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GRANULAR ACTIVATED BAMBOO CHARCOAL AND SILICA GEL AS WATER TREATMENT AGAINST MICROBIAL CONTAMINANTS: A COMPARATIVE ANALYSIS

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ABSTRACT:

The growing demand for clean and safe water necessitates the investigation of innovative materials that can be utilized in water treatment applications. In this regard, a simple and cost-effective water treatment method was developed to address the water supply problem in rural areas. This study provided knowledge and conducted a comparative analysis of the effectiveness of two main methods for treating microbial contaminants in lake water: granular activated charcoal and silica gel. Furthermore, the experiment was subjected to before and after the application of activated carbon and silica gel. The pre-testing was conducted to identify the initial quantity of microbial contaminants. The preparation methods for bamboo into charcoal are initiated with the following steps: cutting, drying, loading, and sealing the drum kiln, heating, carbonization, cooling, and removing charcoal. Afterward, the bamboo charcoal underwent a chemical process to create activation using potassium hydroxide to generate a large surface area and enhance the adsorption capability. The two treatments were added to the lake water sample via filtration. Moreover, the post-testing involves performing serial dilution and microbial counts to determine the difference between before and after the contaminant's growth. Based on the results, the granular activated carbon is more effective than the silica gel because of its greater adsorption capacity resulting from its extensive pore spaces. This research study contributes significantly to researchers in the field and further advancements in utilizing granular activated carbon and silica gel to ensure clean and sustainable resources.

Keywords: *Filtration, granular activated bamboo charcoal, lake water, microbial contaminants, potassium hydroxide, silica gel*

Introduction

Water is necessary to existence. Since the beginning of human civilization, water supply has been an integral part of society for various purposes, including drinking, agriculture, industry, and domestic use. As the world's population rises, the necessity for reliable water sources has grown and become essential worldwide. According to the World Health Organization (2021), an estimated eighty percent of all infections and more than one-third of deaths in developing countries are attributable to consuming contaminated potable water. Globally, microorganism-mediated water contamination is one of the greatest threats to human health and aquatic ecosystems. Therefore, people's health is at risk because of the numerous waterborne diseases caused by pollution, inadequate sanitation, and untreated water, causing stomach aches, diarrhea, cholera, and typhoid fever.

Furthermore, access to clean and sufficient water remains a persistent concern, mostly in rural areas of the Philippines. The World Health Organization (2019) cites that approximately one in ten Filipinos still lack access to enhanced water sources. Highly urbanized cities have access to technologies such as replenishment stations with advanced filtration mechanisms, while others, as in every water district, use chlorination. However, this is not the case in some remote municipalities with limited government services, notably Tadlac Lake at Barangay Tadlac, Los Baños Laguna. According to the Laguna Lake Development Authority (LLDA, 2007), its water quality has been affected due to overpopulation and emissions of aquaculture, primarily through the decomposition of unconsumed commercial feeds and fish wastes. These human activities and natural phenomena have affected water resources and caused waterborne diseases in the community near the lake.

To address the deterioration of the water quality of Tadlac Lake, water treatment is essential in ensuring that humans and animals have access to safe potable water. Among the several treatment technologies for eliminating microbial contaminants from lake water, adsorption is a simple and effective method to reduce contaminants. One of the typical adsorbents for microbial contaminants in water includes activated carbon and silica gel. In this study, common bamboo *(Bambusa vulgaris)* was utilized because it can produce high- quality bamboo charcoal for water treatment. On the other hand, silica gel is commonly used as an adsorbent for various substances. According to Zhang et al. (2021) silica gel is an eco-friendly, porous silica hydrate with high thermal conductivity and surface area.

Water is a vital resource essential for survival. Some Filipinos still need to be included regarding access to improved water sources, especially in rural communities, according to Dr. Gundo Weiler (2019), a representative of the World Health Organization (WHO) in the Philippines. In our country, where water resources face various threats from pollution and overexploitation, the Clean Water Act, also known as Republic Act No. 9275, in 2004 represents a significant milestone in the country's efforts to protect its water bodies. In addition, it provides a thorough framework for maintaining clean and sustainable water sources in the Philippines. Furthermore, the Department of Environment and Natural Resources (DENR) is responsible for establishing water quality standards for different water bodies and creating pollution control programs at both national and local levels. The law mandates obtaining permits for discharging wastewater and pollutants, penalizing violations, and encouraging public involvement in water management.

Therefore, this study aims to assess the microbiological quality and to perceive lake water quality. Furthermore, it addresses the challenges in treating lake water and establishing adaptable, cost-effective and naturally available raw materials as adsorbents for water purification by comparing the potential of activated bamboo charcoal and silica gel as water treatment to enhance access to safe and clean water for Tadlac lake. Despite the water treatment effectiveness of activated bamboo charcoal and silica gel, knowledge gaps still needed to be filled. Identifying the most effective adsorbent methods for lake water purification was an important area for future research. This study aimed to improve the existing knowledge on activated bamboo charcoal and silica gel for treating lake water microbial contamination. The findings would contribute to the development of a method that was both sustainable and efficient, resulting in an improved aquatic ecosystem.

Conceptual Framework

The researchers adapted the input process output (IPO) model to include all of the materials and information that are required in the process.

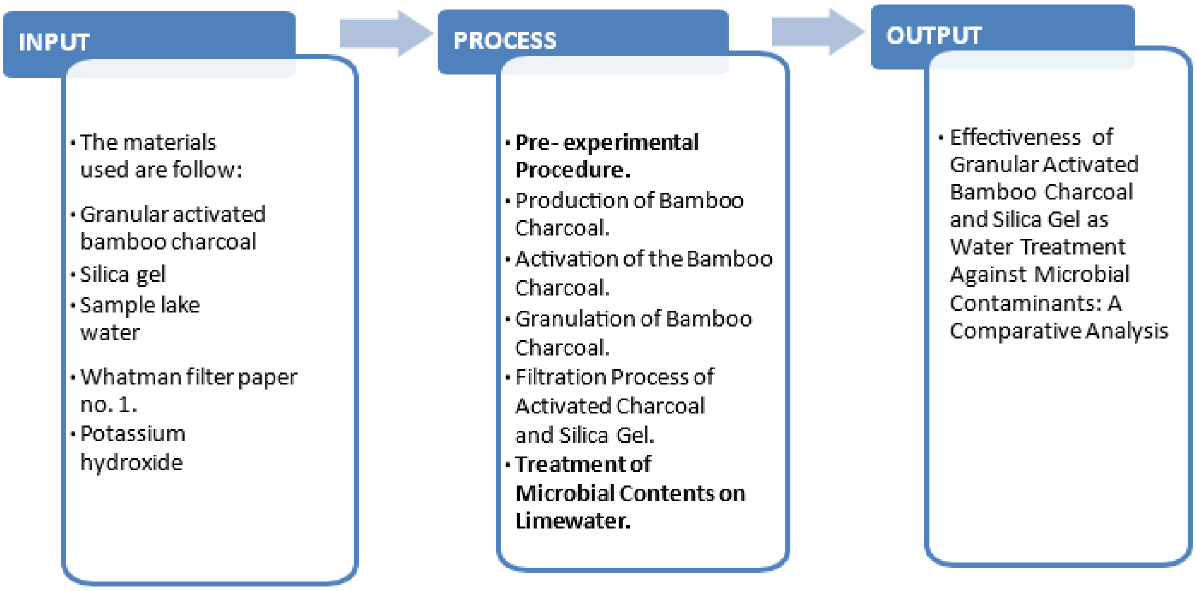

Figure 1. Research Paradigm

Indicators were one of the needs to lessen the threat of intake of these contaminants, especially in the water system. In this study, the concept of adsorption was utilized with granular activated carbon mix and silica gel as the raw material. The adsorbed contaminants in the carbon mix and silica gel were analyzed quantitatively.

Objectives

This study aimed to determine the effectiveness of granular activated carbon and silica gel against the microbial contaminants of lake water.

Specifically, this study sought to determine the effectives the following objectives and hypotheses:

1. To analyzed the microbial count of the water sample treated with granular activated carbon from bamboo (*B. vulgaris*).
2. To determine the microbial count of the water sample treated with silica gel.

3. Is there a significant difference in the microbial count before and after the treatment?
    a. using granular activated carbon; and
    b. using silica gel?
4. Is there a significant difference between the microbial contaminants after the two treatments?

Methodology

This study employed an experimental design in which a controlled variable, lake water, was subjected to a specific treatment for scientific observations involving bamboo (*Bambusa vulgaris*) activated charcoal and silica gel particles. The experiment investigated the efficacy of using the granulated activated charcoal from bamboo and silica gel in treating the microbial contaminants of the water and microbiological water analysis of the filtered lake water, which were dependent variables.

Furthermore, the experimental design enabled the researchers to test the hypothesis with measurable variables. It could be conducted in the laboratory or classroom to establish cause-and-effect relationships. Additionally, it indicated the future investigation to determine what happened when specific variables were thoroughly controlled or manipulated (McLeod, 2017).

The primary focus of the analysis was the effect and adsorption of the granular activated charcoal and silica gel particles, which served as the independent variable. This was done on the microbial contents present in the water. The researchers analyzed the changes in the water resulting from the application of granular activated carbon mix and silica gel following filtration. The data collected through these observations and measurements was then used to compare the effectiveness between the granular activated bamboo charcoal and silica particles in reducing microbial content in lake water.

Analytical Scheme

The paradigm served as a guide on how the study worked. For the water treatment to be conducted, preparation of the materials and samples was initially required. The lake water samples were poured over granular activated carbon and silica gel and filtered to test if they could reduce microbial content in lake water.

Research Procedure

In this study, the research procedure comprises the pre-experimental, preparation of raw materials and methods to produce a lake water treatment for microbial contaminants:

(A) Pre-experimental procedure

(1) Carbonization of bamboo, (2) Activation of bamboo activated charcoal, (3) Granulation of bamboo charcoal, (4) Filtration of activated charcoal and silica gel (B) Treatment of microbial contents in lake water

A. Pre-experimental Procedure

The researchers visited the barangay office of Tadlac, located in Los Baños, Laguna and presented a permission letter to obtain sample lake water from Tadlac Lake, thereby obtaining the necessary authorization to conduct the study.

1. Production of Bamboo Charcoal

Bamboo charcoal was made from *Bambusa vulgaris*. The bamboo stalks were carefully selected and cut into small pieces, about 6 inches long. A total of 25 kilograms of raw bamboo was collected and sun-dried for three days, and it was transported to the DOST-FPRDI facility in Los Banos, Laguna, to conduct the carbonization process. Subsequently, the dried bamboo was placed inside the drum kiln and sealed to prevent oxygen from entering. After reaching the set carbonizing temperature, each bamboo was carbonized for about 5-6 hours at 400-470 degrees Celsius and left to cool down the charcoal overnight. The charcoal was carefully chosen, which is black, lightweight, and brittle. The yield of the bamboo charcoal was about 45% under the condition and proceeded to the activation process.

2. Activation of the Bamboo Charcoal

After choosing the high-quality charcoal that has been produced through carbonization, bamboo-derived activated carbon was prepared using a chemical activation process with potassium hydroxide (KOH) as the activating agent. The bamboo charcoal was incorporated with KOH solution with a 1:1 weight ratio, stirred for thirty minutes, and submerged for twenty-four hours until the paste formed. After the soaking period, the bamboo charcoal was dried using an oven at 120 degrees Celsius and then cooled down. Subsequently, the bamboo charcoal was rinsed thoroughly with distilled water for thirty minutes to remove any residual of KOH. Then, it underwent a drying process using the oven to dry completely to remove excess moisture before storing.

3. Granulation of Bamboo Charcoal

The bamboo charcoal was manually and carefully crushed using a mortar and pestle. Furthermore, the researchers used a strainer to sieve the granular charcoal with large-sized particles separated from powdered fragments.

4. Filtration Process of Activated Charcoal and Silica Gel

For two minutes, the researchers filtered 15 grams of activated bamboo charcoal and 15 grams of silica gel using Whatman blotting paper no. 1, which serves as the filter paper. A method of gravity filtration was performed by gradually pouring the sample lake water through the quadrant-folded filter paper in a glass funnel containing granulated activated charcoal and silica gel, allowing the sample water to flow into the Erlenmeyer flask while trapping the carbon and silica gel particles on the paper.

I. **Water Sampling.** Collection of the lake water sample in Tadlac Lake Los Baños, Laguna

1.1. **Sampling Planning.** The researchers requested permission to collect water sample from Tadlac Lake in Barangay Tadlac, Los Baños, Laguna.

1.2. **Sampling preparation.** The researchers sterilized the sample bottles in the autoclave and prepared gloves to ensure proper sanitization to prevent contamination of the water samples.

1.3. **Collection of lake water.** The researchers employed the grab sample technique to collect water samples from the lakeshore near the residences of Tadlac Lake by partially dipping the sterile sample bottle in the lake water.

1.4. **Label bottles correctly.** Upon collection, each sterile sample bottle was sealed, filled, and coded with date.

1.5. **Store bottles for transport.** After the sample bottles were labeled and the water samples are collected, they were placed inside a styrofoam cooler to avoid exposure to the sun. The samples were transferred immediately to the microbiology laboratory to execute the experimental setup.

B. Treatment of Microbial Contents on Lake water

The lake water sample was treated using a granulated activated carbon and silica gel with three experimental set-ups.

1. **Preparation of Materials.** Sample bottles**,** pipette tips, nine test tubes, each containing nine mL distilled water, and other glassware underwent autoclave to sterilize and eliminate harmful bacteria and sanitize the laboratory tools.
2. **Preparation of Samples and Plates.** The lake water samples were filtered and applied with the treatment (activated carbon and silica gel), while the untreated samples remained constant. Three dilution test tubes and six plates per setup were required, totaling nine dilution test tubes and eighteen plates used in the experiment. For the preparation of agar plates, the researchers conducted media preparation with a measurement of 8.23 grams of Plate Count Agar (PCA) mixed with 360 mL distilled water, autoclaved for fifteen minutes at 29.9 degree Celsius, and allowed to melt and temper agar (12–15 mL) poured into the Petri dish and solidified at room temperature to cultivate and develop microorganisms. After the agar plates solidified, each agar plate and dilution test tube were labeled.
3. **Serial dilutions and Spread plate technique.** A serial dilution was prepared for each setup. Each tube was subjected to a 10-fold dilution, starting with the undiluted tube. The initial tube was diluted at a ratio of 1:10 dilution, the second at a ratio of 1:100, and the third tube at a ratio of 1:1000. The researchers used a pipette to aspirate 1 mL of undiluted solution from the untreated sample and transferred it to the first test tube containing 9 mL of the dilution liquid and thoroughly mixed which resulted in a dilution factor of 10. In the second serial dilution, the researchers aspirate 1 mL of solution from tube 1:10 ratio and combine it with 9 mL of dilution liquid in tube 1:100. A thorough mix was done in tube 1:100 before adding it to the third tube 1:1000. The same procedure was performed for both treatments. Subsequently, a volume of 0.1 mL of each diluted sample tube was dispensed in the center of the petri plate. Furthermore, an aseptic technique was employed to perform the spread plate method using a sterile bent glass rod, facilitating easy counting and isolation of bacteria. After the spread plating method, the plates were sealed with cling wrap, inverted, and placed inside the biosafety cabinet at room temperature for 48 hours to incubate.
4. **Colony Count.** To determine the viable microorganisms in each sample, colony forming units were obtained. The untreated sample was treated with activated carbon and silica gel, cultured in agar plates, and incubated for 48 hours at room temperature. The researchers counted the colony manually by counting each colony dot once using a marker that can point to each counted colony on the back

of the Petri dish. After the researchers counted and recorded the colonies, CFU/mL, or Colony colony-forming units per milliliter, was used to quantify the concentration of viable microorganisms in untreated samples and treated samples of activated carbon and silica gel. The purpose of determining CFU/mL is to assess the level of microbial contamination or the concentration of a specific microorganism in an untreated and treated sample.

5. **Data Collection.** For each setup, the data were observed and gathered. Using the usual plate count, the average data for each setup, including the control setup, were calculated. Assessing whether there was a difference in the means of the treated sample at various time points was significant. As statistical tool, the the Paired T- test was used to check whether there was a significant difference in the outcome between two groups. The results of the test indicated that the study produced effective results.
6. **Decontamination.** Decontamination was performed on the samples, and PCA setups were used to dispose of hazardous material properly. Decontamination, being a post-process, helped to stop the spread of harmful substances. Since microbes were grown and cultivated during the data collection process, decontamination was utilized to prevent any potential spread of these microbes in the laboratory environment.

In this study, the Paired T-test was used to assess microbial contaminants and determine if there was a significant difference in outcomes between the two variables. Hence, this statistical tool helps to determine the significant difference between the results of granular activated bamboo carbon and silica gel particles before and after using them as a water treatment.

Results and Discussion

The microbial count of the water sample treated with granular activated carbon from bamboo (*B. vulgaris*).

Table 1. *Colony forming units (cfu/mL) of the Water Sample Treated with Granular Activated Carbon from Bamboo (B. Vulgaris)*

Variable	*Solution (mL)*	*Plate 1*	*Plate 2*
Untreated Lake water (Control)	0.1 mL	5.9×10^5	6.3×10^5
Granular Activated Bamboo Charcoal	0.1 mL	0	0

As shown in Table 1, a 0.1 mL of untreated lakewater (control) was dispensed onto plate 1 and 2. Another 0.1mL sample of lake water treated with granular activated bamboo charcoal was dispensed onto Plate 1 and Plate 2. After 48 hours of incubations, it shows that the controlled plates 1 resulted 5.9×10^5 and plate 2 has a total of 6.3×10^5 colonies formed. In contrast, the granular activated bamboo charcoal shows that both plate 1 and 2 were 0 or no viable microbial colonies formed.

The results indicated that there were no colony forming units observed in either plate of the water sample treated with granular activated bamboo carbon. There were no viable microbial colonies present in the sample with a CFU/mL count of 0 compared to the CFU/mL count of untreated lake water. As a result of the data, it can be concluded that granular activated bamboo carbon effectively reduced or eliminated microbial contamination in water samples. A granular activated carbon made from bamboo has been shown to remove or inhibit microbes from water, which could be useful in water purification and treatment applications.

In relation to the result of the data, activated carbon, containing carbonized materials with high porosity and surface area, has various applications in water purification, wastewater treatment, desalination, gas refining, odor and pollutant removal, and medical uses. In a study by Heidarinejad et al. (2020), the role of different activation factors in the efficiency of activated bamboo carbon from various precursors was analyzed. It was found that activated bamboo carbon with potassium hydroxide demonstrated higher adsorption efficiency compared to other activators. The data in study indicated that the activated bamboo charcoal has the potential for effective adsorption and removal of various contaminants from solutions or gasses due to its excellent functional properties, including high surface area, significant pore volume, and substantial adsorption capacity for microbial contaminants or methylene blue under specified conditions.

Additionally, activated carbon can be used with a variety of substances to adsorb different characteristics of wastewater because of its large specific surface area and micropore, high adsorption performance, and recycling. This work primarily introduces the structure, adsorption mechanism, modified activated carbon, and microbial-bound activated carbon. Activated charcoal produced through KOH activation demonstrated a notable capacity. Activated carbon derived from bamboo exhibited exceptional porosity, significant surface area, and desirable surface functionalization. In these studies, various substances including heavy metals, dyes, contaminants, antibiotics, and organic compounds were successfully removed (Jiang et al., 2019).

The microbial count of the water sample treated with silica gel.

Table 2. *Colony forming units (cfu/mL) of the Water Sample Treated with Silica Gel*

Variable	*Solution (mL)*	*Plate 1*	*Plate 2*
Untreated Lake water (Control)	0.1 mL	5.9×10^{5}	6.3×10^{5}
Silica Gel	0.1 mL	1.1×10^{5}	2.0×10^{5}

Each variable had a 0.1 mL water sample (both treated and untreated) dispensed onto Plate 1 and Plate 2. The plates containing silica gel-treated and untreated lake water were then incubated for 48 hours. In the table data, it indicates that 1.1×10^{5} and 2.0×10^{5} CFU/mL were observed on Plate 1 and Plate 2 of the water samples treated with silica gel. On the other hand, the untreated lake water has 5.9×10^{5} CFU/mL for

Plate 1 and 6.3×10^5 CFU/mL for Plate 2. Compared with the untreated lake water, the silica gel treated sample shows significantly lower microbial counts on both plates. The reduction in colony- forming units in the silica gel-treated sample indicates the partial efficiency of silica gel as a treatment method, even though there is still some microbial contamination present.

In connection with the study, the study of Pouran Pourhakkak and Mehrorang Ghaedi (2021) explained that silica gel consists of SiO2 units that possess a high degree of porosity. Silica gel is a polymer of four-dimensional silicon dioxide units arranged in a three-dimensional structure. The material exhibits porosity. Silica gel is an effective adsorbent for several substances, such as water, alcohol, phenols, amines, etc. In order to continue adsorption, activated carbon should be added after using silica gel to lower the microbials colonies.

Is there a significant difference in the microbial count before and after the treatment?

Table 3. *Test of Difference on Microbial Count using Granular Activated Bamboo Charcoal*

A. Using Granular Activated Bamboo Charcoal

Variable	*After*	*d*	*t-value*	*p-value*
Untreated Lake Water	6.1×10^5	6.1×10^5	-8.49	0.001
With Granular Activated Bamboo Charcoal	0			

The data presented in this table demonstrates a highly significant difference in microbial counts before and after treatment using Granular Activated Bamboo Charcoal. The microbial count observed after treatment with untreated lake water is 6.1×10^5. On the other hand, the microbial count observed after treatment with activated bamboo charcoal is 0, indicating a reduction in microbial count to zero. The difference (d) in microbial count before and after treatment was calculated as 6.1×10^5. Moreover, the yielded t-value is -8.49 while the p-value is 0.001, which is less than the significance level of 0.01 or 0.05, suggesting the rejection of the null hypothesis. The microbial count of water treated with Granular Activated Bamboo Charcoal has led to a substantial reduction in microbial count compared to the untreated lake water. In conclusion, there is a significant difference between the microbial counts before and after treatment using Granular Activated Bamboo Charcoal.

Activated carbon is considered a reliable adsorbent, according to the Statistics of Relevant Government Departments (2019). Due to its extensive specific surface area and micropores, in addition to its excellent adsorption capabilities and recyclability, it can effectively adsorb various wastewater characteristics when utilized with chemical substances such as potassium hydroxide which may effectively reduce microbial contaminants.

In line with the article reviewed by Nyika et al. (2022) entitled "Activated bamboo charcoal water treatment," bamboo exhibits significant biomass levels, rapid maturation, cost-effectiveness, and sustainability. These characteristics validate its preference as activated carbon. The unique ability of bamboo to adsorb contaminants from water solutions is attributed to its exceptional adsorption capacity and macropore structure. Its utilization is highly preferred compared to other naturally occurring types of activated carbon due to its fast-maturing process and reduced cost. Activated bamboo charcoal is considered a highly effective adsorbent for contaminants and is beneficial in treating wastewater due to its unique structural features.

Table 4. *Test of Difference on Microbial Count using Silica Gel*

B. Using Silica Gel

Variable	*After*	*d*	*t-value*	*p-value*
Untreated Lake Water	6.1×10^5			
		4.55×10^5	2.205	0.115
With Silica Gel	1.55×10^5			

Based on the data presented in the table 4, it appears to be a notable difference between the microbial counts before and after treatment using Silica Gel. Following treatment, the microbial count in the untreated lake water remained at 6.1×10^5. However, the microbial count in lake water treated with silica gel reduced to 1.55×10^5. The difference (d) in the microbial count before and after treatment was calculated as 4.55×10^5, indicating a substantial reduction in the microbial count with silica gel treatment.

Although the calculated t-value of 2.205 suggests a favorable effect of silica gel treatment on reducing microbial count, the associated p-value of 0.115 indicates that this difference may not be statistically significant since it is more than the significance level of 0.01 or 0.05. Therefore, based on these findings, it is concluded that there is no significant difference observed in the microbial counts before and after treatment using Silica Gel.

Is there a significant difference between the microbial contaminants after the two treatments?

Table 5. *Test of Difference on Microbial Count before and after the treatment*

Variable	*After*	*d*	*t-value*	*p-value*
With Granular Activated Bamboo Charcoal	0			
		1.55×10^5	30.5	0.01
With Silica Gel	1.55×10^5			

In Table 5, the results indicate a significant difference in microbial contaminants after treatment with Silica Gel compared to Granular Activated Bamboo Charcoal. The microbial contaminants were substantially reduced to 0 after treatment with Granular Activated Bamboo Charcoal. Meanwhile, the treatment with Silica Gel resulted in a microbial contaminant level of 1.55×10^5. The calculated t-value of 30.5 and the p-value of 0.01 is strong evidence to reject the null hypothesis which means there's a significant difference between the microbial contaminants after the two treatments.

In accordance with these observations, Granular Activated Bamboo Charcoal was highly effective as water treatment, achieving a microbial count of 0 after treatment than Silica Gel in microbial count reduction. Also, it demonstrates that Granular Activated Bamboo Charcoal is an effective and highly efficient way to lessen microbial contaminants in water treatment applications.

Conclusions

Based on the experiment's results, granular activated bamboo charcoal can be used to treat the microbial contaminants present in lake water. Using granular activated charcoal from bamboo *(B. vulgaris)* significantly decreases the microbial count, indicating its potential as a water treatment. However, the treatment of water samples with silica gel also results in a significant reduction in microbial contamination. Silica gel is partially effective at reducing microbial colonies, retaining many viable colonies even after treatment. The comparison between microbial counts before and after treatment shows a significant difference in the effectiveness of granular activated bamboo charcoal and silica gel. While granular activated bamboo charcoal can significantly reduce microbial colonies, silica gel treatment fails to achieve a comparable reduction in microbial colonies.

The study results indicate that using granular activated charcoal from bamboo (*B. vulgaris)* is an effective method for treating microbial contaminants in lake water samples. On the other hand, silica gel treatment is partially effective at reducing microbial contamination. In conclusion, the results indicate that the null hypothesis should be rejected. Therefore, granular activated bamboo charcoal emerges as an advantageous solution for water treatment applications to mitigate microbial contamination in natural water sources.

Recommendations

For the future researchers who will conduct similar studies, the following are recommended for further improvements of the study: The researchers suggested exploring alternative techniques, which may include steaming or carbon dioxide gas, as well as utilizing heat and a combination of physical and chemical methodologies, in addition to chemical activation. Furthermore, to have a transparent color rinse repeatedly or many times after filtering to get rid of the residue of the KOH.

To enhance the efficiency of silica gel, the researchers have also suggested that users may use another substance such as silica sand, to improve its effectiveness in treating microbial contaminants to ensure the highest quality. The researchers suggest that various tests such as including microbiological assessments and water analyses be conducted to verify the efficacy of water treatment using activated bamboo charcoal. Additionally, researchers recommend testing the product in different sources of water to understand its effectiveness against various types of microbial contaminants. This comprehensive testing approach ensures a thorough evaluation of activated bamboo charcoal's potential for effectively treating the water against microbial contaminants. To the municipalities and communities, introducing activated bamboo charcoal for water treatment in cities and communities offers a sustainable, cost-effective solution to reduce microbial contaminants in the water supply. This approach can significantly enhance the quality and safety of water resources.

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