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Harnessing Industrial Wastes from Biomass Power Plants for Clean Water: Efficient Arsenic Removal Using Carbonized Rice Hull and Functional Iron Oxide Nanoparticles (CRH-F-ION)

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ABSTRACT

Arsenic contamination in water is a significant global health issue, particularly in regions with high industrial activity or agricultural runoff. Traditional methods for arsenic removal, such as chemical precipitation and reverse osmosis, often come with high costs and environmental concerns. This study introduces a novel, low-cost, and eco-friendly solution for arsenic removal by utilizing carbonized rice hull (CRH), a waste by-product from biomass power plants, functionalized with iron oxide nanoparticles (F-ION). A green synthesis method was employed to produce iron oxide nanoparticles using guava leaf extract. The CRH-F-ION composite was tested in a filtration system for its efficiency in removing arsenic from contaminated water. Experimental results revealed a high removal efficiency, with CRH-F-ION achieving up to 99.4% arsenic removal, and the best-performing composite comprising a 50% CRH and 50% F-ION ratio. Water quality parameters such as pH, electrical conductivity (EC), and total dissolved solids (TDS) were also analyzed before and after filtration. This study demonstrates the potential of using agricultural waste combined with nanotechnology to provide a sustainable and cost-effective solution for arsenic contamination in water.

Keywords: Arsenic removal, Carbonized Rice Hull, Iron Oxide Nanoparticles, Water treatment, Adsorption.

INTRODUCTION

Arsenic is a toxic metalloid that is widely distributed in the Earth's crust and is frequently found in groundwater, particularly in regions where industrial, agricultural, and mining activities are prevalent. It is a serious environmental pollutant due to its toxic and carcinogenic properties, and its presence in drinking water has been associated with significant public health risks (Pezeshki et al., 2023). Arsenic contamination in groundwater is an emerging global crisis, with over 200 million people exposed to unsafe levels, particularly in parts of South Asia, Southeast Asia, and Latin America (Podgorski & Berg, 2020). Chronic exposure to arsenic has been linked to various adverse health effects, including skin lesions, cancers, cardiovascular diseases, and neurological disorders (Verma et al., 2014). Even at low concentrations, arsenic poses a substantial risk to both human health and the environment, as it enters the food chain through contaminated water sources, affecting aquatic ecosystems and agricultural crops (Kamde et al., 2017).

The presence of arsenic in groundwater is largely due to both natural and anthropogenic sources. Natural sources include the weathering of arsenic-rich rocks and the release of arsenic from sedimentary deposits (Smedley & Kinniburgh, 2002). However, anthropogenic activities, particularly industrial processes such as mining and the use of pesticides and fertilizers, exacerbate arsenic contamination in water bodies (Saha et al., 2016). Mining activities, for instance, contribute significantly to arsenic pollution in regions where minerals containing arsenic are processed, leading to the release of arsenic into surrounding groundwater and surface water bodies (Gomez et al., 2021). These human activities often result in the introduction of high concentrations of arsenic into otherwise safe drinking water sources, further compounding the issue in areas that depend heavily on groundwater as their primary water source.

The public health implications of arsenic contamination are far-reaching, with numerous studies documenting the adverse health effects associated with prolonged exposure to arsenic-contaminated water. Arsenic is classified as a human carcinogen by the World Health Organization (WHO), and its chronic ingestion is linked to an increased risk of several types of cancer, including skin, lung, and bladder cancers (Chowdhury et al., 2016). Additionally, arsenic exposure has been associated with developmental and neurological effects, particularly in children, and can lead to other serious conditions such as diabetes, cardiovascular diseases, and kidney damage (Pezeshki et al., 2023; Ali et al., 2017). As a result, the safe removal of arsenic from contaminated water sources has become a top priority for environmental scientists and policymakers alike.

Various traditional water treatment methods have been developed to address arsenic contamination, including chemical precipitation, reverse osmosis, ion exchange, and adsorption. These methods have varying degrees of effectiveness, but they often come with significant drawbacks. Chemical precipitation, for example, requires the use of chemicals that can generate harmful by-products, while reverse osmosis requires high energy inputs and generates brine waste, which is difficult to manage (Mohan & Pittman, 2007). Moreover, both methods can be costly and are typically impractical in low-resource settings. As a result, there has been increasing interest in the development of low-cost, efficient, and sustainable water treatment technologies, particularly for use in rural and underdeveloped areas where arsenic contamination is most prevalent.

Among the promising alternatives, adsorption has gained considerable attention due to its simplicity, low cost, and ability to remove a wide range of contaminants, including arsenic, from water. Adsorption involves the accumulation of contaminants on the surface of an adsorbent material, driven by attractive forces between the adsorbate (arsenic) and the adsorbent (e.g., carbon-based materials, zeolites, and clays). Many studies have investigated various adsorbents for arsenic removal, and natural materials, such as rice hulls, have shown significant potential as low-cost adsorbents (Mohan & Pittman, 2007). Rice hulls, particularly when carbonized, possess a porous structure that provides a large surface area for adsorption, making them effective for removing arsenic from contaminated water (Asif & Chen, 2015). However, while carbonized rice hulls (CRH) are effective, their adsorption capacity may be limited, especially in the case of low arsenic concentrations, which are often found in natural groundwater sources (Devi & Sahara, 2017).

To enhance the adsorption capacity of CRH and other carbon-based materials, surface modification techniques have been developed, including the functionalization of these materials with metal nanoparticles. Iron oxide nanoparticles, in particular, have shown promise in improving the arsenic removal efficiency of carbon-based adsorbents. Iron oxide nanoparticles have a high surface area, a strong affinity for arsenic, and the ability to form stable complexes with arsenic species, making them highly effective for arsenic removal (Siddiqui & Chaudhry, 2017). Surface modification with iron oxide can increase the number of active sites on the adsorbent, thereby enhancing its ability to remove arsenic even at low concentrations.

Recent advancements in green synthesis methods for the production of iron oxide nanoparticles have further improved the feasibility of this approach. Green synthesis involves the use of plant extracts to reduce metal ions into nanoparticles, providing an environmentally friendly alternative to traditional chemical methods. For instance, guava leaf extract has been used effectively to synthesize iron oxide nanoparticles, offering a sustainable and cost-effective method for nanoparticle production (Xiao et al., 2016). The combination of carbonized rice hulls and green-synthesized iron oxide nanoparticles presents a novel approach for arsenic removal from contaminated water, offering a potentially scalable and sustainable solution for addressing arsenic pollution in affected regions.

This study focuses on the development of carbonized rice hull functionalized with iron oxide nanoparticles (CRH-F-ION) for the efficient removal of arsenic from contaminated water. By enhancing the arsenic removal capacity of CRH through functionalization with iron oxide nanoparticles, this research aims to contribute to the development of a low-cost, sustainable, and effective water treatment technology for regions with high levels of arsenic contamination.

METHODOLOGY

This study follows a structured approach involving the input-process-output framework to achieve its objectives. The methodology comprises the collection of materials, preparation of functionalized adsorbents, arsenic standard solution preparation, filtration setup, and analytical techniques for evaluating the effectiveness of the Carbonized Rice Hull with Functional Iron Oxide Nanoparticles (CRH-F-ION) in arsenic removal from contaminated water.

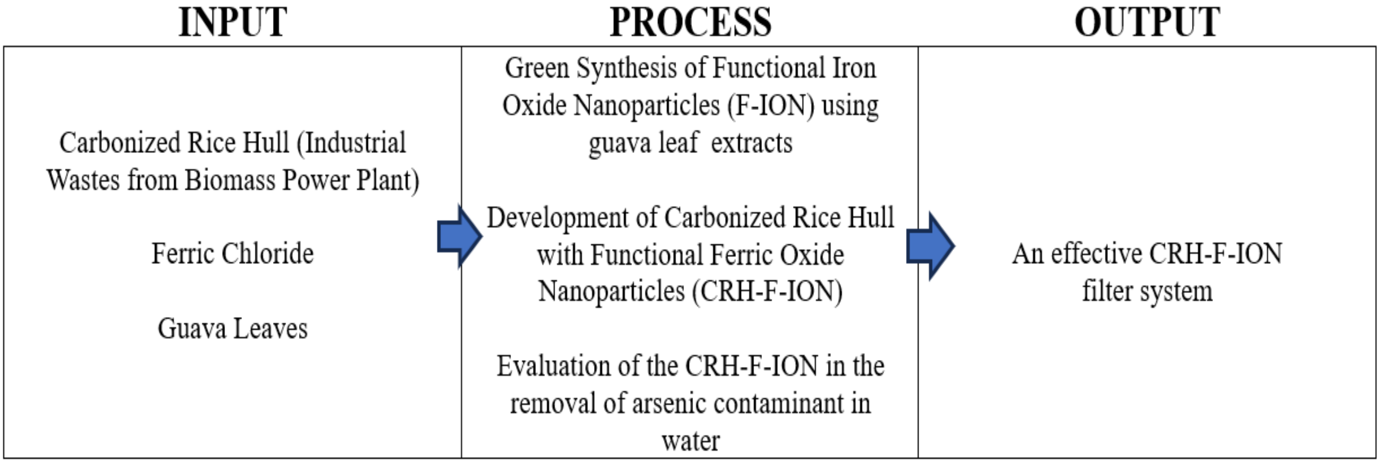


Figure 1. Conceptual framework of the study

Collection of Carbonized Rice Hull (CRH)

The carbonized rice hull (CRH) used in this study was sourced from the GIFT-C Biomass Power Plant, located in Bakal III, Talavera, Nueva Ecija. The GIFT-C plant employs rice hulls as biomass to generate sustainable energy. This plant plays a crucial role in repurposing agricultural waste, converting it into bioenergy for local communities. The collected CRH was used as a base material for the adsorption process after undergoing carbonization, which enhanced its surface area and porosity, making it suitable for contaminant removal.

Preparation of Functional Iron Oxide Nanoparticles (F-ION)

The preparation of iron oxide nanoparticles was carried out using a green synthesis method as described by Allu et al. (2022). Fresh guava leaves were collected, washed with tap water, and then with distilled water to remove dirt and contaminants. The leaves were dried in the shade for 48 hours, then ground into fine powder. To synthesize the nanoparticles, 100 mL of distilled water was heated to 70°C in an Erlenmeyer flask on a hot plate. Subsequently, 10 grams of the ground guava leaf powder was added to the flask and stirred for 3 hours. A 0.1 M solution of ferric chloride ($FeCl_3$) was prepared and added dropwise to the leaf extract, resulting in the formation of a black precipitate, indicating the synthesis of iron oxide nanoparticles. The nanoparticles were then centrifuged at 10,000 rpm for 20 minutes, washed with distilled water, and dried in an oven for 24 hours.

Development of CRH-F-ION Composites

Once the CRH and functional iron oxide nanoparticles were prepared, they were mixed in two different ratios for use in the filtration experiments: CRH-F-ION A (50% CRH:50% F-ION) and CRH-F-ION B (70% CRH:30% F-ION). These composites were thoroughly mixed to ensure uniform distribution of the nanoparticles in the CRH. The CRH-F-ION composites were then tested for their ability to remove arsenic from contaminated water, with each treatment being evaluated separately to determine the most effective ratio for arsenic adsorption.

Preparation of Arsenic Standard Solution

An arsenic standard solution was prepared for use in the batch experiments. To create this solution, arsenic was weighed using an analytical balance, and the required amount was dissolved in distilled water to achieve a concentration of 10 ppm, based on the following calculation formula:

$$Parts\ per\ million\ (ppm) = \frac{mg\ of\ solute\ (arsenic)}{L\ of\ solution}$$

The solution was prepared in a volumetric flask by dissolving the weighed arsenic compound and adding water to the desired volume. The prepared solution was used as the initial concentration for the arsenic removal experiments.

Filtration Setup

A continuous-flow adsorption system was used to evaluate the arsenic removal efficiency of the CRH-F-ION composites. The filtration setup involved a 12-filtration system using burettes, with each treatment consisting of different materials as the adsorbents. The treatments were designed as follows:

- **Treatment 1**: 100% CRH
- **Treatment 2**: 100% F-ION
- **Treatment 3**: CRH-F-ION A (50% CRH:50% F-ION)
- **Treatment 4**: CRH-F-ION B (70% CRH:30% F-ION)

For each treatment, 250 mL of 10 ppm arsenic-contaminated water was passed through the filtration system. The leachate collected from the filtration system was analyzed for arsenic content, and each experiment was repeated in triplicate to ensure the accuracy and reliability of the results. The flow rate and duration of filtration were controlled to maintain consistent conditions across all treatments.

The filtration system design was based on literature, which indicates that factors such as grain size, shape, porosity, and bed depth impact filtration efficiency (Cescon & Jiang, 2020). Additionally, aeration and the use of smaller column sizes can improve arsenic adsorption efficiency (Rohail, 2012). The pH of the solution was maintained in a neutral range, as this condition is known to enhance arsenic adsorption (Afzali et al., 2015). Furthermore, the bed height of the filtration media was optimized to provide sufficient contact time for arsenic ions to attach to the adsorbent surface, with longer contact times leading to higher removal efficiencies (Asif & Chen, 2015).

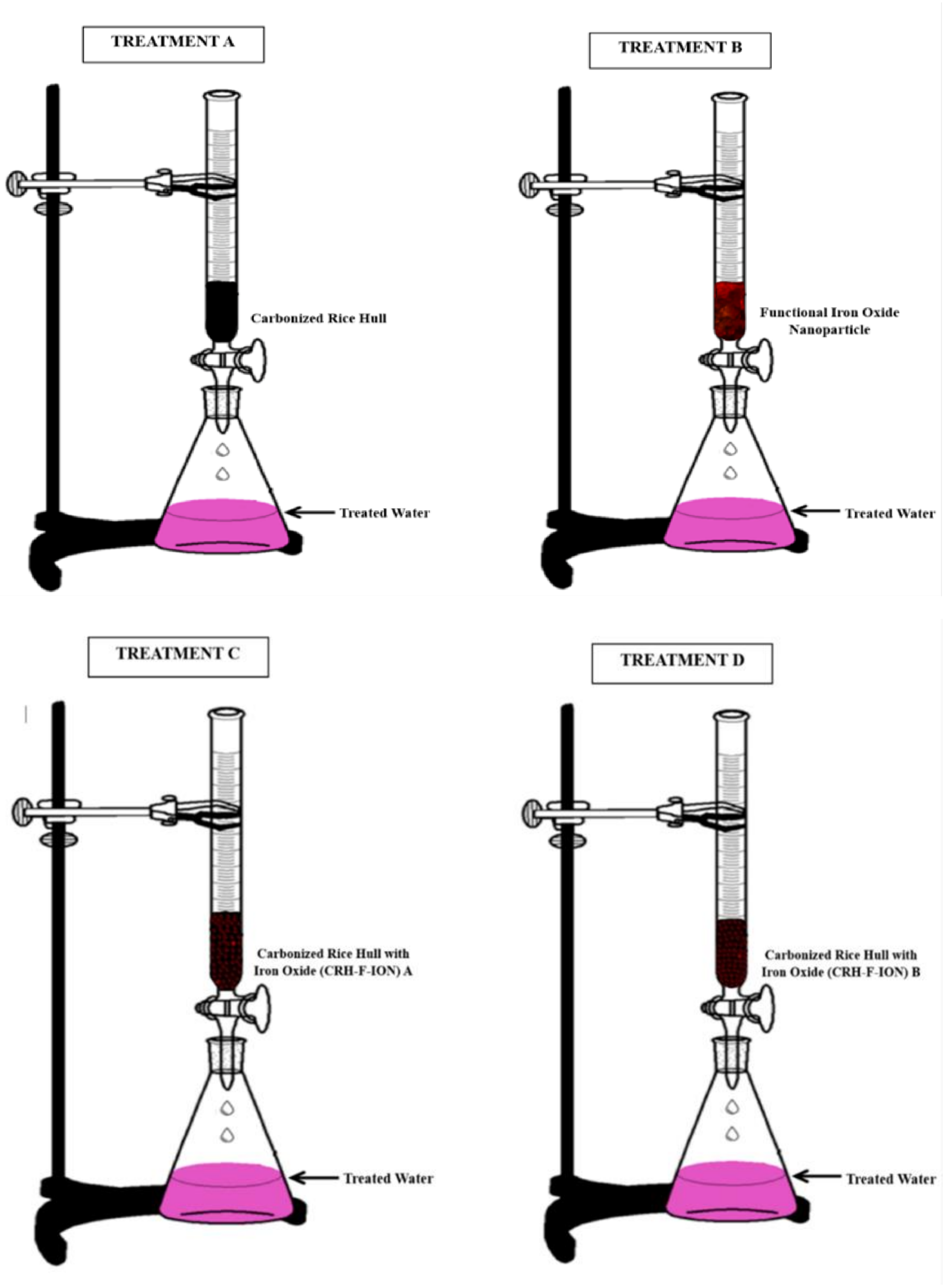


Figure 2. Filtration System Model

Packing of the Filtration System

To prepare the filtration columns, the CRH, F-ION, and CRH-F-ION mixtures were gently poured into the glass columns to form a filtering bed. The materials were compacted using a metal rod to ensure uniform packing and prevent disturbance during the filtration process. A beaker was used to collect the leachate or treated water, and the filtration system was designed to ensure smooth and efficient water flow without compromising the quality of the adsorbent bed.

Quantitative Analysis: Gravimetric Method

To quantify the arsenic removed during the filtration process, the gravimetric method was employed. This method involves reacting the arsenic in the treated water with silver nitrate ($AgNO_3$) to form silver arsenate (Ag_3AsO_4) as a precipitate. The following procedure was followed:

1. **Precipitation**: A 5 mL solution of 1.0 M silver nitrate was added to 20 mL of treated water to produce solid silver arsenate (Ag_3AsO_4).
2. **Filtering**: The solution was passed through filter paper to separate the precipitate from the liquid.
3. **Rinsing**: The precipitate was rinsed with distilled water to remove any excess ions.
4. **Drying**: The filter paper with the precipitate was dried in an oven for 1-2 hours to remove moisture, and the weight of the dried precipitate was recorded.

The amount of arsenic in the sample was calculated based on the stoichiometric relationship between the mass of silver arsenate and the arsenic concentration in the sample.

Parameter Monitoring Before and After Filtration

To assess the effectiveness of the CRH-F-ION composites in purifying contaminated water, various water quality parameters were monitored before and after filtration. These included:

- **pH**: Measured using a pH meter to ensure that the water remained within the neutral range, which is optimal for arsenic adsorption (Afzali et al., 2015).
- **Temperature**: Recorded using a water quality tester to ensure consistency during the filtration process.
- **Salinity**: Measured to assess the ionic content in the water.
- **Total Dissolved Solids (TDS)**: Measured to assess the overall solute concentration in the water.
- **Electrical Conductivity (EC)**: Measured to determine the ion concentration and the ability of the water to conduct electricity.

Characterization of CRH-F-ION

The morphology of the CRH-F-ION composite before and after filtration was examined using Scanning Electron Microscopy (SEM). SEM allows for the direct visualization of surface structures, pore sizes, and the attachment of arsenic ions to the adsorbent surface, providing valuable insight into the adsorption process.

Adsorption Isotherms

To analyze the adsorption behavior of CRH-F-ION, the data from the experiments were fitted to the Langmuir and Freundlich adsorption isotherm models. The Langmuir model assumes monolayer adsorption on a surface with a finite number of identical sites, while the Freundlich model applies to non-ideal adsorption on heterogeneous surfaces. Linear regression analysis was performed using Microsoft Excel to calculate the isotherm coefficients and evaluate the adsorption efficiency of CRH-F-ION.

RESULTS AND DISCUSSION

Green Synthesis of Functional Iron Oxide Nanoparticles (F-ION)

The functional iron oxide nanoparticles (F-ION) used in this study were synthesized through a green method using guava leaf extract, following the procedure outlined by Allu et al. (2022). Fresh guava leaves were harvested, washed, and dried at room temperature for 48 hours. The ground leaves were then mixed with distilled water, and the solution was heated at 70°C for 3 hours. A 0.1 M solution of ferric chloride ($FeCl_3$) was added to the leaf extract, resulting in the formation of a black precipitate. This precipitate, indicative of the reduction of Fe^{3+} ions to Fe^{2+}, was then centrifuged and dried in a vacuum, following procedures described by Liu et al. (2018).

The resulting iron oxide nanoparticles, as shown in Figure 3, were characterized by Scanning Electron Microscopy (SEM) and Energy Dispersive X-ray Spectroscopy (EDX), which revealed the presence of iron (Fe), oxygen (O), and carbon (C), with silicon (Si) as a significant component due to the inclusion of CRH in the final composite. The high peaks of iron in the spectra confirm the successful synthesis of iron oxide nanoparticles, with oxygen molecules primarily derived from the guava leaf extract, which contains flavonoids known to contribute to the reduction process (Farshchi et al., 2018). The SEM-EDX analysis further revealed that the combination of CRH and F-ION resulted in a composite material with enhanced surface characteristics, which played a key role in the arsenic removal process.

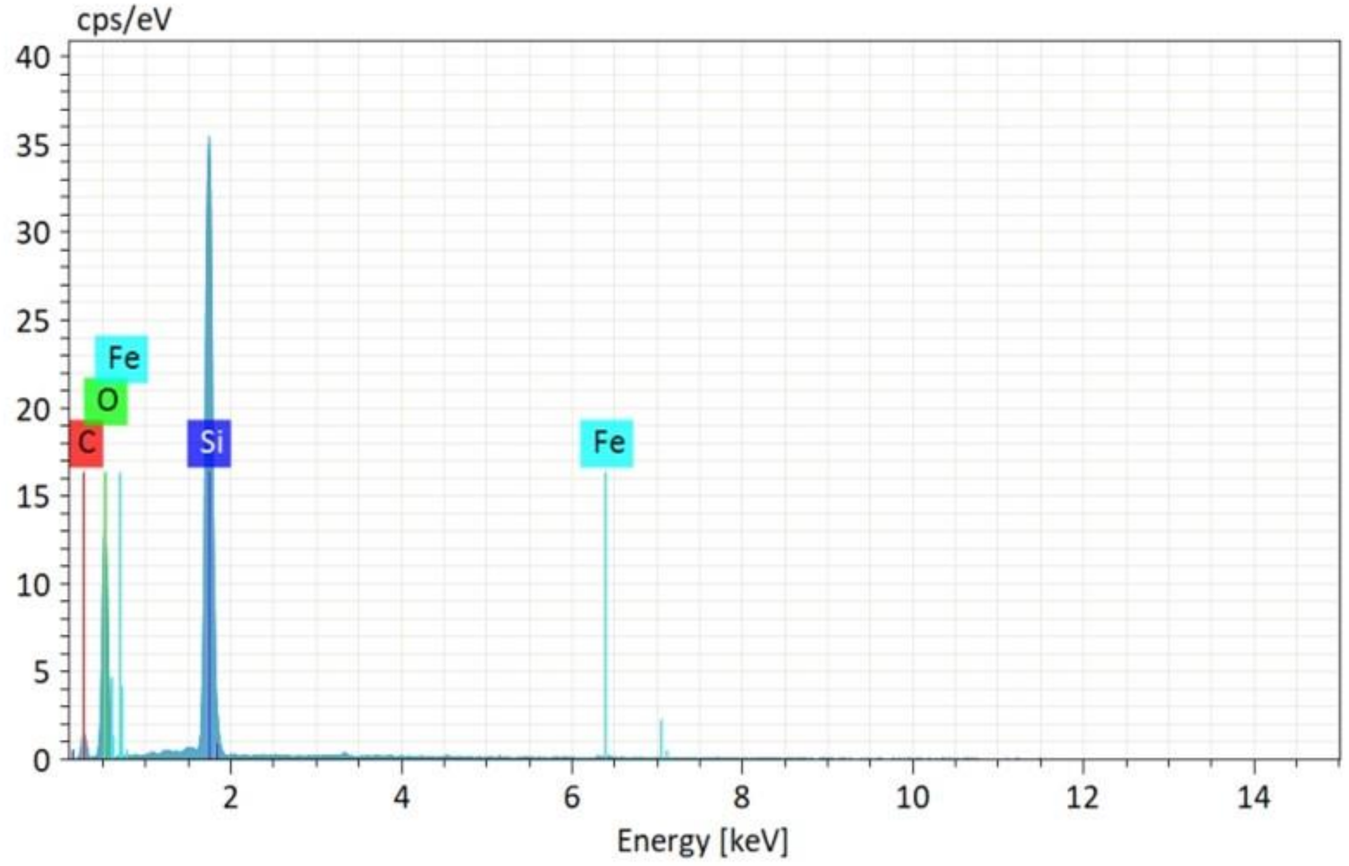


Figure 3. SEM Spectra of F-ION from the combination

CRH-F-ION Filtration System

The filtration system (Figure 4) used in this study employed burettes packed with CRH, F-ION, and CRH-F-ION composites. The adsorbent mass was maintained at 2 grams per treatment, and each treatment was replicated three times to ensure reliable results. A cotton layer was placed at the top and bottom of the adsorbent bed to prevent any disturbance or loss of the adsorbent during the filtration process. The water samples were passed through the filtration columns, and the treated water was collected for further analysis.

The CRH-F-ION composites performed effectively as adsorbents, with varying results based on the ratios of CRH to F-ION. The removal efficiency of arsenic from contaminated water was significantly higher than 90% across all treatments, with Treatment 1 (100% CRH) achieving the highest removal efficiency of 99.43%. The combination of CRH and F-ION (50% CRH:50% F-ION) in Treatment 3 showed an average removal efficiency of 98.79%, which was the most effective combination ratio. Treatment 4 (70% CRH:30% F-ION) achieved an efficiency of 98.51%, while the pure F-ION treatment (Treatment 2) resulted in a removal efficiency of 97.66%.

These results align with previous studies showing that carbon-based materials such as CRH can effectively adsorb arsenic from water, with removal efficiencies often exceeding 90% (Asif & Chen, 2015). The addition of iron oxide nanoparticles significantly improved the adsorption capacity of CRH, likely due to the increased surface area and the formation of stronger interactions between the adsorbent and arsenic ions (Siddiqui & Chaudhry, 2017).

Figure 4. The Actual Filtration Set-up

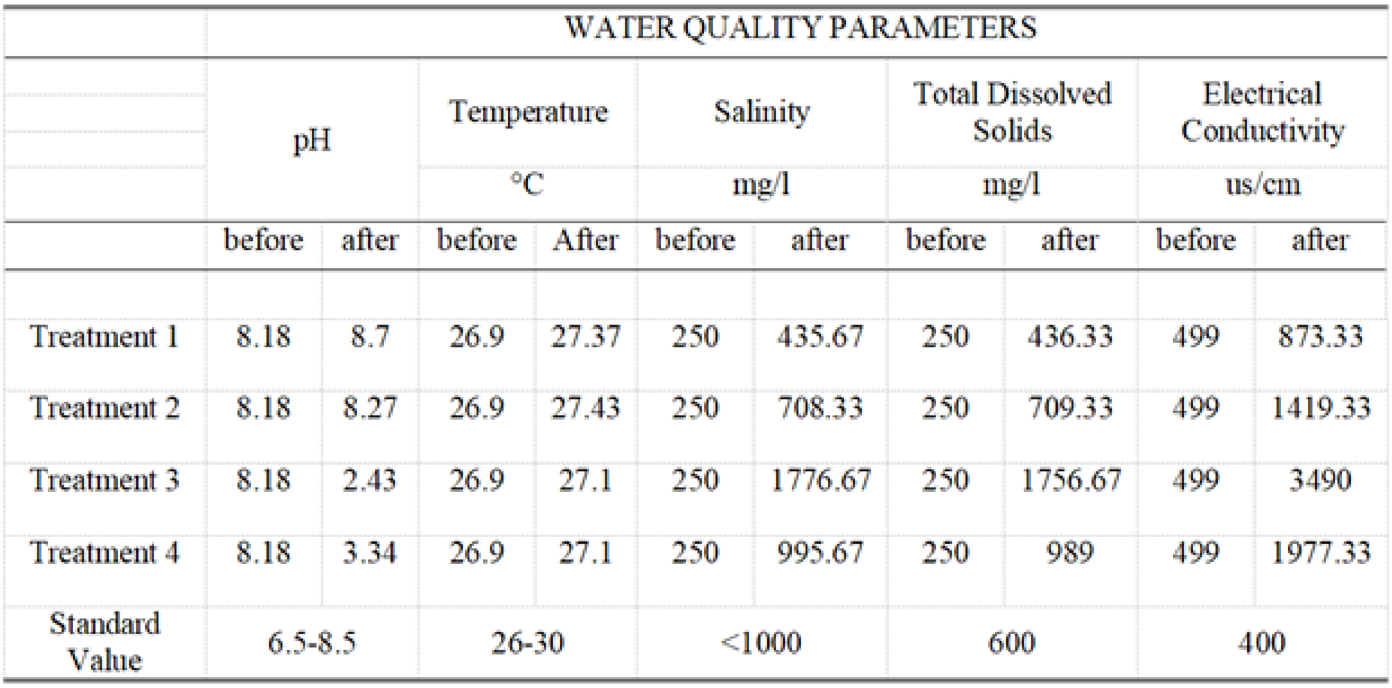
Table 1. Efficiency of the CRH-F-ION in the removal of Arsenic in water

TREATMENTS	CONCENTRATION OF ARSENIC		REMOVAL EFFICIENCY
	Before Filtration	After Filtration	
Treatment 1	10 ppm	0.057ppm	99.43 %
Treatment 2	10 ppm	0.23 ppm	97.66%
Treatment 3	10 ppm	0.12 ppm	98.79%
Treatment 4	10 ppm	0.15 ppm	98.51 %

Water Quality Parameters Before and After Filtration

In addition to arsenic removal, several water quality parameters were monitored before and after the filtration process. These included pH, temperature, salinity, total dissolved solids (TDS), and electrical conductivity (EC).

Table 2. Water quality before and after the filtration.



	WATER QUALITY PARAMETERS									
	pH		Temperature		Salinity		Total Dissolved Solids		Electrical Conductivity	
			°C		mg/l		mg/l		us/cm	
	before	after	before	After	before	after	before	after	before	after
Treatment 1	8.18	8.7	26.9	27.37	250	435.67	250	436.33	499	873.33
Treatment 2	8.18	8.27	26.9	27.43	250	708.33	250	709.33	499	1419.33
Treatment 3	8.18	2.43	26.9	27.1	250	1776.67	250	1756.67	499	3490
Treatment 4	8.18	3.34	26.9	27.1	250	995.67	250	989	499	1977.33
Standard Value	6.5-8.5		26-30		<1000		600		400	

The pH of the treated water increased slightly in Treatments 1 and 2, indicating a shift towards more alkaline conditions after filtration. This result is consistent with previous studies, where CRH adsorption processes were observed to raise the pH of the treated water (Babazad et al., 2010 as cited by Shooto, 2023). The increase in pH is likely due to the basic nature of the CRH material, which may release hydroxyl ions during the adsorption process, thereby raising the water's pH.

In contrast, Treatments 3 and 4, which involved the combination of CRH and F-ION, exhibited a decrease in pH after filtration, resulting in more acidic conditions. This is beneficial for arsenic removal, as the adsorption of arsenic ions is more effective in acidic environments (Ha, Phong & Minh, 2021). The low pH observed in Treatments 3 and 4 supports the theory that the presence of iron oxide nanoparticles in the composite enhances arsenic removal by promoting the uptake of arsenic ions in an acidic environment.

Temperature, salinity, TDS, and EC all increased after the filtration process, which is typical when using adsorbents like CRH and iron oxide nanoparticles. The increase in these parameters is due to the leaching of other ions, particularly from the F-ION component, during the adsorption process. The rise in EC and TDS indicates that the adsorbents interacted with other dissolved ions in the water, which is consistent with findings from other studies on metal ion adsorption (US EPA, n.d.; Shan et al., 2009 as cited by Habuda-Stanic & Nujic, 2015).

Filtration Period and Adsorption Efficiency

The filtration process duration also played a significant role in arsenic removal efficiency as shown in Figure 4. A longer filtration time allowed more contact time between the arsenic ions and the adsorbent surface, resulting in higher removal efficiencies. The results from this study showed that the removal percentage of arsenic increased with longer filtration times, which is consistent with other studies that suggest longer contact times improve adsorption efficiency (Afzali et al., 2015). The optimal duration of 230 minutes for the treatments resulted in a removal efficiency of up to 97%.

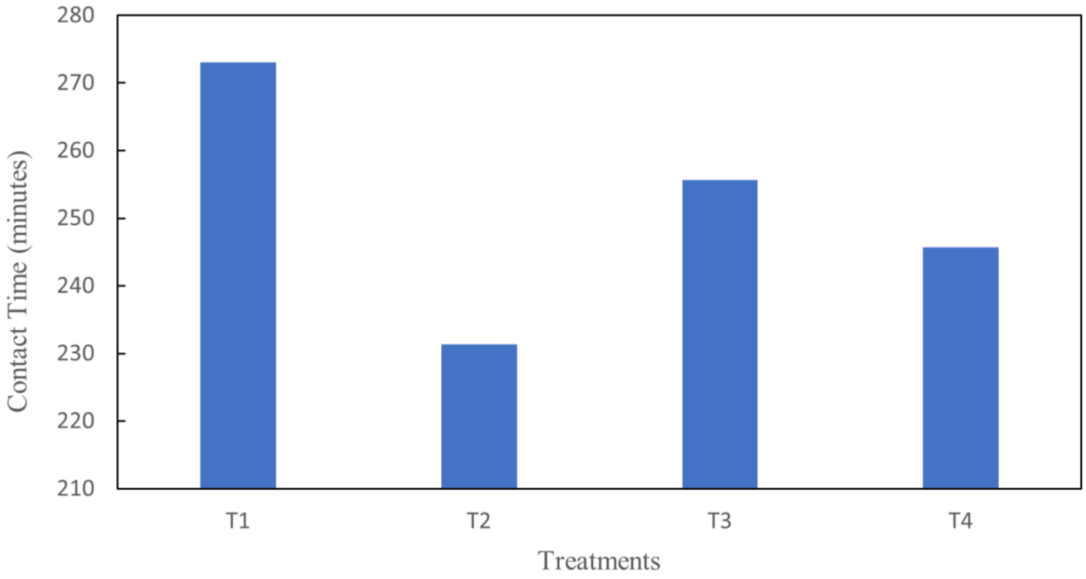


Figure 4. The Removal Percentage and Filtration Time

Langmuir and Freundlich Adsorption Isotherms

The adsorption data were fitted to the Langmuir and Freundlich isotherm models to evaluate the adsorption capacity of CRH-F-ION. The Langmuir model provided a good fit with an R^2 value of 1.0, indicating that the adsorption of arsenic onto CRH-F-ION occurred on a homogenous surface, with a monolayer formation. The maximum adsorption capacity (qmax) was found to be 1.21 mg/g, and the Langmuir constant (KL) of 549.47 suggests strong interactions between the adsorbent and arsenic ions, further supporting the high arsenic removal efficiency observed in the experiments (Figure 5).

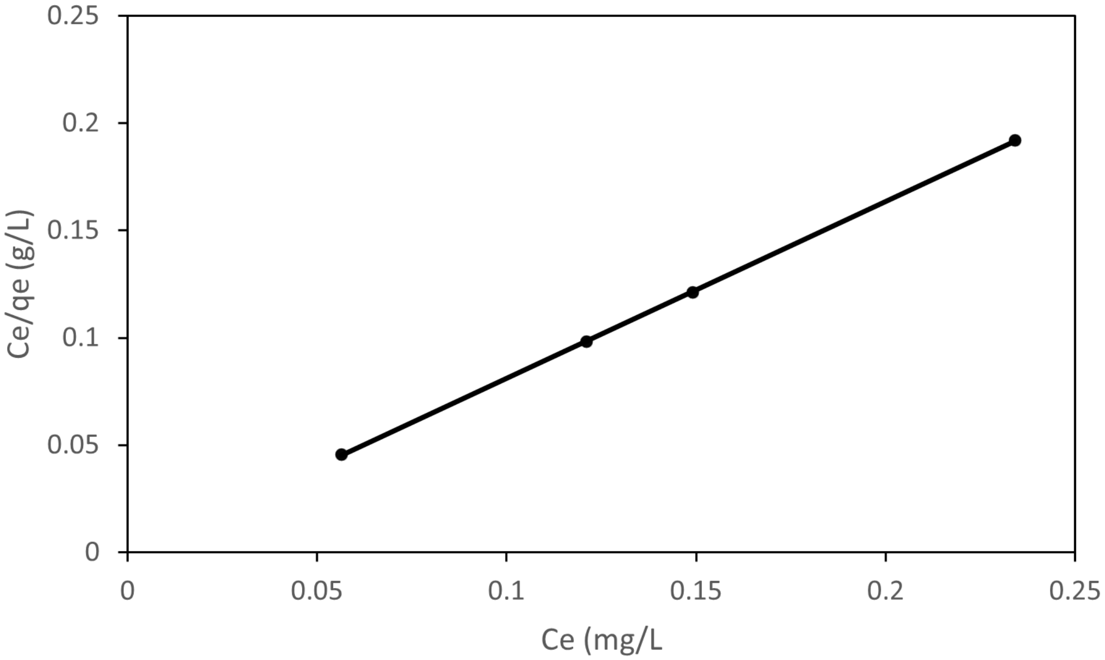


Figure 5. The plot of Langmuir Adsorption Isotherm Model on Arsenic using CRH-F-ION

The Freundlich model, with an R² value of 0.95 as shown in Table 3. Also demonstrated good fit, indicating that adsorption on the CRH-F-ION surface occurred in a non-homogeneous manner, with multiple adsorption sites. The Freundlich constant (Kf) of 1.2 indicates that the adsorption was favorable, but not as uniform as that suggested by the Langmuir model. The results from both models reinforce the high arsenic removal efficiency of CRH-F-ION and provide valuable insights into the adsorption mechanism.

Table 3. The Langmuir and Freundlich Model Parameters

LANGMUIR MODEL			FREUNDLICH MODEL		
q_{max} (mg/g)	K_L	R^2	K_F	1/n	R^2
1.21	549.47	1	1.2	81.3	0.95

Statistical Analysis: One-Way ANOVA and Post-Hoc Test

The statistical significance of the differences between treatments was assessed using one-way ANOVA (Table 4), which showed that there were significant differences in the arsenic removal efficiencies between the four treatments. The post-hoc analysis confirmed that Treatment 1 (100% CRH) was significantly more effective than the other treatments, particularly when compared to Treatment 2 (100% F-ION). These findings suggest that the CRH material itself is highly effective in arsenic removal, but the combination of CRH with F-ION further enhances the adsorption process.

Table 4. One-Way ANOVA Result

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F STAT	P-VALUE	F CRIT
Between Groups	0.049	3	0.016	4.35	0.043	4.067

One-way ANOVA and Post-hoc Test

This test was used to compare the effectiveness of the 4 treatments to treat arsenic in the water and determine whether the means of treatment levels (produced by the independent variable) deviate significantly from the general mean of the dependent variable. The researcher then performs a one-way ANOVA to determine if there is a difference in the final equilibrium concentration of arsenic in the treated water between the four treatments.

Table 5. One-Way ANOVA Result

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F STAT	P-VALUE	F CRIT
Between Groups	0.049	3	0.016	4.35	0.043	4.067

Based on the table, the p-value was less than 0.05 confidence level indicating that there is a significant difference between the final arsenic concentration of the 4 treatments and implying that variation distinguishes the effectiveness of the 4 treatments with different ratios of adsorbents (CRH and F-ION) for arsenic contaminated water treatment so that it has recorded different removal percentage. The F statistical was less than the value of F critical indicating a real difference and the test for the results of this study is significant.

Table 6. Post-hoc Test Quantitative Description

POST-HOC TEST (Bonferroni corrected)	INTERPRETATION
If $P<0.0125$	Significant
If $P>0.0125$	Not Significant

Since the ANOVA result showed that the 4 treatments are significantly different to each other. Then, it's time to use Post-hoc Test through will need to perform separate individual student T-test to control and connecting multiple comparison with the Bonferroni correction.

In this test, the alpha level was adjusted to 0.0125 confidence level via Bonferroni method derived from dividing the 0.05 original alpha level to the number of post-hoc run test which total of 4 then the resulting answer is the post hoc alpha level now. To account for the multiple hypothesis to obtain more chance of discovering the significant result purely by chance that would cause an increase the likelihood of a false positive result.

Table 7. Post-hoc Test Result

Groups	P-value (T-test)	Is Significant?
T1 vs. T2	0.009372792	Yes
T2 vs. T3	0.050444898	No
T3 vs. T4	0.136637117	No
T4 vs. T1	0.002530704	Yes

Note: T=Treatments

The researcher were determined what specific group in each treatment were significant to each other, so that the table showed only T1 vs. T2 and T4 vs. T1 are significant while T2 vs. T3 and T3 vs. T4 was not significant to each other. Post-hoc analysis also revealed that Treatment 1 (0.0057±0.0018 ppm) was significantly effective compared with those in Treatment 2 (0.23±0.09 ppm, $p<0.0125$), Treatment 3 (0.12±0.003 ppm, $p<0.0125$) and Treatment 4 (0.15±0.03 ppm, $p<0.0125$).

The SEM Image of the CRH-F-ION

The SEM image showed the characteristics of CRH-F-ION surface area was heterogenous in nature, the adsorbent was an irregular shape with different particle forms were clumping that consist of pores and slight breakage from apar sight of the image.

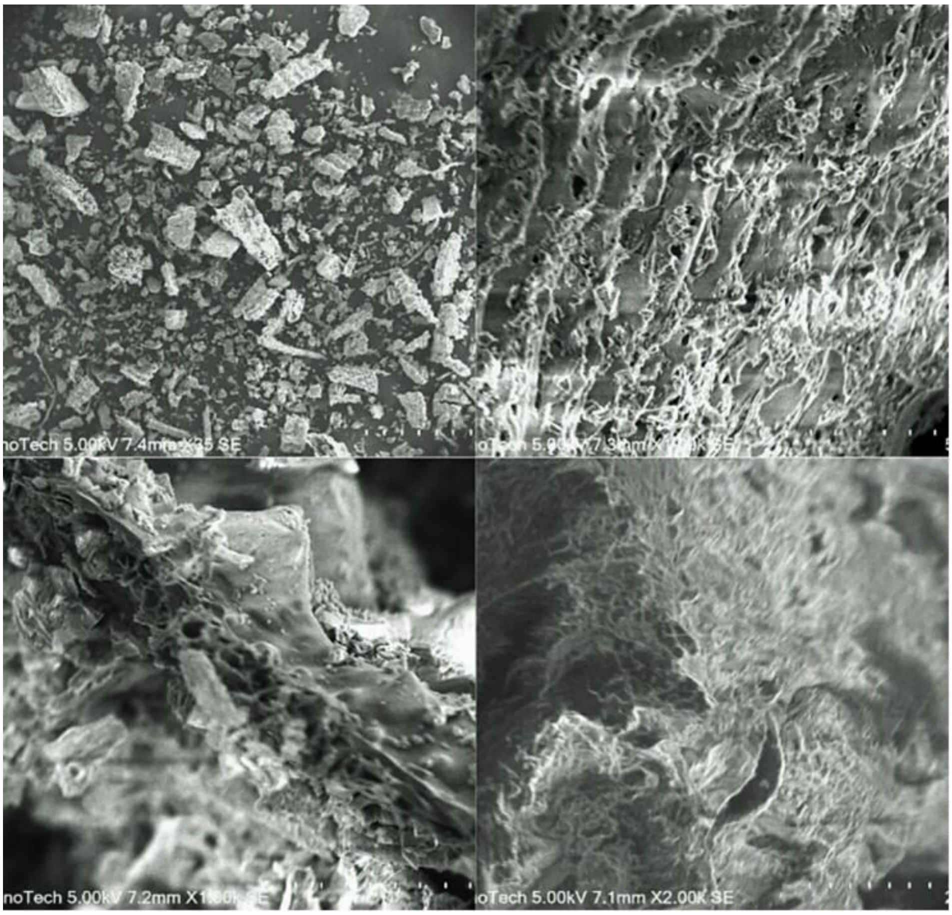


Figure 6. The SEM Image of CRH-F-ION before Filtration

The CRH-F-ION large surface area and pores was providing binding site for arsenic ion upon adsorption process so this was the concept of arsenic removal as the water was in contact with this adsorbent through filtration.

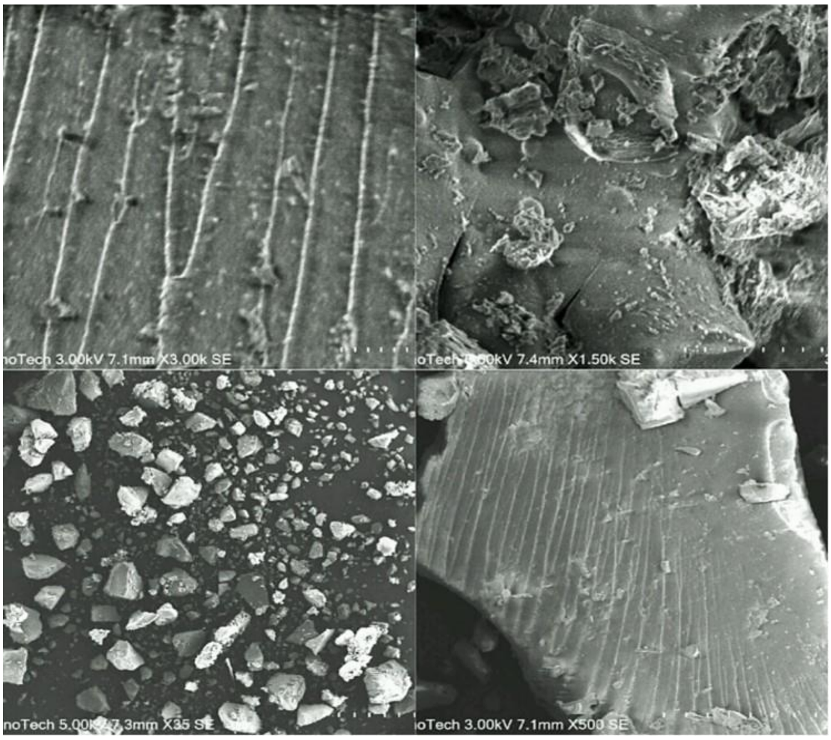


Figure 7. The SEM Image of CRH-F-ION After Filtration

The SEM image showed the characteristics of CRH-F-ION surface area was like a flake clumped to each other, there was a change in particle formation and pores was not visible indicating that there is arsenic ion occupied or attached to the surface area made it change its characteristics.

The sample adsorbent after filtration also undergoes SEM-EDX to obtain deeper analysis of the CRH-F-ION surface structure. This analysis was not destroying the sample material and it useful to identify specifically what are the specific elements present in the sample particularly to determine if there were arsenic adsorbed in the sample through using light with electrons that gave risen to x-rays characteristics to the elements present.

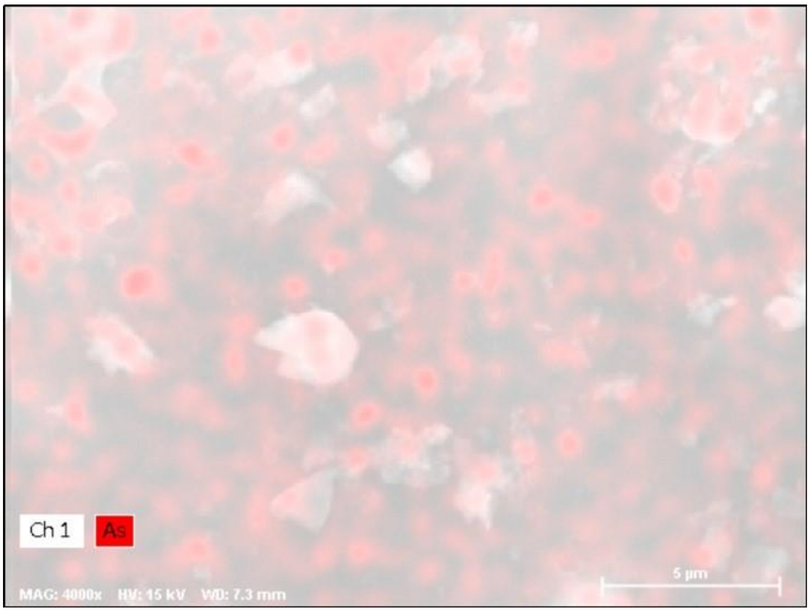


Figure 8. SEM-EDX Image of the CRH-F-ION After Filtration

The image showed a clear illustration of arsenic ions successful attachment in the CRH-F-ION surface through the red dots as legend can be seen almost everywhere occupies the adsorbent surface. This proves that the reduction of arsenic concentration in the water through using CRH-F-ION was effective.

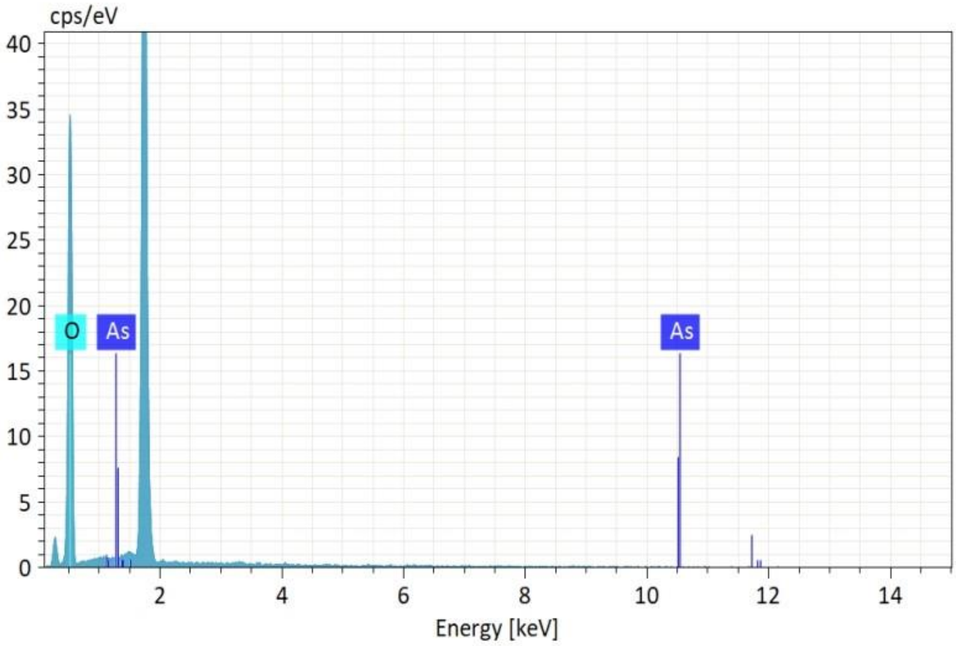


Figure 9. SEM-Spectra of elements present in the sample

The image showed the percent quantity of arsenic ion that has been adsorbed in the surface of CRH-F-ION adsorbent were proven its present in the sample collected after filtration. Other than arsenic, many elements such as oxygen has been found in the sample that was natural components of the leaf extract.

Comparison between the SEM Analysis of CRH and CRH-F-ION

The CRH and CRH-F-ION has a difference in terms of their inner morphological structure particularly the CRH-F-ION was an adsorbent developed from combining properties of carbonized rice hull and functional iron oxide nanoparticle. Therefore, expecting this adsorbent contain much more complex physical characteristics since its forms has been modified.

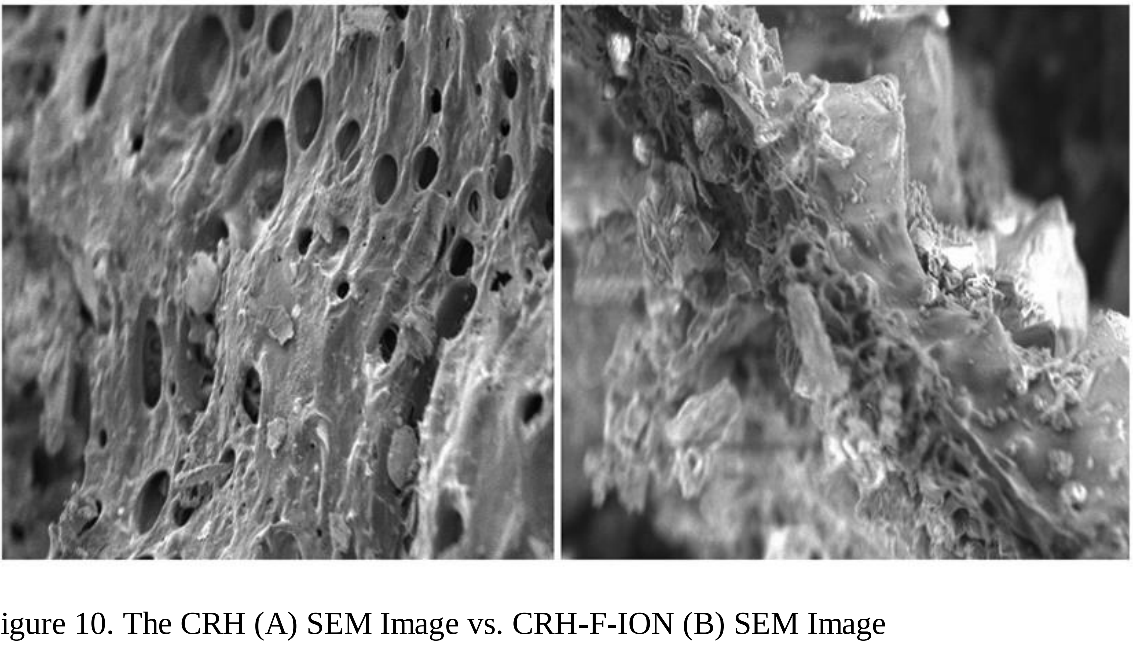


Figure 10. The CRH (A) SEM Image vs. CRH-F-ION (B) SEM Image

The CRH surface area has more porous structure and sequence of irregular pattern with different forms of dimension while the CRH-F-ION surface area also has a porous and slight breakage of the particle, has more irregular forms and the clumped crystalline structure is the result of the developed combination of carbonized rice hull and iron oxide nanoparticles.

IMPACT ASSESSMENT REPORT

This research explores the potential of Carbonized Rice Hull (CRH) and Functional Iron Oxide Nanoparticles (F-ION) in arsenic removal for wastewater treatment facilities. The findings demonstrate significant arsenic removal efficiency, but other water quality parameters, such as salinity, pH, Total Dissolved Solids (TDS), and Electrical Conductivity (EC), remain above or below the prescribed water quality standards, posing risks to human health and the environment.

The establishment of a wastewater treatment facility utilizing CRH-F-ION technology offers a promising avenue for arsenic removal. However, the study emphasizes the need for further optimization to address issues with water quality parameters to ensure safety for public use and environmental compliance. This report presents an impact assessment to evaluate the potential consequences of implementing such a facility, aiming to propose mitigation strategies to minimize adverse effects.

Water Treatment Facility Overview

The proposed water treatment facility leverages CRH-F-ION filtration technology to remove arsenic effectively, even at low concentrations. The study's experimental results form the basis for scaling this technology to community-level applications, ensuring accessible and safe water for public use while meeting environmental standards. However, achieving compliance with water quality standards for pH, TDS, salinity, and EC remains critical for successful implementation.

Potential Impacts of the Water Treatment Facility

Environmental Impacts During Construction Phase

The construction phase may result in environmental, sociocultural, and operational impacts. Key issues include residual solids, noise pollution, air quality degradation, and occupational hazards. Table 8 summarizes these impacts, their levels, and mitigation measures.

Table 8. Summary of Environmental and Socioeconomic Impacts During the Construction Phase of the Water Treatment Facility.

Impact Type	Level	Details and Effects	Remarks
Physico-chemical	Moderate	Residual solids and dust particles may harm respiratory health and soil quality.	Negative
	Moderate	Noise levels up to 100 dB from machinery can disrupt nearby communities.	Negative
	Moderate	Emissions from machinery may degrade air quality and visibility.	Negative
Biological-Ecological	Low	Flora and fauna remain largely unaffected during construction.	Positive
Sociocultural	Low	Employment opportunities for local workers provide economic benefits.	Positive
Economic-Operational	Moderate	Safety risks, such as injuries from heavy equipment, pose occupational hazards.	Negative

Environmental Impacts During Operational Phase

The operational phase introduces additional challenges, particularly related to water quality. Table 9 outlines the potential impacts and their implications.

Table 9. Assessment of Potential Impacts During the Operational Phase of the Water Treatment Facility.

Impact Type	**Level**	**Details and Effects**	**Remarks**
Physico-chemical	Low	Effective arsenic removal (97.88%) meets quality standards (below 0.01 ppm).	Positive
	High	Low pH levels (below 3.34) can lead to health issues and environmental toxicity.	Negative
	High	Increased salinity (up to 435.67 mg/L) can harm aquatic life and human health.	Negative
	High	Elevated TDS (up to 436.33 mg/L) reduces water clarity and quality.	Negative
	High	Elevated EC (up to 873.33 µS/cm) affects human and aquatic health.	Negative
Biological-Ecological	High	Potential water pollution can harm aquatic ecosystems and biodiversity.	Negative
Sociocultural	Low	Provides employment and accessible water services.	Positive
Economic-Operational	Moderate	Safety risks remain a concern during routine facility operations.	Negative

Water Quality Before and After Filtration

The experimental results reveal significant changes in water quality parameters post-filtration. Although arsenic levels were reduced effectively, parameters such as pH, salinity, TDS, and EC exceeded acceptable limits. Table 10 summarizes the findings.

Table 10. Comparison of Water Quality Parameters Before and After Filtration.

Parameter	**Before Filtration**	**After Filtration (Range)**	**Standard Value**
Arsenic (ppm)	10	Below 0.01	0.01
pH	8.18	8.27–3.34	6.5–8.5
Salinity (mg/L)	250	435.67–1776.67	<1000
TDS (mg/L)	250	436.33–1756.67	600
EC (µS/cm)	499	873.33–1977.33	400

Impact Management and Mitigation Plan

To address the identified impacts, the following mitigation measures are proposed:

Construction Phase:

- Proper handling and disposal of residual solids in compliance with RA 6969 (Toxic Substances Act).
- Use of noise-canceling machinery and earplugs to minimize noise pollution.
- Installation of air quality monitoring devices to control emissions.
- Implementation of site safety protocols and training for workers.

Operational Phase:

- **pH Adjustment**: Use of alkaline reagents to neutralize water acidity (target pH: 6.5–8.5).
- **Salinity and TDS Control**: Incorporate reverse osmosis or desalination processes to reduce salinity and TDS levels.
- **EC Reduction**: Lower TDS concentrations to control electrical conductivity.
- **Adsorbent Waste Management**: Proper disposal of adsorbents containing arsenic in compliance with RA 9003 and RA 6969.
- **Water Quality Monitoring**: Regular testing to ensure compliance with water quality standards.

SUMMARY

This study investigated the effectiveness of Carbonized Rice Hull (CRH) functionalized with Iron Oxide Nanoparticles (F-ION) in the removal of arsenic from contaminated water. The CRH was sourced from the GIFT-C Biomass Power Plant in Nueva Ecija, and the F-ION were synthesized using a green method involving guava leaf extract. Four treatments were evaluated, including pure CRH, pure F-ION, and two combinations of CRH and F-ION at different ratios (50% CRH:50% F-ION and 70% CRH:30% F-ION). The adsorption efficiency of these materials was assessed through a continuous-flow filtration system.

The study found that all treatments effectively removed arsenic from water, with Treatment 1 (100% CRH) achieving the highest removal efficiency of 99.43%. The combined CRH-F-ION composites showed slightly lower efficiencies, with Treatment 3 (50% CRH:50% F-ION) achieving 98.79% removal and Treatment 4 (70% CRH:30% F-ION) achieving 98.51%. The results indicated that CRH, especially when combined with iron oxide nanoparticles, is highly effective in reducing arsenic concentrations in water. Additional water quality parameters such as pH, temperature, salinity, total dissolved solids (TDS), and electrical conductivity (EC) were also monitored before and after filtration, showing that the filtration process affected these parameters, especially in treatments involving F-ION.

Statistical analysis using one-way ANOVA and post-hoc tests confirmed significant differences between the treatments, particularly highlighting the superior performance of CRH as a sole adsorbent. The adsorption data followed both the Langmuir and Freundlich isotherm models, with Langmuir providing the best fit, indicating that arsenic adsorption occurred on a monolayer of the adsorbent.

CONCLUSION

The results of this study demonstrate the high potential of CRH functionalized with F-ION nanoparticles for arsenic removal from contaminated water. The CRH alone was shown to be an effective adsorbent, achieving removal efficiencies above 99%, while the addition of F-ION further enhanced arsenic removal, although the improvement was marginal compared to CRH alone. The combination of CRH and F-ION resulted in effective removal, suggesting that a balance between the two adsorbents is ideal for optimizing arsenic adsorption.

The study also highlighted that increasing the quantity of adsorbent could further improve the removal efficiency, as the current experimental setup used only 2 grams of adsorbent per 250 mL of arsenic solution. The findings support the use of CRH as a low-cost, sustainable adsorbent for water treatment, with the potential for large-scale applications in regions affected by arsenic contamination. Furthermore, the functionalization of CRH with iron oxide nanoparticles proved to be a viable method to enhance the material's adsorption capacity.

RECOMMENDATIONS

Based on the findings of this study, the following recommendations are made:

1. **Optimization of Adsorbent Quantity**: Future studies should explore the impact of increasing the quantity of CRH-F-ION composites, particularly for large-scale water treatment applications.

Increasing the adsorbent dose could help achieve closer to 100% arsenic removal, as suggested by the results.

2. **Investigation of Long-Term Stability**: It is essential to evaluate the long-term stability and reusability of CRH-F-ION composites. Assessing their performance over extended periods and under varying environmental conditions would provide valuable insights into the sustainability of this treatment method.
3. **Exploring pH and Other Environmental Factors**: Further research should investigate how different pH levels and other environmental factors affect the performance of CRH-F-ION composites. This would help optimize the treatment process for various water sources, especially those with varying pH or complex contamination.
4. **Scale-Up for Field Applications**: To further validate the effectiveness of the CRH-F-ION filtration system, future studies should focus on scaling up the filtration process to a semi-industrial level. This would help assess the practicality and feasibility of using CRH-F-ION composites in real-world water treatment scenarios, particularly in rural or low-resource regions with arsenic-contaminated water.
5. **Comprehensive Environmental Impact Assessment**: An environmental impact assessment of the production, use, and disposal of CRH-F-ION composites should be conducted to ensure that the process remains sustainable and does not introduce secondary pollution or environmental hazards.
6. **Exploration of Other Green Synthesis Methods**: Although guava leaf extract was used for this study, other plant extracts or bio-based materials should be tested for the green synthesis of iron oxide nanoparticles. This could lead to more efficient or cost-effective alternatives, expanding the range of suitable materials for arsenic removal.

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