Entry into the Stockholm Junior Water Prize 2017

A Novel Purification Process for Extracting Potable Water from Contaminated Water for Developing Countries

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2. PRELIMINARY MATTERS

Abstract

The people from the poorest part of the developing countries have limited or no access to clean water. When presented with solutions, they are either expensive or unsustainable. With the aim to create a sustainable and nearly no-cost solution to this pressing issue, several methods and agents were tested. The abilities of Moringa seeds as a coagulating agent, charcoal as a purifying agent, and the boiling of the water an antimicrobial process to clean the contaminated water has been explored and reported. A solution was developed using a 3 step process that uses resources that can be derived with little to no cost. Based on the experimentation, it has been shown that potable water can be obtained from muddy water using these inexpensive agents/methods.

b. **Table of Contents**

c. **Key Words** Moringa oleifera, Coagulation, Charcoal Filtration, Water Purification, Potable Water, Muddy Water, Boiling Water

d. **Abbreviations and Acronyms**

Moringa - *Moringa oleifera*

e. **Acknowledgements**

Thank you to my father, Dr. Raj N. Rajmohan, for providing me with the supplies necessary for this study. Also, thank you to my mother for supporting me as well throughout this study.

f. **Biography**

Vignesh Rajmohan is a student at J. L. Mann High School in Greenville, South Carolina. He has a passion for science and technology that drives him to explore its many fields, inside and outside of the classroom. His interests consist of anything in the numerous fields of science, piano, track and field, volunteering at the local science center, toying with circuits and robotics, playing with his dog, programming, and creating music digitally. In the future, he wants to study robotics engineering and start a company that creates devices that deal with robotics.

3. INTRODUCTION

Currently, 663 million people around the world lack access to safe drinking water [1]. This tragedy can be experienced firsthand when visiting small villages in the southeast region of Tamil Nadu, India such as Perungulam, Alagankulam, and so on. A few decades ago, families living in these villages had to rely on nearby muddy and filthy ponds for all of their water-related needs such as bathing, drinking, etc. These ponds stored rain water for the villagers until they dry up. Nowadays, there is always an option of purchasing bottled water for drinking. However, still the underprivileged have to rely on these muddy water ponds for their needs, which include drinking.

Over the years, several solutions have been proposed [2-7] to address these crises. Some of these include germicidal tablets [2] which need to be constantly replenished and the obtained filtered water is prohibitively expensive for the poor living in these villages. Another solution is the LifeSaver® Bottle which contains a carbon filter with 15 nm holes to prevent even the smallest virus from passing through

[7]. The reality of the situation was that these solutions were impractical because of their expense and logistics involved in getting those technologies to the people in need. In practice, a powerful solution to this crisis would have to be simple and would have to use the material easily available to the people living in these locations. Imagine if one needs to distribute only the information to the people about cleaning the muddy water by using few simple steps with easily available materials. That kind of solution not only provides clean drinking water for their everyday life but also empowers them with the technology they can easily adopt. Even some can start their own business of making clean water and sell it to others in their village at a very low cost.

Water is not potable when it contains infectious microbes, chemical impurities, and/or fine solid matter dissolved and dispersed into it. A coagulating agent is necessary for the removal of the colloidal mud/dirt, a purifying agent is required for the chemical impurities (chlorine, VOCs, etc.), and an antimicrobial agent is necessary to rid the water of infectious microbes. Coagulants work by neutralizing the negative electrical charge on particles, which destabilizes the forces keeping colloids (particulates) apart, which results in their conglomeration [8]. Simple chemical purifying agents (activated charcoal) work by allowing the water to pass through its fine pores and bind these small chemical impurities to itself [9]. The antimicrobial processes work by creating an uninhabitable environment for the microbes inside of the water (raising the temperature, using radiation) to kill the microbes.

Upon researching for the coagulating agent, one would frequently come across the widely used coagulant known as Aluminum Sulfate. Aluminum Sulfate, commonly known as alum, is currently the most popular coagulant for large scale operations for water purification because of its low cost and high availability [10], but it has been proven to have a negative effect on the environment and human health [11]. Research was conducted by Miraji Hossein of the University of Dodoma, Tanzania in which alum was compared with a natural coagulant known as *Moringa oleifera* [12]. The Moringa plant produces seeds that, when crushed up and dissolved in water, would attract all of the mud particles together and yield transparent water. Also, the *Moringa* plant grows wild in some of the regions that have a lack of potable water [13]. Based on that research, it would be beneficial to use the powdered *Moringa oleifera* seeds as the coagulating agent in the first step of the three-step cleaning process.

A purifying agent is necessary for removing chemical impurities from the water after removing the mud. Examples of chemical impurities are volatile organic compounds (VOC), which include methylene chloride and perchloroethylene, both of which are harmful to human health [14]. Activated carbon is a successful purifying agent used in homes and industries everywhere. Activated carbon has numerous fine holes that yields a large surface area for purification purposes. Since making activated carbon is an involved process, to make the process easier and readily adaptable to the poor in the developing countries, activated carbon can be replaced by regular charcoal. Regular charcoal is versatile and can even be made using primitive methods by exposing carbonaceous materials such as wood pieces, coconut shells, etc. to high temperatures in an oxygen restricted environment. This can be achieved by using mud enclaves, a technology that most ancient civilizations were familiar with.

Finally, for an antimicrobial process, several methods proved to be successful. The use of Titanium Dioxide with the addition of sunlight is a successful method of antimicrobial water purification [15]. Pure, titanium dioxide is not readily available in the environment and certainly not accessible to the poor in the developing nations. The boiling of water, a commonly known practice which causes all of the microbes to die, is sufficient for ridding the water of viruses, pathogenic bacteria, and protozoa [16]. The simple boiling of water is very plausible in developing countries, making it a perfect candidate for the antimicrobial process in the three step process.

The ultimate aim of this work is to develop an affordable and completely self-sustainable method of water purification that can be adopted by the people who need it most. Since most of the processes of charcoal purification and boiling of water are very well known, this paper mainly presents the results of *Moringa* seed treatment and provides a methodology for charcoal filtering.

4. MATERIALS AND METHODS

The *Moringa oleifera* seeds were purchased from Amazon.com for this experimentation and these were sent from Thailand, where they were grown and harvested. A pack of hardwood charcoal used for this work was also purchased from Amazon.com. The “First Alert” water test kits were also purchased from the same website. An electric centrifuge was used to speed up the experimentation process of separating the coagulated particles from the liquid. The other materials used in this experiment were 20 mL centrifuge test tubes with caps, mortar and pestle, glass containers, a pipette, test tube rack, gloves, safety glasses, lake water, electronics balance, measuring cup, cotton balls, and mud. The lake water was acquired from a local lake with relatively transparent water. Also, a color picker app was used for water color determination, the app used was “Pixel Picker” developed by Andrea Bizzotto.

4.1. Muddy water

The muddy water observed in the villages of the southeast region of Tamil Nadu, India, is a colloidal solution of mud in the rain water. The lake water collected for this experimentation in was clear and transparent. To simulate the muddy water for this experimentation, similar to the pond water mentioned above, the red clay soil commonly available in Greenville, South Carolina, USA was used. Every 200 mL of lake water was mixed with 5 grams of red clay mud in a container that was then shaken for about 1 minute to disperse the mud particulates evenly. In order to separate the colloidal muddy water from the sediments, 6 centrifuge tubes were filled with 15 mL of mud/water mixture and were then centrifuged for 2 minutes at 2000 rpm. After the centrifuging time had elapsed, the test tubes were gently removed and the muddy colloidal water solution was carefully separated into a glass container without allowing the settled mud particles to leave the test tubes. These steps were repeated until 150 mL of muddy colloidal water was made and stored carefully for the experimentation.

4.2. *Moringa* powder

The *Moringa oleifera* seeds were de-shelled and ground into a fine powder as shown in fig (1) by using a mortar and pestle. The powder made from the core of the seed was then carefully placed into a sterile jar and stored for future use.

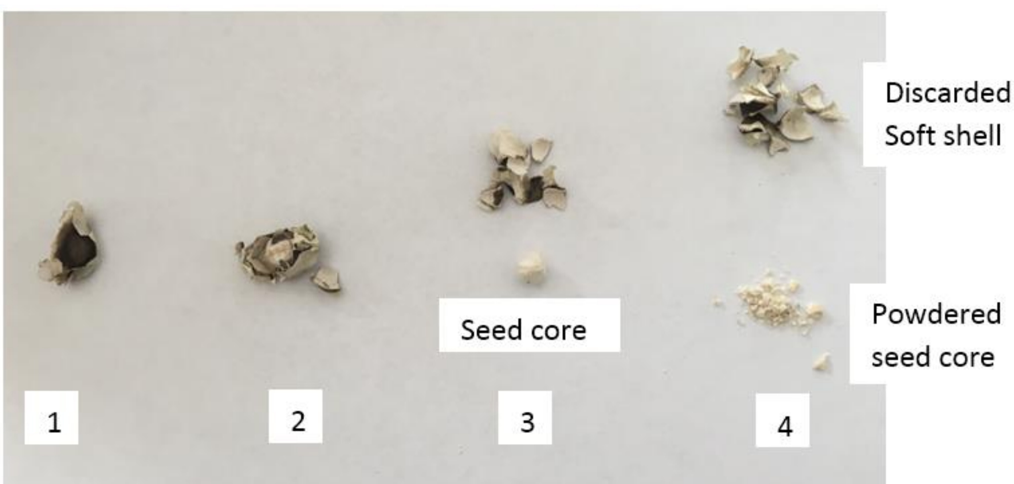

Fig. (1). Stages of making *Moringa* powder from its seed

4.3. *Moringa* Experimentation

Exactly 10 mL of muddy water colloidal solution was taken in each of 16 test tubes. Every 4 test tubes were numbered 1, 2, 3, and 4 and categorized into a separate set to make a total of 4 sets. The first set of 4 test tubes were used as controls to study and compare the strength of the initial muddy water color using its RGB value. The RGB values were determined by using an RGB Color Picker app on an iPhone-6 camera by taking images of the tube at a constant location with controlled lighting arrangement. The control sample of initial muddy colloidal water is presented in fig. (3) in the results section.

Then using an electronic balance, Moringa powder was weighed to measure 0.1g, 0.3g and 0.5g and added to each of the remaining 3 sets of 4 tubes. That's first set of 4 tubes were added 0.1g of Moringa powder and the second set of 4 tubes were mixed with 0.3g of Moringa powder and third set of 4 tubes were then mixed with 0.5g of Moringa powder each. Every tube was sealed with its lid and shaken for 20 seconds by holding the lid tightly in place on the tube. After this 20 second mechanical shaking, the test tubes were centrifuged for 2 minutes at 2000 rpm to get the colloidal mud to coagulate. The carefully topped off water from each test tube was then imaged similar to the control samples using the same iPhone and analyzed using the same RGB Color Picker app. The RGB value of each tube was carefully measured and duly noted down for comparison. The results are presented in fig. (5) as graphs for easy comparison.

Moringa powder is hydrophilic and it absorbs some of the water it treats. The yield of treated water was also measured as a metrics of the Moringa experimentation and presented later in the result section in fig. (6).

4.4. RGB Ratio Calculation

To make a meaningful comparison out RGB values of all the solutions explained in the previous section, RGB ratio was calculated by taking R to the G+B values. For example, if the RGB values are R=212, G = 213, B = 204 then R/(G+B) = 212/(213+204) = 0.508. The calculated ratio for each solution can provide a better comparison to understand the cleanliness of the *Moringa* treated solutions and to compute the optimum *Moringa* powder weight for a given amount of muddy water.

4.5. Charcoal Filtration

After removing mud from the muddy colloidal solution, the solution was treated with charcoal filter. The charcoal filter was made by poking a hole in a test tube and placing a layer of cotton at the bottom of the tube before filling the tube with charcoal as shown in fig. 2.

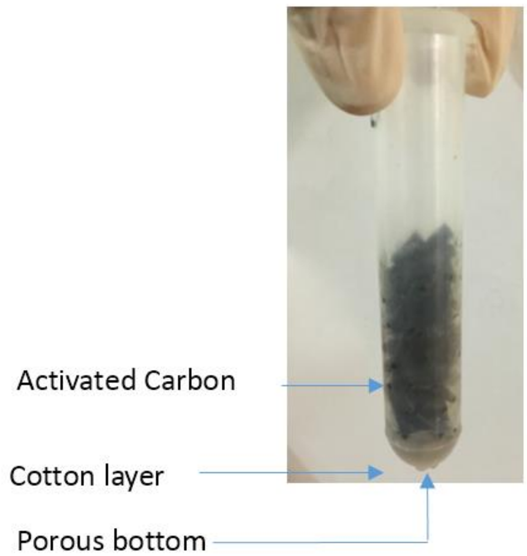

Fig. (2). Charcoal filter

Moringa treated and centrifuged mud removed water was then allowed to pass through the charcoal filter to remove the chemical impurities. The color of the resulted water is presented in fig (4) along with various *Moringa* treated water solution.

4.6. Boiling of water

The boiling of water is a proven method for removing active microbes in any solution. This can be carried out at any place as long as the individual making the clean water as explained in this paper is accessible to dried plant material such as firewood or dried leaves and tree branches. For this work, 20 mL of *Moringa* and carbon-treated water was placed in a glass container and heated until the water started boiling.

4.7. “First Alert” Drinking Water Test

To compare each step of the muddy water to potable water process, the “First Alert” Drinking Water Test was conducted on the selected solutions due to the cost of the test kid. Firstly, 10 mL of muddy water was tested with “First Alert” Drinking Water Test. This was then followed by 10 mL of *Moringa* processed water. Finally, 10 mL of the Moringa and charcoal treated and boiled water was tested. All the values obtained using this test kit such as deadly microbes (Ex: E. Coli), Lead, Pesticides, Nitrates, Nitrites, Chlorine, Hardness, pH were noted and presented in table-1 in result section below.

5. RESULTS

The color of the control and the *Moringa* treated solutions can be seen figs (3) and (4) respectively. The RGB ratio R/(G+B) plotted against various *Moringa* concentration is presented in fig. (5). The amount of water clean water yielded versus the amount of *Moringa* used is as explained in the Moringa experimentation is presented in fig. (6). The results of “First Alert” Drinking Water Test is presented in Table. 1.

Fig. (3). Muddy water before *Moringa* treatment.

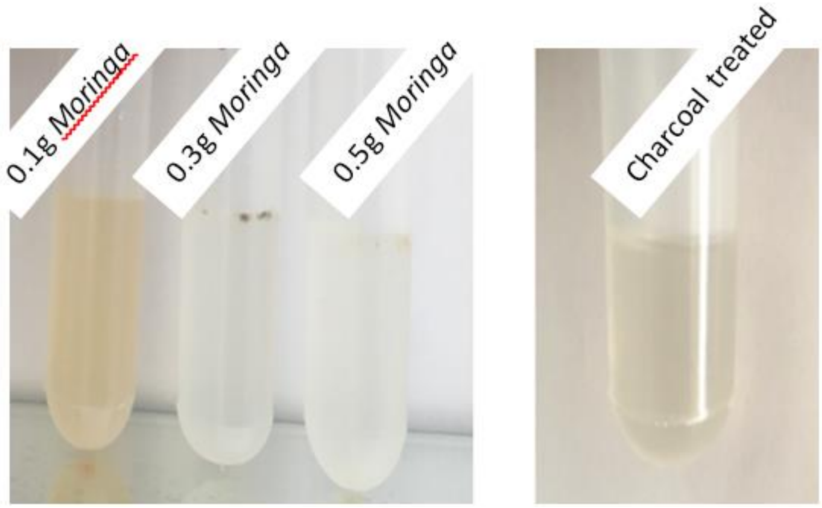

Fig. (4). Colors of Moringa and charcoal treated solutions

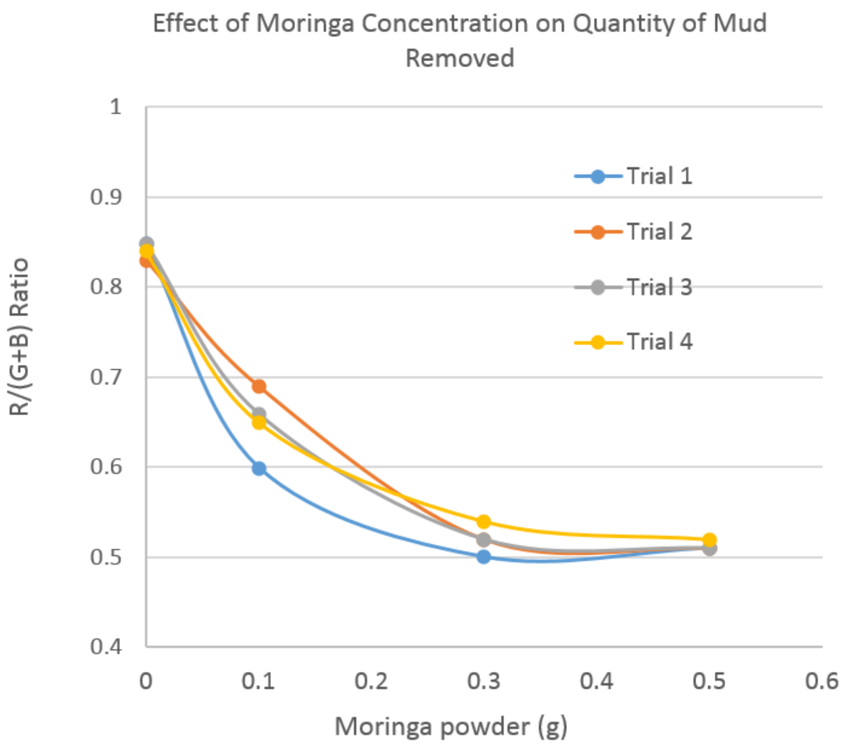

Fig. (5) Line graph showing the effects of the amount of *Moringa* used per 10 mL of water on the color of the treated water

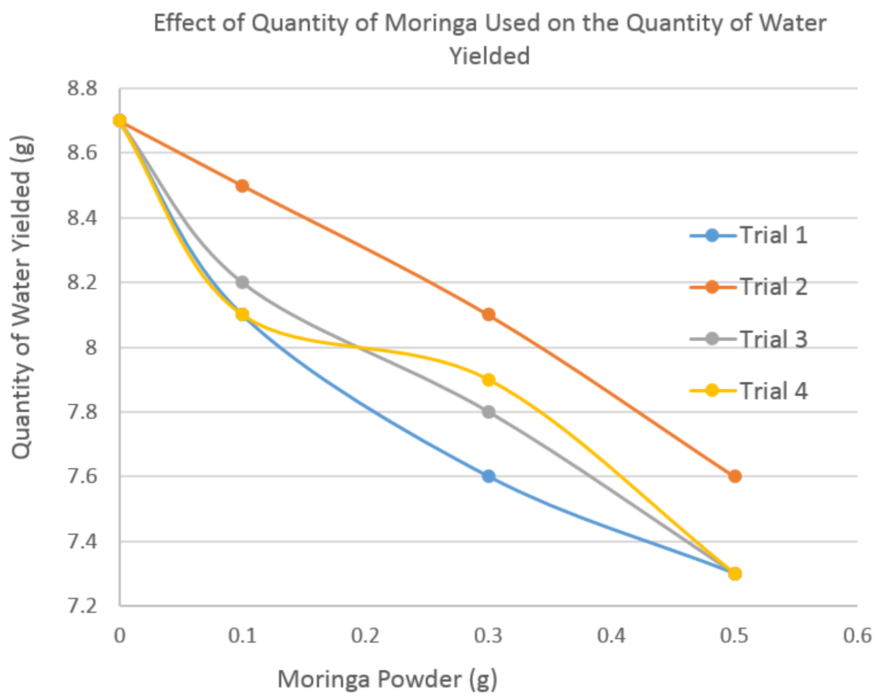

Fig. (6): Line graph showing the effects of the amount of moringa used per 10 mL of water on amount of water yielded

Table 1: "First Alert" Drinking Water Test results

First Alert Water Test	Muddy Water	Moringa Purified Water	Moringa + Carbon + Boiling
Deadly Microbes (E.Coli)	No	No	No
Lead	0	0	0
Pesticides	0	0	0
Nitrates	0	0	0
Nitrites	0	0	0
Chlorine	0	0	0
Hardness	50	120	120
pH	7.5	7.5	7.5

6. DISCUSSION

As explained previously in this paper, the 3-step process of obtaining potable water from the muddy pond water can be explained in the following flow diagram for clarity.

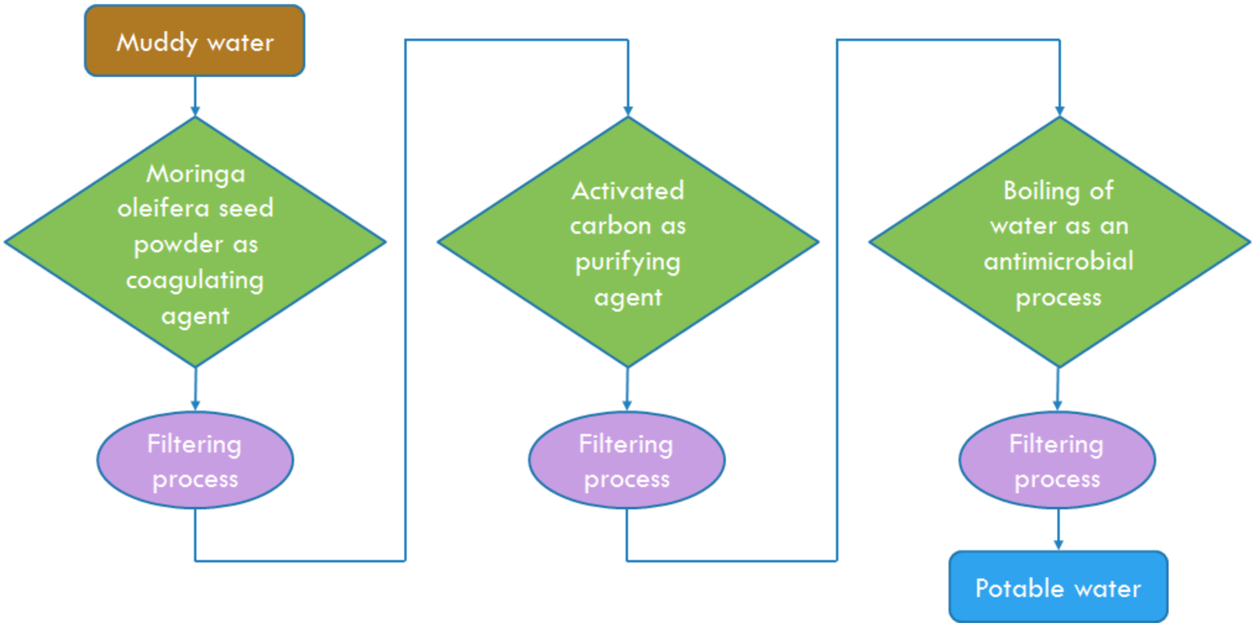

Fig. 7: Flow diagram of the simple and inexpensive water treatment technique

The fig. (3) and (4) shows the visually observable color differences of the *Moringa* and charcoal-treated water. The use of a color scale for water turbidity determination provided accurate results, as proven by the study done by Yizhang Wen, Yingtian Hu, and Xiaoping Wang of Zhejiang University [18]. A simple and novel method as explained in section 4.4, RGB ratio was determined for 0.1g, 0.3g and 0.5g treated water and presented as graphs in fig. (5). Here all 4 trials show the similar trend. The initial muddy sample before the moringa treatment shows an RGB ratio value of 0.83 - 0.85 as the water was redder in color. By treating with 0.1 g of moringa, the RGB ratio came down to a range of 0.6 – 0.69. However, muddy water treated with 0.3 g moringa settle to a range of RGB ratio 0.5 – 0.54. Increasing the amount of moringa to 0.5 g to treat the muddy water, did not alter the RGB ratio as much. It is important to note an RGB value of 0.5 on the white background means that water is very clean and does not have mud particulate contaminations. This is because, when the RGB values are R=255, G=255 and B=255 for a pure white color, RGB ratio namely R/(G+B) would be equal to 0.5. For a predominantly red color solution pictured on the same white background as with the case of muddy water with red clay showed a higher R-value compared to G or B. That is the reason for the RGB ratio of around 0.8 for the muddy colloidal water used for this experimentation. Apart from coagulating the colloidal mud particulates from the muddy water, moringa seeds also very good for health as a super food supplying necessary nutrients to human body [19].

The charcoal treatment had already been noted as a successful method [17] along with the boiling process [16]. Regular charcoal although not as efficient as activated charcoal due to its smaller surface area, it removes chemical impurities when water is passed through it [20] but not as efficiently as activated charcoal. In the present work, charcoal treatment slightly darkened the moringa treated clean water as shown in fig. (4). It is well-proven fact that boiling the water expected to kill all the active microbes that could affect the human health [16].

The use of *Moringa oleifera* for particulate coagulation was explored in the study done by Miraji Hossein, in which the use of moringa is compared with Alum. Because of alum's side effects to human health and the environment, the use of the natural coagulant moringa was explored [12]. The study done in this report differs in that it also determines the optimal amount of moringa and dives into to other steps of water purification to create a full muddy contaminated water to potable water process for developing countries.

The simple "First Alert" Drinking water test showed drinkable water did not reveal any major issues with the treated water (refer Table.1). Though these type of tests are not very accurate, they can alert the user of any abnormality in terms of unwanted contaminations.

As stated before, the 3-step process explained in this paper is simple, inexpensive, self-sustainable, and the raw materials used for this process are already available in locations where the muddy water is available and potable water is lacking. Though the presented technique is not going to solve all the 660 million people lacking potable water (this method requires access to some body of water), definitely several million would benefit from this technique. This process can significantly improve the lives and economies of countries that are suffering from this water crisis because access to clean drinking water has been proven to increase education in these countries which also directly causes economic growth.

Currently, further extension of this research is being carried out to make charcoal out of coconut shells to clean the water. Wherever the moringa is available, coconuts are also available as the environmental conditions needed for coconuts are the same for Moringa trees. Combined with Moringa coagulation, the coconut shell charcoal filtering treatment would prove to be a powerful cleaning treatment for muddy water. This project can be further explored by looking into other natural coagulators to increase the versatility of the three step process developed here. Also this process's novelty may also make it useful in regions that do not have a crisis, but simply need water purification for non-vital tasks. The development of a device that completes these processes would be useful to hikers and travelers in first world countries such as the United States.

7. CONCLUSIONS

1. *Moringa oleifera* is a natural coagulant that successfully removes mud particles from mud contaminated water. By dehulling the moringa seeds, powdering the seed cores, and stirring the powder in a mud water solution, the mud coagulates and settles to the bottom. Transparent water can be easily separated from the mud.
2. The optimal amount of *Moringa oleifera* seed powder is about 0.3 g for every 10 mL of muddy water. The use of this optimal amount allows for the most water to be retained in the form of decontaminated water for a minimum amount of moringa powder.
3. Unlike commonly used coagulant alum, moringa powder is healthy as it is a superfood providing not only the clean water but also the necessary nutrients needed for humans. Moringa, unlike alum, is a natural coagulant and is not harmful to the environment.
4. Further purification of water after Moringa treatment by removing dissolved chemicals can be developed through the use of the normal charcoal filter as explained in fig (2) using a small piece of cotton or fabric, and a tall container.
5. Among various possibilities available in the market for removing the active microbes, boiling the water using dried plant matters such as wood, twigs, and leaves is a proven way to kill microbes.
6. The combinations of moringa powder as a coagulation agent, charcoal as a purifying agent, and the boiling of water as an antimicrobial process allow for an inexpensive way to produce potable water from muddy and contaminated water.

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