is testing regarding the effectiveness of its mucilage in removing arsenic, a very dangerous metal sediment as previously described (Rullens 3), from water sources. This process is best defined by an absorption that takes place as the mucilage is exposed to the sediment in the water that is described best as a flocculation–coagulation (FloC) system, a chemical process of contact and adhesion whereby the particles of a dispersion form larger-size cluster allowing them to be more easily removed from water as shown in figure (9).

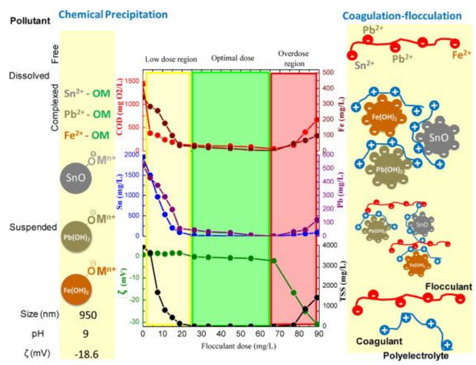


Figure 9 - Representation of the FloC process

Research into the more efficient methods to extract mucilage from cacti has also been conducted by the University of South Florida, as seen in figure (10).

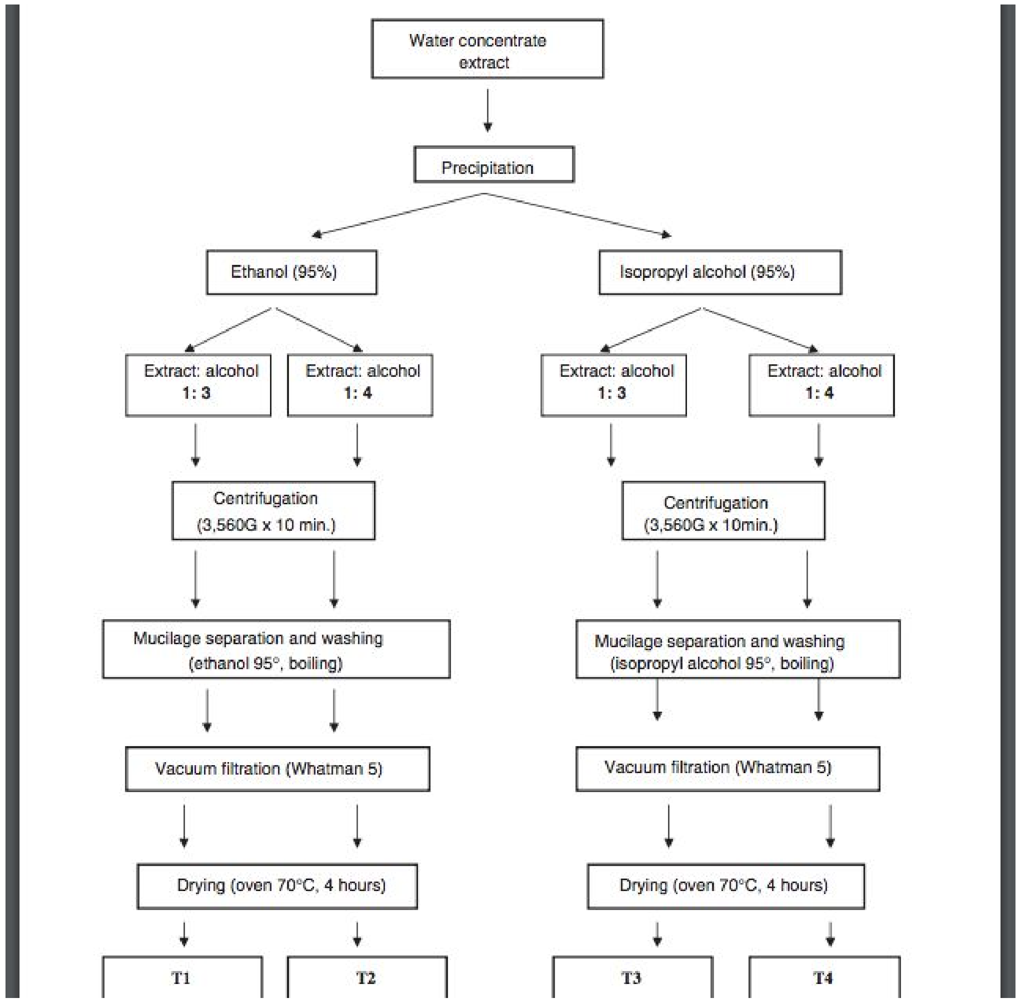


Figure 10. USF Efficiency Process Studies Extracting *OP Basiliris* mucilage

To broaden the knowledge of what the cacti mucilage can do, characteristics of arsenic were compared to other metals to predict what the cacti purifying limits are. Research is ongoing to measure these predicted characteristics through the use of graphene-based sensors.

Graphene-based sensors are devices that detect events, such as the presence of heavy metals, that occur in the physical environment and responds with an output, usually an electrical, mechanical or optical signal (Eyring 2012). These devices have been used detect heavy metals in water based on their unique electrical properties (Natarajan A. T, 1996).

THE CASE FOR IMPLEMENTATION OF CACTUS MUCILAGE FILTRATION SYSTEMS

As described above, the topic of water pollution, and even water pollution by heavy metals, are still very broad subject areas and span research being conducted in multiple disciplines. However, data has indicated that one of the most critical water pollution issues which is leading to health issues and deaths around the world that needs to be addressed is the arsenic contamination problem. The remainder of this paper will focus on research regarding arsenic contamination and effectiveness of arsenic filtration systems

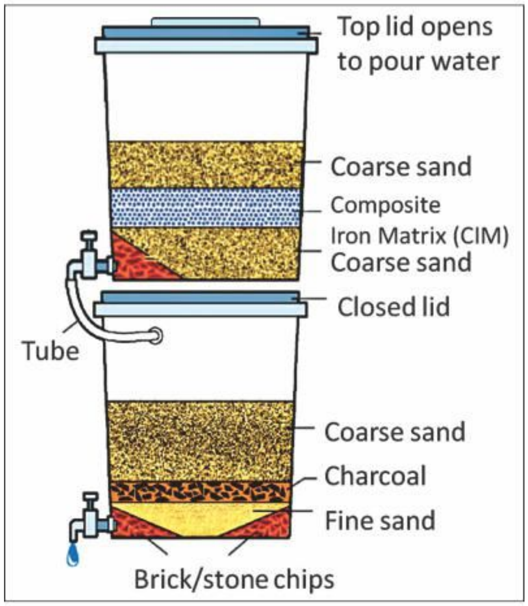
The relation between water pollution and human health has been a topic of conversation dating back to at least 1976. With all the focus on air pollution at the time and its effect on health, research by Rajidar K. Koshal claimed to be the first to be the first to identify effects the water pollution has on humans. It was concluded that the implementation of water filtration systems was the answer, specifically chlorine in the matter of cleaning water using an element easy and safe to apply (Koshal 1976). Since then, researchers have been able to specify what sediments are the most contaminating and which are having the biggest result on people. In 2010 researchers concluded that while research didn't specifically connect water pollution to human health until the 1970's, it has been evident to many that water quality was influenced by its surroundings in a negative way long before then. *Scientific American*, the oldest science journal that is publishing today, wrote a brief passage about a newly found problem of water pollution caused by recently introduced iron pipes that ran water from Boston to South Boston. While this article was more concerned with the pipes being able to be used, it shows how early water picking up sedimentary particles had been identified.

As introduced previously from ResearchGate's article *Global Water Pollution and Human Health*, Arsenic has been found to be one of the most harmful substances in water. This claim was supported by Masud Karim's article *ARSENIC IN GROUNDWATER AND HEALTH PROBLEMS IN BANGLADESH* written in 1998 which highlights the details of the common problems experienced by those who ingests arsenic contaminated water. "Arsenic poisoning can lead to skin lesions, hyperkeratosis, skin cancer, liver disease, etc"(Karim 1998), and "arsenic can interfere with DNA replication, DNA repair and cell division. Earlier studies have shown that arsenic can inhibit ligation of DNA strand breaks and if present during DNA synthesis, it can induce chromosomal aberrations, sister chromatid exchanges and malsegregation of chromosomes"(Natarajan et al., 1996). These articles show the health risks people are facing due to arsenic contaminated water. Arsenic is well known to be harmful, but as introduced by Donald R. Runnell a researcher working at Colorado State University, article, *Metals in Water*, a question posed in many previous articles, including Masud Karim's article about Bangladesh's water pollution, is what could this pollution could be a result from. Runnell's studies assessed various mountain valleys including Red Mountain and Mississippi. He provides the example, "It is visually obvious that Red Mountain Creek is affected by metal-rich drainage from abandoned mines, waste dumps, and tailings piles"(Runnell 1992), which could answer the "how it happened question" when pertaining to metal contamination in this water.

While this, and similar discoveries, continue to help identify the sources of the problems, it takes the combination of research from many articles to identify potential solutions. After researching several methods previously introduced by literature reviews and noting flaws identified for each for specific situations, there is one method that has been identified as a potential strong fit for all situations. This solution, the use *Opuntia Basilaris (OP Basilaris)* as a filtration medium, has been studied by University of South Florida engineering professor Norma Alcantar and her team that are using the flesh from Prickly Pear cacti, called mucilage, to clean up toxins from water. With support from the National Science Foundation (NSF), Alcantar has spent the last few years confirming something that her grandmother told her years ago, that cacti can purify water. Alcantar's article is a 109 page literature review, going over every discovery they have made as well as those presented in other sources. Their main focus was strictly on the mucilage which is provided from the *Opuntia Basilaris*. This is a gap well explored by other article *Combining Ferric Salt and Cactus Mucilage for Arsenic Removal from Water*, by Dawn I. Fox. While the review by Alcantar focuses of mucilage, Alcantar also is credited for writing this article penned by Fox. Combining Ferric Salt, "was investigated as a flocculation−coagulation system to remove arsenic (As) from water" (Fox 2015), and therefore proved to increase ability of the already effective mucilage. To show how effective the mucilage is already alone, " 94% of the NE trials and 81% of the GE trials showed mucilage activity in transporting Arsenic to the air−water interface. For both extracts, 56% of the trials showed mucilage activity greater than the average performance of each extract. We observed that sometimes the GE was able to separate up to 50% of the arsenic in the water"(Thomas Pickner 2012), is an example given in the article *Removing Heavy Metals in Water: The Interaction of Cactus Mucilage and Arsenate (As (V))*.

Water pollution is a global threat to all countries, especially in developing countries such as Bangladesh and other South Asian countries. However, many of these countries do not have, or have not demonstrated, the ability to address this problem as it has been documented that only 40% of drinking water in Bangladesh is purified and that percentage does not even come close to the safety standard (Ahmad 1998). To address this issue, a method of purification is needed that is affordable and environmentally friendly for the health of the people and the benefit of the country's environment and economy. The use of *O. Basilaris* as a filtration medium could be the answer to this problem, as it has proven to purify water from various substances (As, Fe), and if it is safely contained, it can be used to address many, if not all all, of the toxic sediments within the contaminated water.

One of the actions taken to support developing countries in their battle against water pollution is the "Arsenic Removal Filter" and it's patented filtration device known as the SONO filter (Hussam 2007). The SONO filter is a simple device made of multiple layers of sand, and iron matrix, and brick, as shown in figure (11). It was a result of a challenge taken on by several engineers in the year 2007 and its was Dr. Hussam that developed the winning invention with his filter. The SONO filter only costs 35 U.S dollars to make and has been distributed to 20% of Bangladesh, the focus country of water pollution severity. However, many people in Bangladesh are not participating in this way to clean water. The answer, the SONO is to complicated and time consuming which has led it to not gain wide attention and attraction amongst the poor. To be truly effective, a filtration system must not only be effective at removing contaminants, but also address the social and cultural norms of the populations, in order to be successfully implemented.



The Sono water filter invented by Prof Hussam.

Figure 11- SONO Filtration System Developed by Prof Hussam

RESEARCH QUESTION

With the threat of sediment contaminated water impacting the population's health in many developing countries, a method is needed that will efficiently clear the poisonous metals being brought into the water. After proving its characteristics of purification, *Opuntia Basilaris (OP)* has been researched to the point where we know it can filter Arsenic, a heavy metalloid. The question this paper will focus on is; Is using Opuntia Basilaris mucilage a feasible, natural method that can successfully clean arsenic (AS) contaminated water in developing countries?

HYPOTHESIS

The mucilage provided from the *Opuntia Basilaris* has been proven to pick up sediment in contaminated water, more specifically the dangerous heavy metal, arsenic. When implemented in a filtration system, I hypothesise that the OP mucilage will be able to work at a high level when implemented into a practical water purifying operation. Null Hypothesis wise, this effort will underachieve its set goal and prove ineffective in implementation into a practical water purification systems. Additionally, assessment of the effectiveness for large scale implementation is beyond the scope for the the methods available to test this hypothesis.

METHODS

Meta-Analysis was used in the study connecting *Opuntia Basilaris* and its ability of water purification to a worldwide problem of sediment contaminated water. Scholarly articles were identified from sources such as Ebscohost, Google Scholar, and ResearchGate. The articles were published from 2008-2016, making them valid today and reflective of the most recent studies done on the topic, while allowing enough time to show the evolution of the research. After all the sources were documented, a SYSTEMATIC LITERATURE REVIEW was completed in order to recognize the papers reviewed and to detail the content. This information was later reduced and best fit to other data throughout this paper. The papers checked most often were those that tested arsenic concentrations and how their mucilage based solutions were able to make a positive impact. The principal tests done were done while using processed mucilage, meaning mucilage that underwent boiling and structure change in order to fit into the tubes used for the test. To verify this could be done on a larger scale outside of the laboratory, I reviewed a series of documents that gave examples of groups currently using muciage in their common purifying and cleaning systems for needed water. This research was primarily focused on use of mucilage by commercial fish farms in a variety of locations apply portions to clean waste in the water produced by the fish.

This large scale implementation was a key point of this research. From there, additional research focused on the different ways cactus mucilage was implemented and surprisingly there were not many other applications were mucilage was being used commonly. The University of Southern Florida released a set of lab reports published through Environmental Science and Technology (EST) that provided three of main data collecting articles that were current. Results were primary collected from these series of papers later to be reviewed for accuracy with other tests. Before investigating solutions that had already been done, background knowledge research was completed to determine in what specifically mucilage was and what characteristics allow it to filter out heavy metals, arsenic (As) specifically. Ten of the fifty papers reviewed were characteristic specific to certain cacti varieties which provided data on what type of cacti would prove most efficient. Articles also referenced the interaction between Ferric Salts and Cacti Mucilage, and worked on by the same researchers, Dawn I. Fox and Norma Alcantar as well as Thomas Pickner. The articles above show how water pollution and arsenic contamination has been previously addressed and why water pollution is such a problem. The next steps is to look into the gaps of other substances that have or could be used in combination with the cactus, and what locations need this new technology of filtration.

GAP STUDIED

After researching characterization of different types of cacti, heavy metals in water, and methods used combining the three aspects of my research, it was time to compile ideas taking into account all of the following. With my decided type of cactus being the *OP Basilaris* and the restriction of not being able to test a variety of combinations between *OP Basilaris* mucilage and other heavy metals, it was simple to pick one that has had previous tests, making my focus quite clear. Completing the research, it was found that the information lacking the most was the methods of implementations. While used commercially in fish farms, the fish farms problem wasn't arsenic getting into the water. There were no other solutions cited that specifically tied commercial use of cacti musilage to arsenic removal. This transition is the gap investigated by this paper.

RESULTS

SOURCES OF RESULTS

Table 1. Percentage of Arsenic Before and After Various Mucilage Treatments.

	% Concentration AS pre-mucilage treatment per ug/L	% Concentration of Arsenic per ug/L-after
Processed mucilage	63	15
Opuntia Basilisas pads	63	23
Ferric salt + OP Mucilage	63	7

	% Concentration Arsenic cleaned with Mucilage-bef ore	% Concentration of Arsenic per ug/L-after
Processed mucilage	56	30

Opuntia Basilisas pads	56	32
Ferric salt + OP Mucilage	56	6

Artifically Contaminated water with Arsenic	% concentration of arsenic per ug/L	% Concentration of Arsenic per ug/L-after
processed mucilage	90	43
Opuntia Basilisas pads	90	47
Ferric salt + OP Mucilage	90	19

DISCUSSION

Results presented in table (1) demonstrate that applying *OP Brasileiras* mucilage to Arsenic (As) contaminated water is effective in clearing 75% to 90% of the toxic sediment (Alcantar 2012). Tested within test tubes, the mucilage undergoes a FloC process that clumps together As and the different selected mucilage combinations and forms to indefinitely improve the conditions of the once contaminated water. The hypothesis was proven to be correct as all the tests showed a positive trend of high percentages of arsenic removal. In the developing countries that need this method of natural water purification, all various variables pertaining to type of mucilage administered worked. Test 1 tested Bangladesh's water , Test 2 , India’s water, and Test

3 was a reenacted artificial version of water from the Mediterranean sea. The combination of Ferric Salt and *OP Basilaris* mucilage proved most effective, averaging out a 85% removal percentage. Giving us a clue what to implement in the future development of water purification inventions, providing a liquid solution that can be mixed with other substances that can combat other metals of issue later to arise.

This Arsenic Treatment Purifier (ATP) theoretically developed would work as it combines the successes of other elements. The water pumped would carry water and the arsenic embedded inside the water in a pressurized fashion into the front half of the ATP. It would then be sent into a lower compartment where the synthesised mucilage and Ferric Salt combination would be resting. The FloC process would then occur and the arsening would form clumps with the mucilage combination, weighing it to the bottom. The remaining water particles would be them pushed into the back section where the water exit is located.

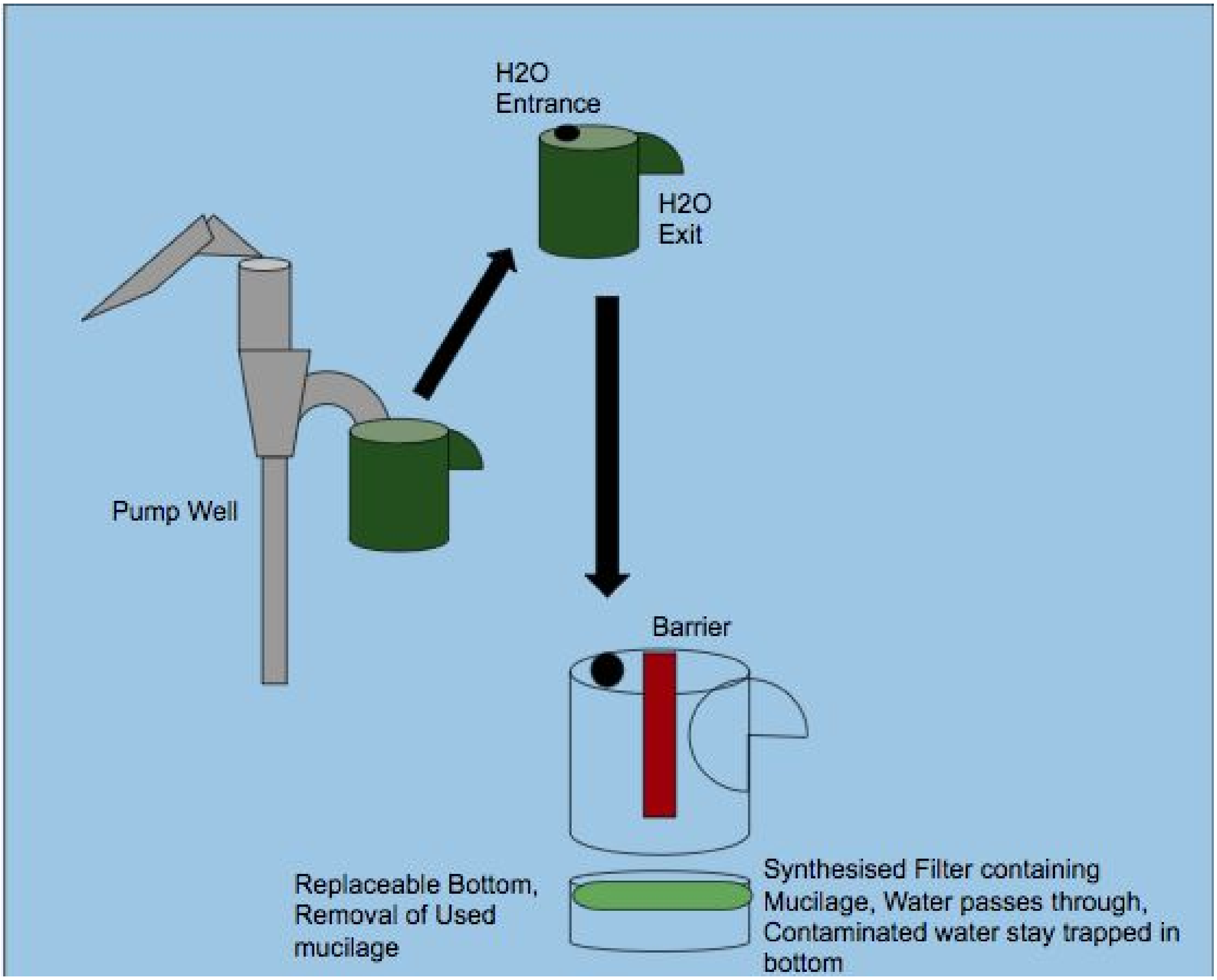


Figure 12. Theoretical ATP solution to Water Pollution in Well Water

The drawing in figure (12) was done as a theoretical solution to the problem of arsenic contamination based on the data analysis of previous research done in this area. The goal of this design was to provide a method that could be easily implemented in developing countries that uses pump or tube wells as a primary water source, for example 90% of the population of Bangladesh relies on these wells for water (Hussam 2007). The wells don't go deep into the ground as affordability plays a role on the depth of which is drilled for the water leading to more contamination from ground runoff of industrial waste. Another factor considered in the design was to ensure that any potential solution would be socially acceptable in these areas that have culturally relied on wells for their water. The sketch in figure (12) is a filtration device that theoretically can be made by combining successful attributes of a water treatment plant with a synthetic filtering medium made up using the Ferric Salt and OP Basilaris combination proven in my results to have large impact on the amount of Arsenic (As).

FURTHER WORK

Development and implementation of the theoretical ATP (Arsenic Treatment Purifier) would be the next step in this research to prove if the hypothesis to the research question presented is correct. Developing the purifier and evaluating its performance under a variety of tests would be required its effectiveness under the stress of different water sources. Research could also be done on what other metals are possible to get filter out of in the heavy metal water, and if mucilage has the ability to do so. Additionally, different combinations of mucilage with other natural materials should be studied to improve the Ferric Salt *OP Basilaris* combination, however as of now this is the best combination identified to date. Additionally, if the *OP Basilaris* was desired to be grown locally to save costs, research would need to be conducted to understand if the *OP Basilaris* would affect the ecosystem, potentially causing more harm than good.

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