A Comparative Analysis of Pectin and Iron (III) Oxide-Hydroxide Modified Bagasse Beads for Lead Filtration

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Abstract

Water has become heavily polluted due to overexploitation. Various global river systems, such as the Meycauayan River, have been shown to have lead concentrations that are hazardous for human consumption. Lead is one of the heavy metals that are associated with this pollution, as it brings alarming health threats due to bioaccumulation. Different filtration materials have been explored in the past for their capabilities in lead adsorption, including sugarcane bagasse and pectin. And thus, the project aimed to compare pure pectin beads and beads containing sugarcane bagasse modified with iron (III) oxide-hydroxide for their capability to filter a simulated wastewater. The study also aims to study the relationship of lead concentrations in rivers with water pH and temperature as a measurable indicator for areas with high potential for lead contamination. Sugarcane bagasse was modified through submersion and mixing with $FeCl_2$ and NaOH. A 6% pectin solution was prepared and dropped into a 1.5 M $CaCl_2$ solution, with modified bagasse being incorporated in a separate batch. The formulated beads were then placed in a simple filtration setup and a 500 ppm lead acetate solution was run through. The effluent water was then measured for lead absorbance. The pure pectin beads reflected a mean lead removal percentage of 67.76%, while the beads containing modified bagasse had an average of 40.33%. Past research shows modified bagasse's lead adsorption works best with higher contact times, so it may be a more feasible material for large-scale wastewater treatment. Pectin-based solutions have shown in the past their capability to absorb lead with shorter contact times. Past studies have related increased lead concentrations with acidic water and higher temperatures, so it is recommended for areas meeting these conditions to evaluate lead contamination and to employ effective and cost-efficient methods for lead filtration.

Keywords *- lead contamination, pectin, sugarcane bagasse, iron (III) oxide-hydroxide, filtration*

INTRODUCTION

Background of the Study

Water is an essential resource to the survival of every human being. It is a key pillar for growing food and keeping individuals healthy, and it is tied to the vitality of the economy through its use in multiple industries and in hydropower (Pradinaud et al., 2019). Due to the numerous climate impacts affecting the reliability and safety of our water supply (Hugonnet et al., 2021), which has spared no continent or region in the globe, the United Nations have decided to include the management of our available water and its sanitation as a Sustainable Development Goal (SDG).

There are a few key factors that can be attributed to the constant damage of the planet's water resources throughout the years. Fast population growth encourages the overexploitation of freshwater resources that are utilized by many industries. As such, a large inflow of foreign pollutants such as non-biodegradable plastics, synthetic chemicals, and heavy metals accumulate in aquatic environments throughout time (Chaudhry & Malik, 2017).

In the Philippines, the Meycauayan River is considered to be one of the most polluted rivers in the country due to the exorbitant amount of organic pollutants and heavy metals present in the water. Specifically for lead, the river has shown lead concentrations as high as 947 ppm upstream and around 391 ppm midstream (Pleto et al., 2020). Both these measurements would not pass the lead concentration standards set by the National Oceanic and Atmospheric Administration (Buchman, 2020). Not only did this high amount of lead lead to the gray-black color of the river in different sections, but also an increased pH and temperature.

Lead is widely recognized as one of the most dangerous health threats plaguing the environment, especially sources of water as it is known to accumulate in the human body (Brown & Margolis, 2012). Past research has shown that increased lead contamination in drinking tap water directly correlates to the increase of lead in the bloodstream of consumers (Triantafyllidou & Edwards, 2012). Some studies have even revealed the impact of lead on the neurodevelopment of children, even with very little exposure to this heavy metal (Levallois et al., 2018).

As a result of various community health problems arising due to high lead concentrations, researchers and institutions have explored the different methods for reducing and removing lead from drinking water, such as using graphdiyne filters and surface-induced precipitation techniques (Liu et al., 2017; Wei et al., 2021). Other studies have explored various types of materials that have particularly notable adsorption capabilities, as the adsorption material is relatively eco-friendly and low cost for removing heavy metals (Rashid et al., 2021).

One of these materials is sugarcane bagasse, with past studies exploring the waste material's capability to remove heavy metals such as lead (Pb), nickel (Ni), and copper (Cu) (Ezeonuegbu et al., 2021). Other studies have also reported that modified sugarcane bagasse, with the use of iron (III) oxide-hydroxide, can improve the material's adsorption for lead ions (Praipipat et al., 2023).

Another promising material that has been studied for its adsorption properties is pectin, a complex starch found in citrus fruits that is commonly used as a gelling agent (Aronson, 2015). Past research has revealed that beet pectin has particularly high affinity for lead, while citrus pectin have higher affinity for nickel (Kartel et al., 1999). Modern studies have also worked with adipic acid or other cross-linking agents to modify pectin, which increased its saturated loading capacity for lead (Li et al., 2007; Martinez-Sabando et al., 2023).

Objectives

The project aims to assess the differences of pure pectin beads with pectin beads containing sugarcane bagasse modified with iron (III) oxide-hydroxide in terms of their capability to filter out lead in simulated wastewater. Specifically, the study targets to accomplish the following:

1. Modify sugarcane bagasse with iron (III) oxide-hydroxide using ferric chloride ($FeCL_2$) and sodium hydroxide (NaOH);
2. Formulate a batch of pure pectin beads and pectin beads with modified bagasse incorporated;
3. Simulate a wastewater solution with lead concentrations adapted from real-life measurements at the Meycauayan River in Bulacan, Philippines;
4. Compare and contrast the lead adsorption of the two filter materials; and
5. Provide insight into the possible environmental factors that may further influence the effectiveness of lead adsorption filters.

Significance of the Study

The study results may specifically benefit the local government unit of Bulacan, particularly for the communities residing nearby the Meycauayan River, as this project would present the community members with a relatively simple, effective, cheap, and easy to operate filtering solution for the water. This would further reduce the risk of health emergencies amongst the residents in the area, as well as increase the productivity of water that otherwise would be unused in the area due to severe contamination.

The study may also benefit other areas of the Philippines struggling with heavily polluted rivers and bodies of water, such as the infamous Pasig River and the Marikina River as well. Aside from these, the study results may also provide individuals in very remote areas to filter their own water using some common waste materials from their practices.

Scope and Limitations

The study will cover the modification of sugarcane bagasse using $FeCL_2$ and NaOH, the formation of pure pectin beads and pectin beads enclosing modified bagasse, the simulation of wastewater in the school laboratory, the measurement of the filtered lead through Atomic Absorption Spectroscopy (AAS), and the study of the relationship between lead concentration and other environmental factors affecting water quality. The study will not cover the study of real-life water samples from heavily polluted rivers in the Philippines due to time constraints and inaccessibility to some locations.

METHODOLOGY

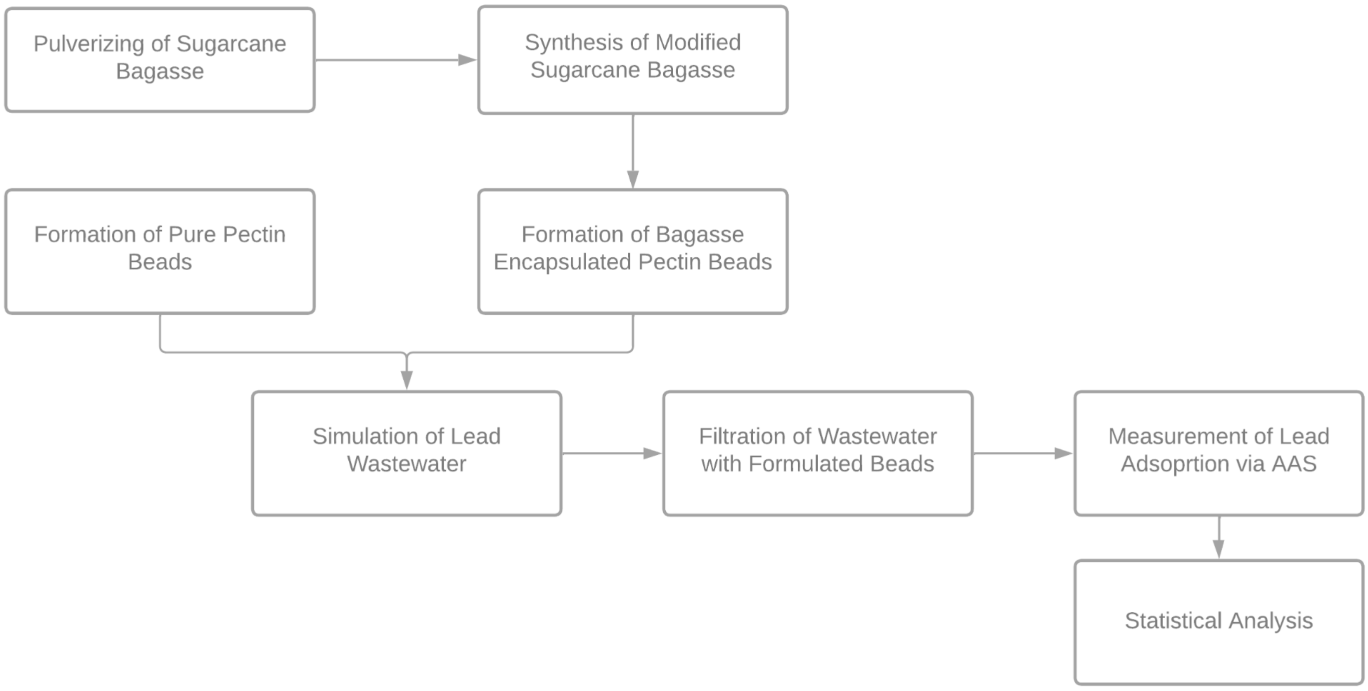

Figure 1: Process Flow Chart of the Methodology

Pulverizing of Sugarcane Bagasse

Sugarcane bagasse was washed with tap water to remove any possible contaminants, and placed in a drying oven at 105ºC) for 24 hours. The resulting bagasse was then pulverized using an immersion blender and further ground using a mortar and pestle. A sieve was used to separate the remaining large pieces.

Synthesis of Modified Sugarcane Bagasse

About 5 grams of powdered bagasse was added to a 500 mL Erlenmeyer flask, with 160 mL of a 5% $FeCl_2$ solution. The flasks were then placed and mixed in an orbital shaker set at 37℃ and 200 rpm for 3 hours. The resulting mixture was then filtered and air-dried for 12 hours. The yielded bagasse was then mixed with 160 mL of a 5% NaOH solution in a 500 mL Erlenmeyer flask, and then mixed in an orbital shaker set at 37℃ and 200 rpm for 1 hour. Afterwards, the mixture was filtered and air-dried for 12 hours, and kept in a desiccator before use.

Formation of Pure Pectin Beads

A 6% pectin solution was prepared by adding 60 grams of powdered pectin into 1 L of water in a beaker. The solution was then homogeneously mixed and heated on a hot plate on medium heat and stirring speed. Around 400 mL of pectin solution was separated for the production of pure pectin beads. The latter solution was poured in drops on a 1.5 M $CaCl_2$ solution in a petri dish, and left to soak overnight. The resulting beads (PT) were then filtered and washed with DI water, and kept at room temperature before use.

Formation of Modified Bagasse Encapsulated Pectin Beads

Around 400 mL of the earlier prepared pectin solution was separated for the production of bagasse encapsulated pectin beads. Around 3.5 grams of modified bagasse was slowly added to the pectin solution on a hot plate at medium heat and stirring speed, until the bagasse was fully incorporated in the solution. Afterwards, the solution was poured in drops on a 1.5 M $CaCl_2$ solution in a petri dish, and left to soak overnight. The resulting beads (DB) were then filtered and washed with deionized (DI) water, and kept at room temperature before use.

Simulation of Lead Wastewater

Simulated samples of lead wastewater were prepared by dissolving varying amounts of lead acetate in water. Concentrations of 250 ppm, 500 ppm, 750 ppm, and 1000 ppm were prepared as standards for the calibration of the atomic absorption spectrophotometer (AAS) to be used for measurements. Around 500 mL of 500 ppm lead acetate solution was also prepared as a simulated wastewater for filtering tests, as modeled by the average lead concentration at the Meycauayan river.

Filtration of Wastewater with Formulated Beads

A simple water filter setup was constructed using 100 mL plastic bottles, which were cut open at around 1 inch from the base. A cheesecloth was also tied to the nose end of the bottle to act as a strainer, and to prevent the beads from leaving the enclosure. Three (3) filter setups were made for each type of filtration material, for a total of six (6) filters.

After placing the produced pure pectin and bagasse encapsulated pectin beads in their respective filters, around 50 mL of the 500 ppm lead solution was poured into each setup for filtration. A beaker was placed underneath each filter setup to collect the effluent water.

Measurement of Lead Adsorption via AAS

The collected effluent water was then poured into 15 mL tubes, and were centrifuged at 5000 rpm for 10 minutes. Then, the samples were measured for lead absorbance using the AAS machine after the calibration with the standard solutions. Each sample was measured one at a time, with the machine being rinsed with DI water after every measurement.

GLOBE Observer Data Entry

The following data were entered into the GLOBE Observer website, using the Meycauayan River System as a basis for information.

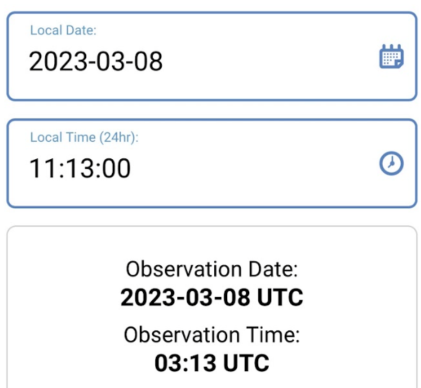

Figure 2: Screenshot of the Observation Date and Time in the GLOBE Observer App

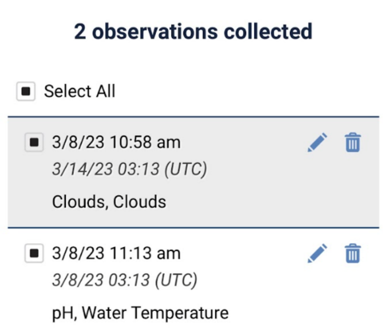

Figure 3: Screenshot of the Measured Data in the GLOBE Observer App

Statistical Analysis

The gathered data were consolidated into a spreadsheets file and were expressed in terms of mean and standard deviation. Normally distributed data was analyzed using one-way analysis of variance (ANOVA) and the Duncan Multiple Range test and the Tukey's Post-Hoc test to quantify the significance of the differences gathered between the two filtration material setups. SPSS Statistics v.28 was used to conduct the analysis, and a p-value of 0.05 was used throughout the entire evaluation.

RESULTS AND DISCUSSION

The concentrations taken from the two types of filter setups were taken and compared to the measurement of the simulated wastewater sample, which had a measured 521 ppm lead concentration. The following data is expressed in terms of mean.

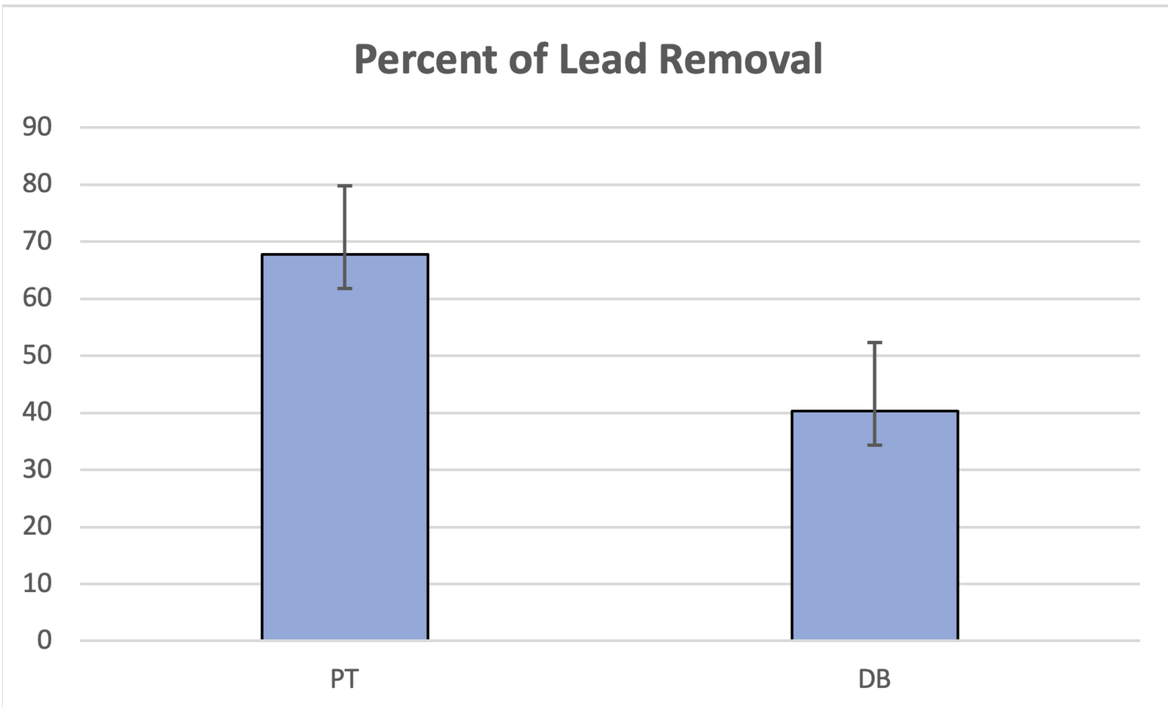

Figure 4: Test Results for Lead Removal Percentage of Pure Pectin Beads and Pectin Beads with Enclosed Modified Bagasse.

Comparison of Pure Pectin Beads with Pectin Beads Encapsulating Modified Bagasse

The filtering setups containing pure pectin beads had an average lead removal percentage of 67.76%, while the pectin beads with incorporated modified bagasse had an average lead removal percentage of 40.33%. This would make the result of the DB beads significantly different from the pectin beads ($p<0.05$), and the two treatments do not appear in the same homogenous subset.

Both pectin and modified bagasse have shown their capability to absorb lead in past research. Modified bagasse has shown to have around 100% lead removal efficiency (Praipipat et al., 2023), but the paper's methodology reveals that a contact time of at least 2 hours was given for the beads to filter out the lead. This would establish modified bagasse beads as a viable material for bulk wastewater treatment in large-scale treatment facilities. However, the requirement for a prolonged contact time for effective lead removal diminishes its feasibility for more direct filtration applications, wherein direct flow through is involved.

As for pectin's capability for lead removal, most studies have delved into the various derivatives and variations of pectin. One such study utilized pectin-producing algae, which had a 32.7% lead removal efficiency (Byamba et al., 2022). Another derivative of pectin, calcium pectate, has exhibited around 60% lead uptake with a minute of bead submersion (Khotimchenko et al., 2007).

Relationship of Lead Concentrations to Water pH and Temperature

Aside from high lead concentrations being a health hazard in its own right, it also has a correlated effect with water pH and temperature. A past study has explored the relationship of lead and water pH, and discovered that lead solubility in pipe loops increases as water becomes more acidic, and decreases as it becomes more neutral (Kim et al., 2011).

As for water temperature, around 59.2 ppb combined dissolved and undissolved lead concentration was measured during the summer, as compared to an 11.2 ppb measurement during the winter (Sumner, 2016). The paper also cited that an increase of 1℃ can boost dissolved lead concentrations by 17%, and undissolved lead concentrations by as much as 36% (Masters et al., 2016)

And so, it is notable to consider areas of low pH concentrations and high temperatures in water bodies for potentially high lead concentrations. Such regions of interest include the Pasig and Manila Rivers on a local scale, as well as the Rio Tinto River in Brazil due to their high pH (Galan et al., 1999). Rivers and water bodies near the equator, such as the African region, must also be further researched for lead contamination due to the higher temperatures. The Akaki River in Ethiopia may serve as an example, with heavy metal contamination already having affected the cultivation of vegetable crops in the region (Prabu, 2009).

GLOBE Visualization

The following screenshot was taken confirming the entry of data in the GLOBE Observer system through the GLOBE Visualization website.

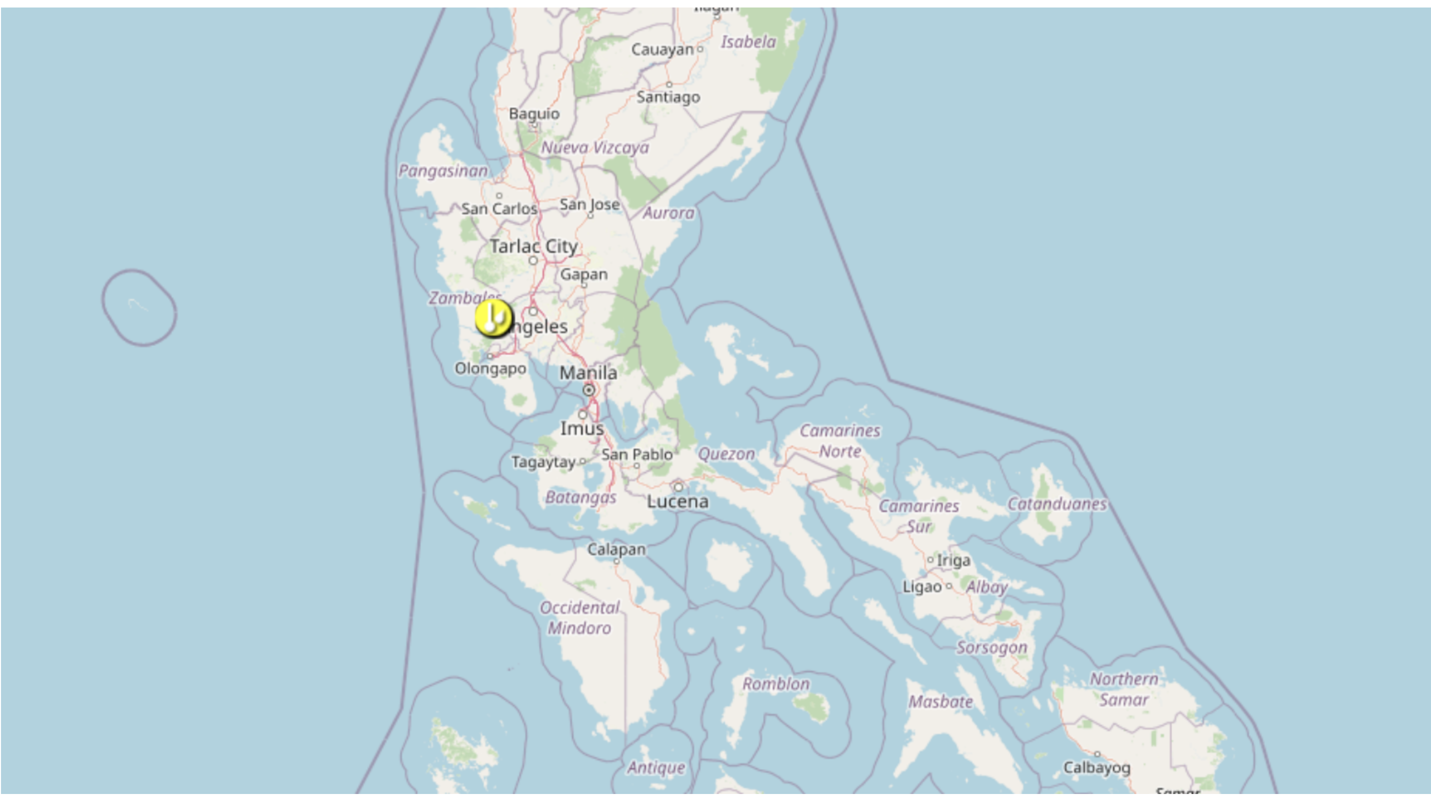

Figure 5: Screenshot of GLOBE Visualization System

CONCLUSION

In conclusion, the filtrations setup containing pure pectin beads exhibited the more effective lead removal percentage, in comparison to the pectin beads containing iron (III) oxide-hydroxide. The pure pectin beads may be more appropriate for rapid filtration applications, wherein wastewater is designed to flow through the filtration system, while the modified bagasse may be more appropriate for large-scale wastewater treatment applications with longer contact and submersion times.

Areas with low water pH concentration and high water temperatures are encouraged to conduct assessments for lead contamination in local rivers and water bodies, and to employ efficient and cost-friendly filtration methods such as using pectin and sugarcane bagasse. It is vital for such measures to be taken to reduce the emergence of community health emergencies due to heavy metal contamination

It is recommended for future studies to experiment with more concentrations of lead solutions to further support the results of the paper. Using real world wastewater with an alarming content of lead concentration is also encouraged. Lastly, experimentation including water pH and temperature measurements is encouraged to further analyze their relationship with lead concentration, and perhaps their effect on the potency of filtration methods as well.

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BADGES

I am a Collaborator. The project involved the three student proponents of the study to work together harmoniously through paper writing and experimentation. Some proponents were assigned with the modification of bagasse, the testing of water filters, and the writing of the paper. Given the short time provided to do the project, the essence of collaboration was highly necessary to ensure a quality output was submitted.

I am a STEM Professional. This project implementation would not be possible without collaborations with our teachers at school. We would like to thank Sir Mark Xavier Bailon for advising us on our lab experimentation, and Ma'am Josephine Joy Antalan for helping us with our statistical analysis and entry for GLOBE Observer data. We were able to gain a lot of insight from the two, which further enriched our paper.