De la Salle Santiago Zobel School

Senior High School

STEM Strand

Distillation via Solar Disinfection and Rapid Sand Filtration on Reducing Pathogens and Contaminants in Water

Submitted to:

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In partial fulfillment of the requirements for

Research 3: Scientific Research

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January 2018

ACKNOWLEDGEMENTS

We would like to thank our colleagues from De La Salle Santiago Zobel School for providing insights that have greatly assisted in the completion of this research. We would like to thank Mr. Fritz Ferran for guiding and supporting us by answering our questions and helping us correct mistakes. Finally, we would also like to extend our gratitude to Mr. Tomas Santos for providing physical support in the construction of our necessary research devices.

ABSTRACT

Water is a necessity for all human beings and is used for a variety of activities including cleaning, cooking, and drinking. Despite this, many underdeveloped countries lack access to clean drinking water. The research aimed to examine the effects of a three-phase purification procedure consisting of rapid sand filtration, solar distillation, and sterilization on 5 sewage water samples. It found that the subjection of the samples to the purification treatment caused a significant reduction in turbidity and the general presence of foreign contaminants. This was demonstrated by the reduced absorbance level and increased transmittance level for each wavelength of electromagnetic radiation (EMR), as well as the average normalization of the samples' pH levels to near 7. In addition, there was a significant reduction in the pathogenic content of the water as indicated by pathogenic density. It was recommended that the other factors of water potability be taken into consideration in future research, and that the purification device and procedures may be utilized on unsanitary water, but further purification would be needed before being considered safe for consumption.

TABLE OF CONTENTS

CHAPTER 1: BACKGROUND OF THE STUDY

I. Introduction

Water is a multipurpose tool used for drinking, washing, and cooking. It is essential to the survival of human beings, yet many developing countries lack access to safe and potable water. A country facing water scarcity is defined to have a drinking water supply of below 1,000 m^3 per individual. Populations where the supply drops below 500 m^3 per individual are said to be facing absolute scarcity (United Nations Environment Programme, 2005). Around 2.6 billion people live in areas of water scarcity, while another 1.6 billion people live in areas of shortage (United Nations Water, 2007).

Millions of people die yearly due to consumption of contaminated water, and most of them live without improved services. Diseases that are contracted due to its consumption include diarrhea, intestinal helminths, schistosomiasis, and trachoma, each of which contribute greatly to the mortality rate in developing countries (Elimelech & Montgomery, 2007). Poor sanitation and lack of potable water not only affects the lives of the people, but also the economy of the population. Not investing in water and sanitation costs 4.3 percent of the sub-Saharan African Gross Domestic Product (GDP). The loss of 6.4 percent of India's GDP is predicted to be due to the cost of inadequate sanitation. Efforts have been made by the World Health Organization and the United

Nations to counter this problem, including the creation of the Sustainable Development Goals, which aims to eliminate the problem of water scarcity and ensure the availability of sustainable management of water and sanitation to everyone by 2030 (United Nations, 2017). Without wanting to negatively affect the environment any further, eco-friendly water purification processes are the need for the hour. Studies in the past have been conducted on viable ways to purify contaminated water and make it safe for consumption.

Although previous studies in the past have shown that methods like distillation, solar disinfection, and rapid sand filtration are effective in removing contaminants, these processes were conducted individually. Other methods of treatment were required to finish the purification process. For example, the experiments conducted by McGuigan, Joyce, Conroy, Gillespie, & Elmore-Meegan (1997) only focused on the use of solar disinfection, which is used to eliminate pathogens in the sample. It did not take into consideration the removal of other potentially harmful substances in the sample including trace elements and chemical wastes. Likewise, the study conducted by Chuang, Tung, & Wang (2011) focused on determining the effectiveness of rapid sand filtration in eliminating trace elements like chlorine and haloacetic acids in the water, but not other contaminants like pathogens. This study aims to determine the effectiveness of using all three methods simultaneously to purify water. This would provide a deeper insight on how rural communities would be able to construct their own or adapt a water purification system when professional facilities are unavailable, and how the simple combination of several cheap procedures could prove more efficient in the process.

II. Conceptual Framework

As shown in figure 1.1, the study conducted compares the pH level, pathogenic content, and foreign contaminant content in untreated sewage water that is exposed to the treatment process with those of a control group of the same degree of water quality that is not exposed to the experimental treatment at all. The treatment includes the processes of solar disinfection, rapid sand filtration, and distillation in purifying water. These variables are linked through four major scientific concepts: the water cycle, ultraviolet mutagen, mechanical straining, and physical *adsorption*.

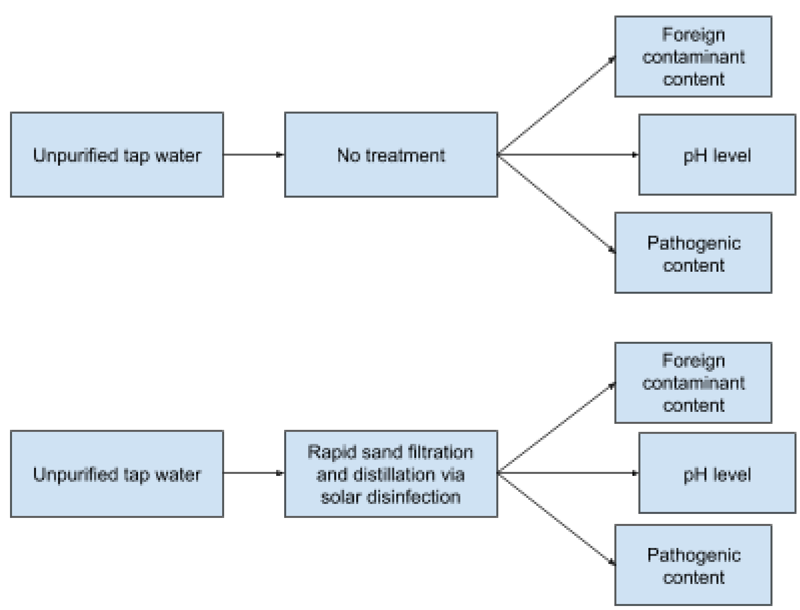

Figure 1.1 Effect of rapid sand filtration, distillation, and solar disinfection on the foreign contaminant content, pH level, and pathogenic content of water

The water cycle involves two particular processes: evaporation and condensation. Evaporation is the phase change that turns liquid water into vapor, its gaseous form. This occurs due to the decrease in the intermolecular forces holding the water molecules together. Condensation is the phase change that turns vapor back into its liquid form (National Geographic Society, 2012). Likewise, this is the result of the strengthening of intermolecular forces. These phase changes occur due to changes in heat, where additional heat provides the energy necessary for the molecules to overcome the attractive forces. As water may contain contaminants/ that require different amounts of heat to change phase, evaporation may be used to transform liquid water into vapor to separate it from such contaminants (Sharma, Srivatsa, & Madras, 2004).

Mechanical straining involves the use of another material to separate a solution from its solid contaminants. Particles that are too large to pass through the straining material are left behind. Physical adsorption involves the sticking of smaller particles to the surfaces of the material due the the Van Der Waals forces (Minnesota Rural Water Association, 2009). Certain chemicals known as flocculants may be added to improve adhesion (Schmitt & Shinault, 1996). These s may explain the effectiveness of the rapid sand filtration method, as the contaminants are stuck between and on the sand particles as the water passes through the medium.

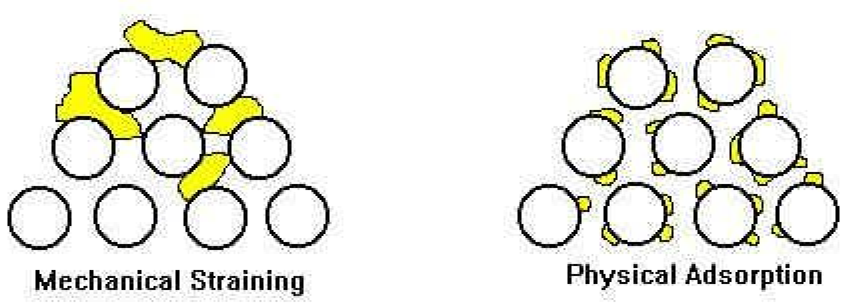

Figure 1.2 Schematic of the basic filtration principles (Schmitt & Shinault, 1996)

Ultraviolet radiation (UV) has been found to have mutagenic properties, meaning they cause hereditary changes in the DNA of organisms. UV is a form of non-ionizing radiation, wherein certain wavelengths excite the electrons in molecules. This causes the formation of extra bonds between pyrimidines in DNA, especially thymine (Evans, 1991). It changes the shape of the molecule and may cause complications during replication. Cells often attempt to fix the affected molecules, but often end up forming additional mutations. This may explain the effects of solar radiation on pathogens, as it itself contains UV.

III. Statement of the Problem

This research investigates the effectiveness of three methods of purification on making contaminated water potable. It primarily aims to support the findings of Heinonen-Tanski, Pessi, Pulkkanen, & Rajala (2003), who found that rapid sand filtration and subsequent UV irradiation are effective against pathogens and improving the overall quality of water. Unlike previous studies, the several methods of water purification will be implemented as part of a multi-step process through the use of a single device created by the researchers. Thus, this study attempts to answer the following questions:

1. What are the effects of the purification procedure on the pH and pathogenic content level of the sewage water?
2. Is there a significant difference on the presence of potentially harmful pathogens in sewage water before and after the treatment?
3. Is there a significant difference on the presence of foreign contaminants in the sewage water before and after the treatment?

IV. Significance of the Study

This study is intended to increase the understanding on the possible ways of purifying water, especially because most of the world does not have sufficient access to potable water. Some of these methods include solar disinfection and rapid sand filtration, both of which are used to remove foreign contaminants and pathogens in the water. Specifically, this research would be beneficial to rural communities and future researchers for the reasons stated therein:

Rural communities. The results of this research could provide possible solutions to the lack of potable water in rural areas. This would allow the construction of relatively cheap, yet effective, water purification systems. It would also be sustainable, as people could easily construct and maintain it on their own without the need of expensive equipment. This could reduce the mortality rates in their respective areas, as purified water may eliminate disease-causing bacteria and harmful water borne toxins. This water could be used for drinking, cleaning, and cooking.

Disaster-stricken communities. Areas that have been devastated by natural disasters such as earthquakes and typhoons may not have access to water processing facilities. The survivors would have to resort to eating and drinking what is already available to them. The water from nearby ponds and lakes may be contaminated by debris, and it is necessary to purify it for safe consumption. The methods investigated in this research may provide cheap alternatives that could easily be used even in times of disaster.

Future researchers. This would increase and inspire further research on the use of sustainable and recyclable materials in the creation of a water purification system. The results could be used by researchers in the development of a more efficient, and perhaps more effective device that could purify water in areas where water processing facilities are absent. This would also prove useful in the field of microbiology, as it provides further understanding on the effects of sunlight on various microorganisms present in aqueous solutions.

V. Scope and Delimitations

This study focused on determining the effectiveness of three methods of water purification, namely distillation, solar disinfection, and rapid sand filtration. The samples used for the study included only 5 samples of 500-ml sewage water due to the time constraints, as the experimental procedure took at least a day to complete for each sample. The experiments were conducted at the home of one of the researchers and the science laboratories of De La Salle Santiago Zobel - Vermosa. The construction of the water purification device and the experimental procedure lasted between September and November 2017. The experimental procedure was concerned about finding changes in each of the samples' pH levels, pathogenic content, and foreign contaminant content. The study was limited by the insufficient access to professional equipment, which did not improve the accuracy of the measurement of the dependent variables.

VI. Definition of Terms

The following terms are conceptually and operationally defined for better understanding of the readers:

- **Foreign Contaminants** - These include substances from human activities like fertilizers, pesticides, and industrial waste. They may also include chemicals from the natural environment like arsenic, salts, and fluorides (Bredero & Brikké, 2003).

- **Pathogens** - Otherwise known as biological contaminants, these are substances that are biological in origin and may cause illness when ingested. These include bacteria, viruses, fungi, and worms (Bredero & Brikké, 2003). In this study, pathogenic presence in water is measured in colony-forming units per milliliter (cfu/ml).

- **pH Level** - This refers to the potential of hydrogen of an aqueous substance. The value is within a range between 0.0 and 14.0, where any value less than 7.0 is acidic, and any value greater 7.0 is basic. Neutral substances have a pH level of 7.0 (Zumdahl & Zumdahl, 2007). In this study, pH is an indicator of the purity of the substance under observation.

CHAPTER 2: REVIEW OF RELATED LITERATURE

I. Introduction

This literature displays the efforts of previous researchers to formulate efficient and more effective ways to remove harmful substances in water in order to improve its potability. Methods such as rapid sand filtration, solar distillation and disinfection have been proven effective in eliminating foreign impurities in water. Certain materials are capable of straining water to separate it from foreign contaminants, including sand and gravel support (Schmitt & Shinault, 1996; Arndt & Wagner, 2003; Shirasaki, Matsushita, Matsui, Oshiba, & Ohno, 2010). This literature provides extensive study on the qualities of potable water as well as several methods to purify contaminated water. However, it also presents relevant gaps, particularly on the efficacy of these methods in rural scenarios.

Qualities of Potable Drinking Water

The World Health Organization (2004) defines potable water to be free from harmful chemical constituents, radioactive material, and pathogens, and must also be free of tastes and odors that would be considered unappealing for the majority of consumers. It must also be free from variables that can have an indirect effect such as colour and ammonium. Water that is contaminated or does not meet these guidelines poses a threat to the safety of its consumers, especially young children and the elderly.

The World Health Organization (2017) specified that there are certain conditions of quality that the samples must pass in order for the water to be considered as potable water. Three conditions are taken into consideration: microbial water quality, chemical water quality and source waters. Each of which have specific requirements. Microbial water quality includes the testing for *E. coli,* a dependable indicator of fecal pollution. Chemical water quality takes into account multiple factors, including the availability of appropriate analytical facilities, possible deterioration of samples, stability of the contaminant, and the occurrence of the contaminant in various supplies, among others. Source water specifically depends on the place where there is no water treatment (World Health Organization, 2017).

According to Meierhofer & Wegelin (2002), many pathogens are transmitted through water. This, in addition to poor sanitation, is the leading source of infection and disease. Bacteria such as Vibrio cholera, Shigella, Salmonella, and E. coli are some of the most common waterborne pathogens. Water sources are easily infected by the human and animal feces (World Health Organization, 2004). Some of these bacteria are also known to produce toxins, known as “cyanotoxins.” In addition to bacteria, other biological hazards such as worms need to be accounted for. These waterborne microbes could be transmitted by other routes, including person-to-person contact, droplets, and food.

Chemical constituents in water has a different effect on humans as compared to that of microbial contamination (World Health Organization, 2004). Health effects are felt after prolonged periods of exposure. In most cases, water that has been chemically contaminated will be considered undrinkable due to its taste, odor, and appearance. Prolonged exposure to high levels of fluoride, which occurs naturally, could lead to tooth decay and skeletal fluorosis. Arsenic is another compound that occurs naturally and may result in cancer and skin lesions. Other chemicals are introduced into the water supply as a result of human activity, examples being nitrate and nitrite, which are associated with *globinaemia* in infants. These compounds appear due to the overabundance of fertilizers and organic wastes in groundwater (World Health Organization, 2004).

The pH level of water, while not directly relevant for the consumer, is an important part of the purification process (World Health Organization, 2017). It is used as an indicator for disinfection and decontamination. For optimum disinfection of water with chlorine, the pH must be less than 8. However, the operational pH level should lie within the 6.5 - 8.5 range. This value may differ depending on the composition of the water, especially with the presence of certain foreign contaminants. Extreme pH values may either be overly corrosive or alkaline. In the case of professional water purification systems, the causes of such extreme values include accidental spills and treatment breakdowns (World Health Organization, 2017). There is no recommended standard guideline on the optimum pH level of water in regards to health.

Measurement of Waterborne Contaminants

The pathogenic content of a substance could be measured using the heterotrophic plate count method (HPC). It measures the colony formation of heterotrophic bacteria in drinking water. It also allows the measurement of the overall bacteriological quality of potable water. According to Reasoner & Geldreich (1985), plate count agar is the recommended medium for the HPC method at 35 ^{o}C. However, results showed that plate count agar does not allow certain bacteria that may be present in water to multiply and grow. This led to the development of a new medium known as the R2A. It contains ingredients that would facilitate the growth of more bacterial samples compared to that of the regular plate count agar. Results from parallel studies with multiple “waterborne contaminant measurer” procedures showed that the R2A medium yielded a significantly higher bacterial count than the plate count agar (Reasoner & Geldreich, 1985). This allowed a more accurate measurement of the bacterial content in water.

The chemical content of water is most often measured through UV-visible spectrophotometry (Thomas & Burgess, 2007). It is based on the principle that electromagnetic radiation (EMR) has various effects on the interaction with molecules and atoms. These interactions produce emission and absorption patterns specific to the molecule or atom in question. According to the Beer-Lambert Law, the absorbance of a substance is directly proportional to its concentration (Hardesty & Attili, 2010). Using this information, one may measure the concentration of a particular mineral or chemical in the substance. Spectrometry has been found to be effective in detecting the presence of oil and grease in water (Pisal, 2009). The device used was accurate with a detection limit below 0.5 mg/L. Lai et. al (2011) used photonic crystal spectroscopy to identify the presence of xylene in water, finding the device to be five times more sensitive compared to other devices.

Rapid Sand Filtration

Rapid sand filtration is the process of moving water through a granulated medium to remove any particulates that are contaminating it (Minnesota Rural Water Association, 2009). It is distinguished from other forms of filtration due to its speed. It is 40% faster than slow sand filtration (Schmitt & Shinault, 1996). One of its major drawbacks is that it must be maintained daily through a process known as backwashing, where the flow of water through the medium is reversed. According to Rittmann & Snoeyink (1984), rapid sand filtration is among the several methods that are considered effective in removing solid wastes in water. This, in coordination with biofilm application, also provides a barrier to microorganisms.

A rapid sand filter is made up of several major parts: a filter tank, filter media, and gravel. The most essential component of the filter, the filter media, is the part that removes the particles from water. There are four materials that are commonly used as filter media in rapid sand filtration units: gravel, fine sand, coarse sand and activated carbon (Minnesota Rural Water Association, 2009). The most common type of filter media is sand as it is the fastest in removing particles. Filters normally contain around 60cm to 75cm thick layers of sand . Gravel acts as the filter media's support, allowing the even distribution of water throughout the filter. It prevents sand from separating from the main filter. The sizes of individual pieces of gravel range from 2.5mm to 50mm in multiple layers of thickness ranging from 45cm to 50cm (Minnesota Rural Water Association, 2009). Less commonly, activated carbon is used as the top most filter medium. It is used to purify water from certain contaminants such as methylene chloride, trichloroethylene, benzene, chlorobenzenes, carbon tetrachloride, vinyl chloride, and radon. It will also reduce the lead quantity in water along with the toxic compounds and harmless-tasteless odor chemicals (Minnesota Rural Water Association, 2009).

Rajala, Pulkkanen, Pessi, & Heinonen-Tanski (2003) found that rapid sand filtration was effective in eliminating suspended solids by 90%, reducing turbidity by 70-80%, and color by 20-50%. It also improved the UV transmittance of water by 20%. They used polyaluminium chloride as a coagulant that also helped remove certain pathogens like microbes by 90-99%. Trace elements like phosphorus in water were also found to be reduced to 0.05 mg/L. They purified the water and effectively removed most contaminants, often below the detection limit. The findings of Choi & Dempsey (2004) support this, as they concluded that the process of rapid ultrafiltration (UF) were effective in the removal of natural organic matter and turbidity in both synthetic and natural raw waters. This was coupled with the use of methods such as charge neutralization and flocculation.

Rapid sand filtration has been shown to be effective in removing pathogens, in addition to foreign contaminants and trace elements. Shirasaki et. al (2010) found that coagulation-rapid sand filtration eliminated traces of Norovirus (NV) particles, which is a leading cause of epidemic acute non-bacterial gastroenteritis. The use of different coagulants such as polyaluminum chloride, alum and ferric chloride had varying degrees of effectiveness in the reduction of the particles. In particular, the use of polyaluminum chloride and ferric chloride achieved a significant 3-$\log_{10}$ removal of the particles. Arndt & Wagner (2003) had similar results, as they used rapid sand filtration to remove Triactinomyxon actinospores, the waterborne stage of *Myxobolus cerebralis*, from contaminated water. The filter they used consisted of sand beds 10 cm deep and gravel that was 10 cm deep. The sand was sieved to create a size range from 180 to 2000 μm. They found a significant reduction in the water infection.

Solar Disinfection

Solar disinfection is technique that involves the exposure of plastic or glass containers that contain contaminated water to the sun (McGuigan et. al, 2012). According to Hameed & Ahmad (1997), it is unnecessary to boil the water to eliminate bacteria. Heating water to 65 ^{o}C is sufficient to sterilize the water. Water temperatures that are around 50 ^{o}C significantly increase the inactivation rate of bacteria, while the temperature range of 20 - 50 ^{o}C steadily increases this rate (Wegelin et al., 1994). In developing countries, wood as a source of fuel is scarce, but solar energy is readily available. In particular, UV rays from the sun have also been found to be effective in eliminating pathogens (Hameed & Ahmad, 1997).

The study conducted by Barnes, Conroy, Elmore-Meegan, Joyce, & McGuigan (1996) found that the use of solar disinfection significantly reduced the occurrence of diarrheal complications among Kenyan Maasai children. The Maasai people lacked the resources to properly filter and purify their turbid water supply, and an alternative was needed. Another study conducted by McGuigan et. al (1998) involved the exposure of water contaminated with *Escherichia coli* stored in plastic bottles to sunlight. They found that solar disinfection is effective where there is strong sunlight available, and that it is cost-efficient as it does not require the use of expensive equipment. However, the findings of Mäusezahl et. al (2009), who conducted a field trial using solar disinfection on rural Bolivian children, suggested that there was insufficient evidence to prove that there is a significant reduction in diarrheal cases in children with the use of such purification methods.

The study conducted by Rajala et. al (2003) found that solar disinfection was incredibly effective in eliminating bacteria, with an overall reduction rate of up to 99.9%. Rapid sand filtration was used a pre-treatment that also improved UV transmittance in the water, allowing better exposure. Oates, Shanahan, & Polz (2003) conducted an experiment where they measured the efficacy of solar disinfection on the elimination of *E. Coli* and H_2S-producing bacteria. They found that the amount of time that the contaminated water was exposed affected the effectiveness of the procedure. Those that were exposed for one-day had a 52% bacterial inactivation rate, while a two-day exposure had better results, with a 100% bacterial inactivation rate. They also recommended that people cycle three groups of bottles, so two groups are out in the sun and one is being used for consumption. Similarly, Ubomba-Jaswa, Navntoft, Polo-Lopez, Fernandez-Ibáñez, & McGuigan (2009) found that UV radiation was effective in inactivating E. Coli K-12. The samples were kept inside poly(ethylene) terephthalate (PET) bottles and exposed to varying amounts of sunlight. They found that in order to complete the deactivation of pathogens, the solar disinfection process must remain uninterrupted and continuously.

Despite its advantages, there are several limitations in the effectiveness of solar disinfection. Air temperature, topography, climate, and water turbidity are some of the factors that could influence the efficacy of solar disinfection (Oates et. al, 2003). Topological effects can create locally adverse microclimates that affect air temperature and presence of solar radiation. Water turbidity is also a limitation as it affects the amount of light that passes through the water, and therefore affects UV transmittance. Thus, it is often recommended that pretreatment be conducted on the water to remove impurities and to improve turbidity (Meierhofer & Wegelin, 2002).

Solar Distillation

Solar distillation has been proven to be both economical and eco-friendly as a technique, particularly in rural areas. Distillation is a method used for separating key substances from a liquid mixture by means of evaporation and condensation (Mathur, Thomas, Lineswala & Nayar , 2015). Instead of using conventional means of heating for experimentation, solar energy is used to evaporate the liquid. The investigation conducted by McCluney (1984) found that solar distillation systems were designed to meet the demands of a single family to an entire village depending on the size of the still. McCluney (1984) further stated that solar distillation is commonly practiced in areas where freshwater is scarce, and that this method is the most economically effective way of separating pure water from contaminants.

The study conducted by Mathur et. al, (2015) showed that the rate of evaporation was dependent on how much solar radiation the liquid received. They observed that the largest amount of distilled water they could obtain in a single day was only 15 liters and found that their solar still had a volumetric efficiency of 23.33%. The pH level of the distilled water was tested resulting in a pH value of 6 (Mathur et. al, 2015). According to Sampathkumar, Arjunan, Pitchandi & Senthilkumar (2010), solar distillation is classified into two distinct processes, namely passive and active solar stills. Sampathkumar et. al (2010) describes passive solar stills to receive solar radiation directly and uses it as its only source of energy for heating, while active solar stills use mechanical and electrical energy to heat water or to increase the temperature of the substance. The distillation device created by Hikment, Aybar, Egelioglu & Atikol (2005) utilized an inclined solar water distillation system.

Despite its benefits, solar distillation has certain limitations. Sampathkumar et. al (2010) stated that the performance of solar distillation cannot be improved due to uncontrollable factors such as solar radiation intensity and ambient temperature. Kanjeev & Tiwari (1999) found that water temperature and heating efficiency decreased when the area of the container increased; thus, distillation processes must be contained within small containers to maximize efficiency. Though the use of solar stills have been effective, most distillation systems have been discarded due to long production time (Tiwari, Singh & Tripathi , 2003).

Synthesis

As per the standards set by the World Health Organization, water was considered to be non-potable if it contained any harmful chemicals, pathogens, radioactive elements, tastes, and odors. In terms of the purification of non-potable water, rapid sand filtration was proven to be effective in removing foreign sediments, and even microbes to a certain degree. It has also been shown to be cost effective and energy efficient. Previous studies have shown that solar disinfection is a cheap and efficient way to eliminate waterborne pathogens without the need of expensive equipment or energy consumption. Solar distillation also involves the harnessing of solar energy to vaporize and condense water, effectively separating it from certain chemical constituents.

The literature provides sufficient study on the different methods of water purification. The studies had similar results in regards to the incredible effectiveness of the three different purification methods; however, certain limitations for these methods were accounted for and expounded upon, especially with regards to the efficacy of solar radiation in the distillation and disinfection of contaminated water (Oates et. al, 2003). The literature showed that multiple uncontrollable factors such as weather conditions and temperature affected the performance of such methods (Sampathkumar et. al, 2010). There also seemed to be a lack of attention surrounding the use of these methods of purification as a part of multi-step procedure; therefore, this study attempts to find the effects of their use on three major dimensions of water potability: pH level, bacterial content, and the presence of foreign substances.

CHAPTER 3: METHODOLOGY

This chapter describes the methodology used in the research. The chosen research design and rationale are discussed here. This includes the gathering of samples, construction of the purification device, the execution of the experimental procedure, and the analysis of the data collected. The entire data collection procedure is discussed in full detail. This methodology aims to answer the research problems presented in Chapter 1.

I. Research Design

The study utilizes a completely randomized experimental research design. This allows the testing of the hypotheses to determine the relationships between the change in an independent variable and its effects on the dependent variables. In this case, the effects of three stages of water purification was tested on unfiltered sewage water. There will be one group will be tested with the instrument and the other group will be left as it is to determine the following. From here, the major factors of water potability, including pathogenic content, pH level, and foreign contaminant content were measured. The effects of such purification methods on the factors were determined through the use of nutrient plates, a pH meter, and a mass spectrophotometer respectively. These factors serve as the dependent variables of the research. Through this design, the overall effectiveness of such procedures was summarized.

II. Research Locale and Set up

The construction of the purifier was done at the homes of the researchers, and the experiments were conducted outdoors in the afternoon from 10:00 AM until 4:00 PM in order to maximize the exposure to sunlight for the solar distillation and disinfection procedures. The analysis of the treated and untreated water was held at the chemistry laboratory of De La Salle Santiago Zobel - Vermosa.

The water samples used for the experiment were obtained from the home of one of the researchers. The water was divided into two major groups for the purpose of the experiment: control and experimental. The control group consisted of 5 samples of untreated sewage water that were not to be subjected to treatment, while the experimental group consisted of 5 samples of untreated sewage water that were to be subjected to the treatment. Each sample held 100 ml of the water.

III. Research Materials and Instruments

The materials used in the construction of the purification device included a 1.5 L polyethylene terephthalate (PET) bottle, 2 clear 10 L PET bottles, and a polyvinyl chloride (PVC) pipe. A waterproof and non-toxic epoxy was used to hold the structure together. A nutrient plate was used to determine the pathogenic content of the water. The nutrient plates allow the growth of pathogens in colonies, making them visible to the naked eye. These plates were composed of powdered gelatin, sugar, low sodium beef bouillon, and water. The pH level was measured using a pH meter. A mass spectrophotometer was used to determine the concentration of trace elements and other foreign chemical contaminants in the water. The pH meter and spectrophotometer were provided by De La Salle Santiago Zobel - Vermosa.

IV. Construction of Purifier

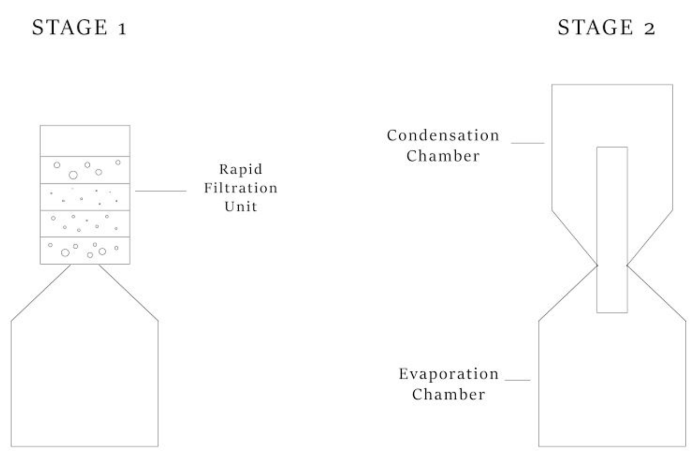

Figure 3.1 Water Purifier Schematic

Figure 3.1 shows the overall design of the two-stage water purification device. The purifier was divided into three distinct sections: the rapid sand filtration unit, the evaporation chamber, and the condensation chamber. These units are meant to be connected via a single PVC pipe, making the entire system modular for ease of maintenance. In particular, the evaporation and condensation chambers were connected by a single 1 inch PVC pipe that extended up to 7 cm below the top of the condensation chamber. This pipe was fixed to the bottles' caps using the epoxy. The two stage filtration process begins with the water being filtered by the rapid sand filtration system. This passes through the main pipe and collects at the bottom of the evaporation chamber. After this stage has been completed, the filtration unit is detached and the condensation chamber is attached to the pipe via the bottle cap. The water evaporates at the bottom chamber, rises up the pipe, and collects in the condensation chamber.

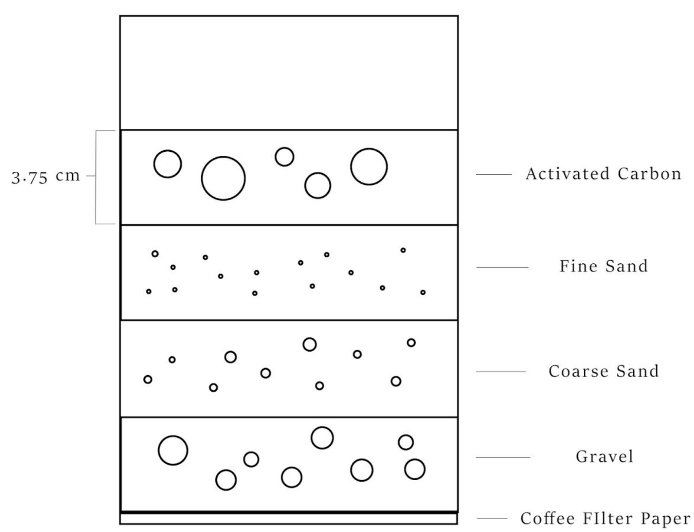

Figure 3.2 Rapid Sand Filtration Schematic (Schmitt & Shinault, 1996)

Figure 3.2 shows the structure of the rapid sand filtration unit. This was contained inside a 1.5 L PET bottle that had been cut near the bottom. The bottle opening was covered with a coffee filter paper, which acted as the semi-permeable membrane. Inside, there were layers of filter media consisting of fine sand, coarse sand, gravel, and activated carbon. Each layer was 3.75 cm in thickness. The first layer from the bottom was the gravel, which supported the all other filter media above it. The second layer was composed of coarse sand, and the third layer was composed of fine sand. These acted as the primary filter media which removed foreign particles from the water. Finally, the top layer was composed of activated carbon, which removed certain chemicals and trace elements from the water.

V. Data Collection Procedure

Safety Measures

In order to prevent major injuries, certain protective measures were held during both the construction of the purification device and the testing of the treatment. These measures included the following:

1. Wear protective eyewear and gloves to prevent injury in contact with sharp or hot objects.

2. Wear a lab gown or apron while cooking the nutrient solution to prevent boiling substances from making contact with skin and clothing.
3. A clean work space should be kept in moderation to prevent any accidents.
4. Do not ingest the substances involved in the study.
5. If there are any spilled solutions, be thorough in cleaning the spilled area and dispose of or clean any item that was contaminated.
6. Disinfect the workplace before and after the experiment is complete.

Experimental Procedure

The experiment was conducted outdoors at the home of one of the researchers. The unfiltered sewage water from the experimental group was poured in through the rapid sand filtration unit. The filtered water then collected at the bottom of the evaporation chamber, where it slowly evaporated and rose to the top of the condensation chamber. The water collected at the bottom of this chamber, and was allowed to rest for at least an hour. The water was then collected and stored in sterile containers for testing. After this time, the device was taken apart and cleaned. The rapid sand filtration unit underwent a backwashing procedure, wherein water was poured in from the opposite direction, and the activated carbon units were replaced in preparation for future experiments. This was repeated for each of the remaining samples of water. The experimental procedure began on November 12, 2017 and ended on November 16, 2017.

Testing of Treatment

A letter of permission was given to De La Salle Santiago Zobel - Vermosa for the use of laboratory equipment. Nutrient plates were developed by the researchers for each sample of untreated and treated water. 25g of powdered gelatin, sugar, and low sodium beef bouillon was dissolved in 100mL of water and cooked until boiling for sterilization. The mixture was left to cool and kept in 10 sterilized containers that act as the nutrient plates. For each sample, 1mL of the treated or untreated water was swabbed on its corresponding nutrient plate, and the growths were observed over the course of 5 days. The number of colonies per unit volume was then counted digitally using the OpenCFU software, and the pathogenic density of water was measured in colony forming units per milliliter (CFU / ml). A pH meter was provided by the institution for the measurement of the pH level of the treated and untreated water. The meter was dipped into the sample, and the printed value was recorded. The remaining samples underwent analysis through a mass spectrophotometer. The testing of the treatment began with the pre-testing of the samples on November 8, 2017 and concluded with the post-testing of the samples after the experimental procedure on November 28, 2017. After the data had been collected, appropriate statistical treatment was performed to establish a relationship and to compare the final values.

VI. Statistical Treatment

The analysis involved the descriptive comparison of the quantitative values obtained from the data collection procedure. The numerical means (averages) of the pH level, pathogenic content, and chemical content of the control group was compared with those of the experimental group, and the overall percentile changes were obtained. This describes the change in a value relative to its original value (George Brown College, 2014). This was given through the following formula:

$$C = \frac{V_f - V_i}{V_i} \times 100$$

The variable C represents the overall percent change between two values. The variables V_i and V_f represent the initial and final values respectively. Through this method, it was possible to determine whether the effect of the three purification processes including distillation, solar disinfection, and rapid sand filtration on the pH value, pathogenic content, and foreign contaminant content was positive or negative. It also allowed the measurement of the degree of such effects on the variables.

CHAPTER 4: DATA ANALYSIS AND INTERPRETATION

This chapter describes the analysis and interpretation of the data obtained through the investigation. The discussion concerns the effects of the purification treatment presented in Chapter 3 on the pathogenic content, pH level, and presence of foreign contaminants in the water samples. The findings aim to answer the research questions presented in Chapter 1.

Research Question 1: What are the effects of the purification procedure on the pH and pathogenic content level of the sewage water?

Table 4.1 pH Level of Water Averages

Sample	Pre-test pH	Post-test pH
1	5.28	6.5
2	5.3	9.6
3	5.3	8.1
4	4.74	7.3
5	4.57	7.4
AVERAGE	5.038	7.78

Table 4.1 shows the pH levels of the samples before and after they were subjected to the purification procedure. The pH levels of the pre-treatment samples were less than 7, which are within the range of high acidity. The average pH of the

pre-treatment samples was measured to be 5.038. After the samples were subjected to the purification procedure, their pH levels increased. The average pH of the treated samples was measured to be 7.78, which is only slightly basic. This suggested a 54.43% increase in pH. This is only slightly above neutrality, indicating a drastic reduction in foreign impurities.

These findings are supported by those of Deboch & Faris (1999). They recorded an increase in the acidic pH of their water samples after they have been exposed to rapid sand filtration procedures. This is explained by the natural filtration and physical adhesion of foreign particles to the sand and activated carbon filters (Schmitt & Shinault, 1996). They examined a similar filtration device to that used for the samples that involved layers of activated carbon, sand, and gravel.

Table 4.2 Pathogenic Content Averages

Sample	Pre-test Pathogenic Content (CFU / mL)	Post-test Pathogenic Content (CFU / mL)
1	8	1
2	7	3
3	7	7
4	6	6
5	8	4
AVERAGE	7.2	4.2

Table 4.2 shows the pathogenic content of the water samples before and after they were subjected to the treatment. On average, there were about 7 colonies per milliliter that formed in the pre-treatment water. After the samples were subjected to the treatment, about 4 colonies formed on average per milliliter. This suggests a 42.86% reduction in the amount of pathogens present in the water within the 24-hour span. This is supported by the findings of Oates, Shanahan, & Polz (2003), who have recorded a 52% pathogenic inactivation rate within a 24-hour span and a 100% inactivation rate within a 48-hour span. This indicates that the treatment procedure is efficient enough to completely eliminate the pathogens present in the water, albeit within a longer time period. This is explained by the principle that UV radiation from sunlight may affect the DNA of pathogens, causing excess bonds between pyrimidines (Evans, 1991). This results in mutations that may render the pathogen inactive.

Research Question 2: Is there a significant difference on the presence of potentially harmful pathogens in sewage water before and after the treatment?

Table 4.3 Test of Homogeneity of Variances for Pathogens

Levene Statistic	df1	df2	Sig.
4.348	1	8	.071

Table 4.3 shows the test of homogeneity of variances between the pathogenic density of the samples from before and after the treatment is applied. This is a requirement for ANOVA, based on the assumption that the variances between the

samples are equal, and it is shown that there is no statistically significant difference among the variances (p = .071). Thus, it can be assumed that there is a lack of homogeneity in the variances (Erjavec, 2011).

Table 4.4 ANOVA for Pathogens

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	22.500	1	22.500	7.031	.029
Within Groups	25.600	8	3.200		
Total	48.100	9			

ANOVA was conducted on the number of pathogens before and after the treatment, as shown in table 4.4. It indicates that there was indeed a statistically significant difference between the values, $F(1) = 7.031$, $p = 0.029$. This indicates that the effect of the treatment on the number of pathogens present in the samples was significant.

Research Question 3: Is there a significant difference on presence of foreign contaminants in the sewage water before and after the treatment?

The concentration of foreign contaminants may be measured through their interactions with electromagnetic radiation (EMR). The spectrophotometer used to measure the absorbance and transmittance (emission) patterns in a substance for certain wavelengths of light (Thomas & Burgess, 2007). According to the Beer-Lambert Law, there is a linear relationship between the concentration of a substance and its absorbance level (Hardesty & Attili, 2010). The lower the absorbance value of the substance, the lower the concentration of the contaminant in the substance. Similarly, the higher the transmittance, the lower the concentration, as indicated by less turbid water.

Table 4.5 Test of Homogeneity of Variances For All Wavelengths

WL	Transmittance		Absorbance	
	Levene Statistic	Sig	Levene Statistic	Sig
400	.600	.461	4.850	.059
420	4.012	.080	.045	.838
440	2.153	.180	1.478	.259
460	2.687	.140	.000	1.000
480	2.880	.128	.554	.478
500	4.198	.075	1.133	.318
520	3.798	.087	.210	.659
540	.852	.383	.278	.612
560	.536	.485	.180	.683
580	1.627	.238	1.053	.335
600	.059	.815	.987	.349
620	.258	.625	.643	.446
640	.295	.602	4.852	.059
660	.279	.611	2.769	.135
680	.086	.776	.496	.501

700	.510	.496	3.841	.086
720	1.524	.252	4.137	.076
740	.914	.367	2.327	.166
760	2.913	.126	7.501	.025
780	.983	.351	3.798	.087
800	1.909	.204	3.834	.086

1. WL = wavelengths

Table 4.5 shows the test of homogeneity of variances for the absorbance and transmittance values before and after the application of treatment. The assumption that the variances are equal across all groups is not met for all wavelengths ($p > .05$), with the exception of wavelength 760 nm ($p = .025$). Thus, the ANOVA conducted for the wavelengths are presumed to be valid (Erjavec, 2011).

Table 4.6 ANOVA For All Wavelengths

WL	Transmittance Level					Absorbance Level				
	Mean		df	F	Sig	Mean		df	F	Sig
	Pre	Post				Pre	Post			
400	15.00	83.00	1	924.800	.000	.7100	.0800	1	31.227	.001
420	19.4	91.2	1	991.392	.000	.7040	.0380	1	1.109	.000
440	28.6	85.4	1	1104.877	.000	.538	.0640	1	1069.886	.000
460	23.6	86.6	1	9922.500	.000	.6160	.0640	1	2308.364	.000
480	25.2	85.6	1	1176.816	.000	.5920	.0640	1	1742.400	.000
500	28.4	88.4	1	1118.012	.000	.5500	.0480	1	2423.115	.000
520	29.2	88.2	1	945.924	.000	.5320	.0520	1	1294.382	.000

540	32.60	88.6	1	725.926	.000	.4960	.0480	1	1672.533	.000
560	39.4	89.8	1	907.200	.000	.3940	.0420	1	1239.040	.000
580	41.6	91.6	1	1033.058	.000	.3760	.0360	1	672.093	.000
600	43.4	95.0	1	2113.143	.000	.3580	.0200	1	1215.362	.000
620	45.4	93.6	1	1095.868	.000	.3480	.0260	1	864.033	.000
640	47.2	94.8	1	2097.926	.000	.3260	.0220	1	1026.844	.000
660	48.8	95.0	1	2541.000	.000	.3100	.0200	1	700.833	.000
680	49.6	94.60	1	1985.294	.000	.3000	.0240	1	1002.316	.000
700	51.4	93.2	1	1344.031	.000	.2820	.0300	1	756.000	.000
720	53.4	95.8	1	1057.506	.000	.2680	.0180	1	519.661	.000
740	55.0	95.0	1	1066.667	.000	.2520	.0160	1	506.327	.000
760	57.6	95.0	1	568.602	.000	.2380	.0180	1	410.169	.000
780	58.8	96.2	1	706.444	.000	.2260	.0160	1	479.348	.000
800	60.6	96.6	1	459.574	.000	.2160	.0140	1	268.447	.000

1. WL = wavelengths

As shown in table 4.6, ANOVA was conducted on the samples for all wavelengths comparing the absorbance and transmittance values between the pre-treatment samples and the post-treatment samples. It indicates a statistically significant change in both absorbance and transmittance after the samples have been subjected to treatment ($p < .05$). This holds true for all wavelengths from 400 to 800 nm, with the exception of the transmittance values at 760 nm due to the significant test of homogeneity as shown in table 4.5.

Figure 4.1 Average Absorbance Levels

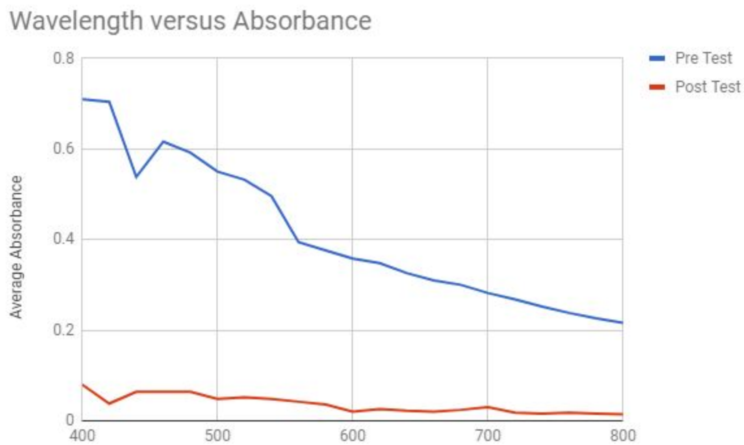

Figure 4.1 shows the average absorbance levels of the samples at different wavelengths ranging from 400 to 800 nm. These levels were measured before and after the samples were exposed to the purification treatment. It shows a drastic decrease in the absorbance of the water at all wavelengths, with the values becoming relatively closer to 0. Based on the pre-treatment and post-treatment means for the wavelengths presented in table 4.6, there was an 91.56% average reduction in the absorbance levels of the samples for all wavelengths.

Figure 4.2 Average Transmittance Levels

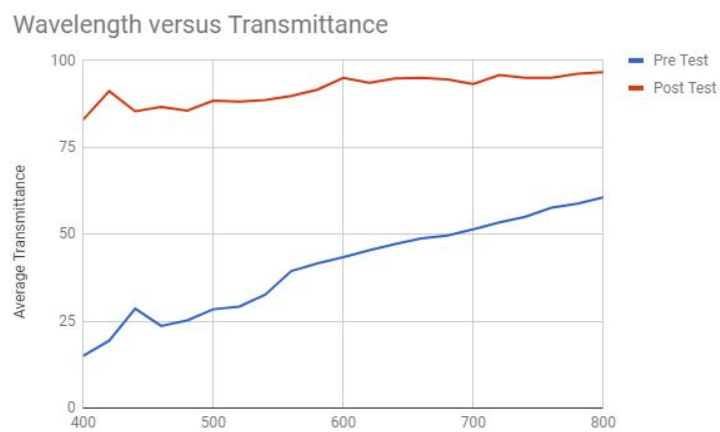

Figure 4.2 shows the average transmittance levels of the samples at different wavelengths ranging from 400 to 800 nm. These levels were measured before and after the samples were exposed to the purification treatment. It shows a drastic increase in the transmittance levels of the samples at all wavelengths, with the values becoming relatively closer to 100. The means presented in table 4.6 show that there was an 156.88% average increase in the transmittance levels of the samples for all wavelengths.

This, in conjunction with the decreased absorbance values, indicates reduced turbidity in the samples after they have been exposed to the treatment. These findings are supported by Rajala, Pulkkanen, Pessi, & Heinonen-Tanski (2003), who found that the rapid sand filtration procedure in particular was able to reduce turbidity and improve UV transmittance through the removal of foreign particulates found in the samples.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

This chapter discusses the conclusions generated from the results of the study. These will answer the research questions as stated in Chapter 1. It discusses the findings, their implications, applications in other fields of study, and the recommendations to further improve future research on the subject.

Conclusion

The study aimed to find the effects of the purification procedure, which involved rapid sand filtration and solar distillation and disinfection, on the presence of pathogens and foreign contaminants in water. The results were sufficient to answer the research questions:

1. The pH values measured before and after the purification treatment show that normalization occurs, wherein the pH value becomes close to the neutrality value of 7. This, in addition to the absorbance and transmittance values, indicates the removal of foreign substances from the water.
2. The purification procedure displayed a significant 42.86% reduction in the average number of pathogens present in the samples, as indicated by the pathogenic density.

3. The absorbance and transmittance values measured before and after the purification treatment indicate a reduction of foreign contaminants in water. This was implied from the significant 91.56% reduction of absorbance and the 156.88% increase of transmittance for all wavelengths from 400 to 800 nm ($p < 0.05$).

Recommendation

1. Other factors that indicate potability of water could be taken into consideration, including conductivity and the presence of specific compounds like nitrates and phosphates.
2. Furthermore, it was recommended that a larger sample space be used for the experiment, as well as a greater variety in terms of the effects of the purification on certain types of water. These water samples may vary in terms of turbidity, pH, and other factors that may affect water potability.
3. Finally, as the purification method used in this study was a three-phase procedure, it was recommended that the state of the water after each procedure was measured to provide more insight on the effectiveness of each of the procedures.
4. Additional research may also be conducted on other forms of purification.
5. The effects determined by the research provide insight on the effectiveness of the three-phase purification procedure consisting of rapid sand filtration, solar

disinfection, and distillation on the pH, absorbance and transmittance values, and pathogenic density of water. This suggests that the use of such procedures in conjunction significantly improves the quality of the water.

6. These results have applications in engineering due to the construction of devices that may perform the procedure, as the device used in the study was understood to be easy to maintain and produce. Thus, more efficient devices may be built in the future. The results of the study may also have applications in microbiology, allowing the further understanding of the effects of sunlight on the pathogens present in the water samples.
7. The researchers recommend to utilize the purification device on unsanitary water, but to further purify it through other means before deeming it safe for consumption.

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APPENDIX A: PERMISSION LETTERS

Ms. Carmelita Estidola
High School Science Coordinator
De La Salle Santiago Zobel School – Vermosa

Dear Ms. Estidola,

Greetings of Peace!

The undersigned are senior high school students under the STEM strand at the De La Salle Santiago Zobel School – Vermosa. We are currently conducting our research titled, **"The Effects of Distillation via Solar Disinfection and Rapid Sand Filtration on the Presence of Pathogens and Foreign Contaminants in Water"**.

In line with this, the undersigned would like to request permission and endorsement to allow the conduction of the experiment inside the laboratory within the De La Salle Santiago Zobel – Vermosa Campus. The equipment used would include a pH meter and spectrophotometer for the post-assessment of the untreated tap water. This will be accomplished on November 28- 29 during brunch and recess breaks from 10:25 - 11:05 a.m. and 1:05 - 1:30 p.m.

We are truly grateful in anticipation of your favourable response to this request.

Respectfully yours,

Keith Leonardo
STEM Student

Matthew Buensalida
STEM Student

Baron Castillo
STEM Student

Diego Macias
STEM Student

Jean Timbol
STEM Student

Noted by:

Mr. Fritz Ferran
Research Adviser

Mr. Jonathan Sarza
Chemistry Teacher

Mr. Richard Lasap
Strand Coordinator

Approved:

Ms. Carmelita Estidola
Science Coordinator

Sr. Jonathan Sarza
Senior High School Chemistry Teacher
De La Salle Santiago Zobel School – Vermosa

Dear Sr. Sarza,

Greetings of Peace!

The undersigned are a senior high school students under the STEM strand at the De La Salle Santiago Zobel School – Vermosa. We are currently conducting our research titled, **"The Effects of Distillation via Solar Disinfection and Rapid Sand Filtration on the Presence of Pathogens and Foreign Contaminants in Water"**.

In line with this, the undersigned would like to request permission and endorsement to allow us to conduct our experiment inside the laboratory within the De La Salle Santiago Zobel - Vermosa Campus. The equipment used would include a pH meter and spectrophotometer for the pre-assessment of the untreated tap water. This will be accomplished on November 6 - 7 during brunch and recess breaks from 10:25 - 11:05 a.m. and 1:05 - 1:30 p.m.

We are truly grateful in anticipation of your favourable response to this request.

Respectfully yours,

Keith Leonardo
STEM Student

Matthew Buensalida
STEM Student

Baron Castillo
STEM Student

Diego Macias
STEM Student

Jean Timbol
STEM Student

Noted by:

Mr. Fritz Ferran
Research Adviser

Approved:

Sr. Jonathan Sarza
Chemistry Teacher

Ms. Agnes Panaligan
Senior High School Head
De La Salle Santiago Zobel School – Vermosa

Dear Ms. Panaligan,

Greetings of Peace!

The undersigned are a senior high school students under the STEM strand at the De La Salle Santiago Zobel School – Vermosa. We are currently conducting our research titled, **"The Effects of Distillation via Solar Disinfection and Rapid Sand Filtration on the Presence of Pathogens and Foreign Contaminants in Water"**.

In line with this, the undersigned would like to request permission and endorsement to allow us to conduct our experiment inside the laboratory within the De La Salle Santiago Zobel - Vermosa Campus. This will be accomplished on October 18, 2017 from 10:25 a.m. to 11:05 a.m. and 1:05 p.m. to 1:30 p.m. during brunch and recess. Rest assured that any damages are inflicted upon instruments and labware will compensated for.

We are truly grateful in anticipation of your favourable response to this request.

Respectfully yours,

Keith Leonardo
STEM Student

Matthew Buensalida
STEM Student

Baron Castillo
STEM Student

Diego Macias
STEM Student

Jean Timbol
STEM Student

Noted by:

Mr. Fritz Ferran
Research Adviser

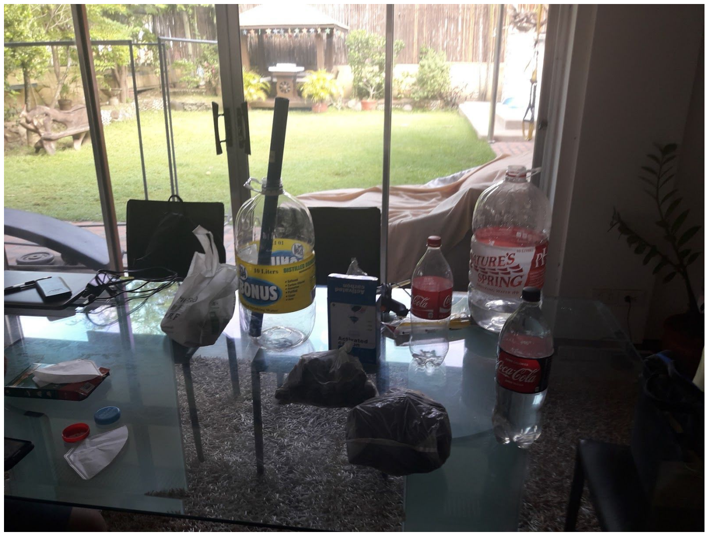
Mr. Jonathan Sarza
Chemistry Teacher

Mr. Richard Lasap
Strand Coordinator

Approved:

Ms. Agnes Panaligan
Senior High School Head

APPENDIX B: DATA COLLECTION PROCEDURES



APPENDIX C: PATHOGEN CULTURES