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Water Treatment by Using Thermally Activated Carbon Prepared from the Shells of *Cocos Nucifera*: Low Cost Technique

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Abstract : This study focuses on the preparation of carbon materials from coconut shells (*Cocos nucifera*) and their use in water treatment. Coconut shells were heated at 400°C for 2 hours, followed by 450°C for another 2 hours, without using any chemical activating agents. The resulting material was crushed and sieved to obtain powdered carbon (PAC) and granular carbon (GAC). Both forms were tested at five different dosages, ranging from 0.25 to 1.25 g, using 50 mL water samples. Changes in temperature, pH, electrical conductivity (EC), total dissolved solids (TDS) and turbidity were recorded after treatment. The results showed changes in all five water quality parameters, with PAC showing better results than GAC for the selected parameters in the reported dataset. SEM images showed rough and porous surfaces in both materials. EDS analysis also showed that carbon was the major detected element, with 95.59 Atomic % in PAC and 91.90 Atomic % in GAC. The study explores the use of discarded coconut shells as cost effective raw material for preparing carbon-based materials for water treatment.

Keywords: *Cocos Nucifera*, Coconut Shell, Activated Carbon, Drinking Water, Water Purification.

1. INTRODUCTION

Water is an essential natural resource for the survival of all living organisms. However, the quality of surface water resources has gradually deteriorated due to various natural and human activities. Water contamination is a major environmental concern because the consumption of polluted water can lead to several health problems. Dandge and Patil (2021) highlighted the importance of drinking water quality assessment in identifying contamination-related risks. The effects of water pollution may extend beyond the present generation and can also affect future generations. Kumar et al. (2017) reported that approximately 40,000 people had been exposed to polluted water over a period of 14 to 20 years, with a higher occurrence of birth defects, cancer, and diseases affecting the brain, lungs, skin, liver and kidneys in the affected community. Common raw materials used for the production of activated carbon include coal, coconut shells and wood (Samdin et al., 2015).

Activated carbon is widely used in water treatment because of its porous structure and high adsorption capacity. Its internal pore structure provides a large surface area, allowing it to adsorb various contaminants from water (Hu and Srinivasan, 2001). It is a carbon-rich solid material produced by thermal treatment under oxygen-limited conditions, followed by activation to develop its pore structure (Chali and Yakub, 2013; Serio and Chen, 2001). The use of activated carbon in water purification has increased because of its microporous structure and high surface area, which help in removing pollutants from contaminated water. Its application is therefore important in water quality improvement and pollution control (Telgote and Patil, 2020; Sharma and Bhattacharya, 2017). Agricultural waste generated during food and agricultural processing is another important source of raw material for activated carbon production. Carbon prepared from different biomass materials may have different surface characteristics, pore structures and adsorption properties (Khalil et al., 2013). In general, the adsorption performance of activated carbon depends on its surface area, pore characteristics and the nature of the pollutants. Several studies have examined physical and chemical activation methods to improve the surface area and pore structure of activated carbon (Mohd Akhir et al., 2017).

Coconut has considerable cultural, social and economic importance in India. It is widely used in religious and traditional practices, and the whole green coconut is an important part of several Hindu religious rituals (Ahuja et al., 2014). Coconut cultivation also supports the livelihoods of a large number of small and marginal farmers, particularly in peninsular India. The coconut sector provides employment in cultivation, processing and trade. India is among the major coconut-producing countries, with a substantial cultivated area and annual production (Raghavi et al., 2019).

Coconut shells are an agricultural waste material generated after the removal of the edible kernel and coconut water. Instead of being discarded, these shells can be used as a raw material for producing activated carbon for water treatment (Rolence et al., 2014). Coconut shell-based activated carbon has attracted attention as a useful and relatively low-cost adsorbent. Coconut shells are considered suitable for producing microporous activated carbon because of their natural structure and relatively low ash

content (Pinatik and Tooy, 2014). The resulting carbon also offers advantages such as high purity, high density and good mechanical strength, which help reduce dust formation and material loss during handling (Bharadwaj et al., 2016; Elsheikh et al., 2004).

The present study focuses on the preparation and application of activated carbon from *Cocos nucifera* (coconut shell) for the treatment of contaminated drinking water. The study examines the use of both powdered activated carbon (PAC) and granular activated carbon (GAC) as adsorbents for improving water quality. PAC, GAC and pelletized activated carbon are the three commonly used forms of activated carbon. PAC generally consists of fine carbon particles, commonly below 70 mesh, whereas GAC consists of irregularly shaped particles within the range of 3 to 70 mesh. Pelletized activated carbon is produced in an extruded cylindrical form, generally with diameters corresponding to the 3 to 20 mesh range (Samdin et al., 2015). In this investigation, PAC and GAC prepared from coconut shells were used to evaluate changes in selected water quality parameters, including pH, electrical conductivity (EC), total dissolved solids (TDS), turbidity, chloride and total hardness (TH). The prepared activated carbon samples were also characterized using Fourier transform infrared spectroscopy (FTIR), scanning electron microscopy (SEM) and energy-dispersive X-ray spectroscopy (EDS) to examine their surface functional groups, surface morphology and elemental composition.

2. MATERIAL AND METHODS

2.1. Study Location and Laboratory Analysis

The experimental work was conducted in the Department of Environmental Science. Laboratory analysis of the water samples was carried out in a laboratory facility. Scanning electron microscopy)SEM(coupled with energy-dispersive X-ray spectroscopy)EDS(was performed at a central analytical facility to examine the surface morphology and elemental composition of the prepared activated carbon samples.

2.2 Sampling and sample preparations

Coconut shells)*Cocos nucifera*(were collected from a local market in Aurangabad city, Maharashtra, India. The collected shells were thoroughly washed with distilled water to remove dust and other surface impurities. They were then dried under sunlight for approximately two weeks, following a pretreatment approach reported by Efeovbokhan et al.)2019(. After sun drying, the shells were further dried in a hot air oven at 110 °C for 6 hours to remove the remaining moisture)Jasna et al., 2021(. The dried material was then used for the subsequent carbonization and thermal activation process**.**

2.3 Carbonization and Thermal Activation of *Cocos Nucifera*

Producing activated carbon)AC(from biomass involves several challenges. Large-scale production is one of them)Ukanwa et al., 2019(. Simple and economical production methods are therefore needed. The present study used coconut shells as the raw material. A chemical-free thermal treatment method was followed. No chemical activating agents were added.

The washed and dried coconut shells were wrapped in aluminium foil. Small openings were made in the foil to release gases during heating. The wrapped material was placed in a muffle furnace. It was heated at 400°C for 2 hours for carbonization. The material was then heated at 450°C for another 2 hours. This temperature sequence was based on the procedure reported by Efeovbokhan et al.)2019(. The overall preparation process is shown in Figure 1.

After heating, the material was allowed to cool. It was then crushed using a mixer and sieved. The fraction smaller than 2 mm was collected as powdered activated carbon)PAC(. The coarser fraction was retained as granular activated carbon)GAC(. No chemical activating agents were used during the preparation process.

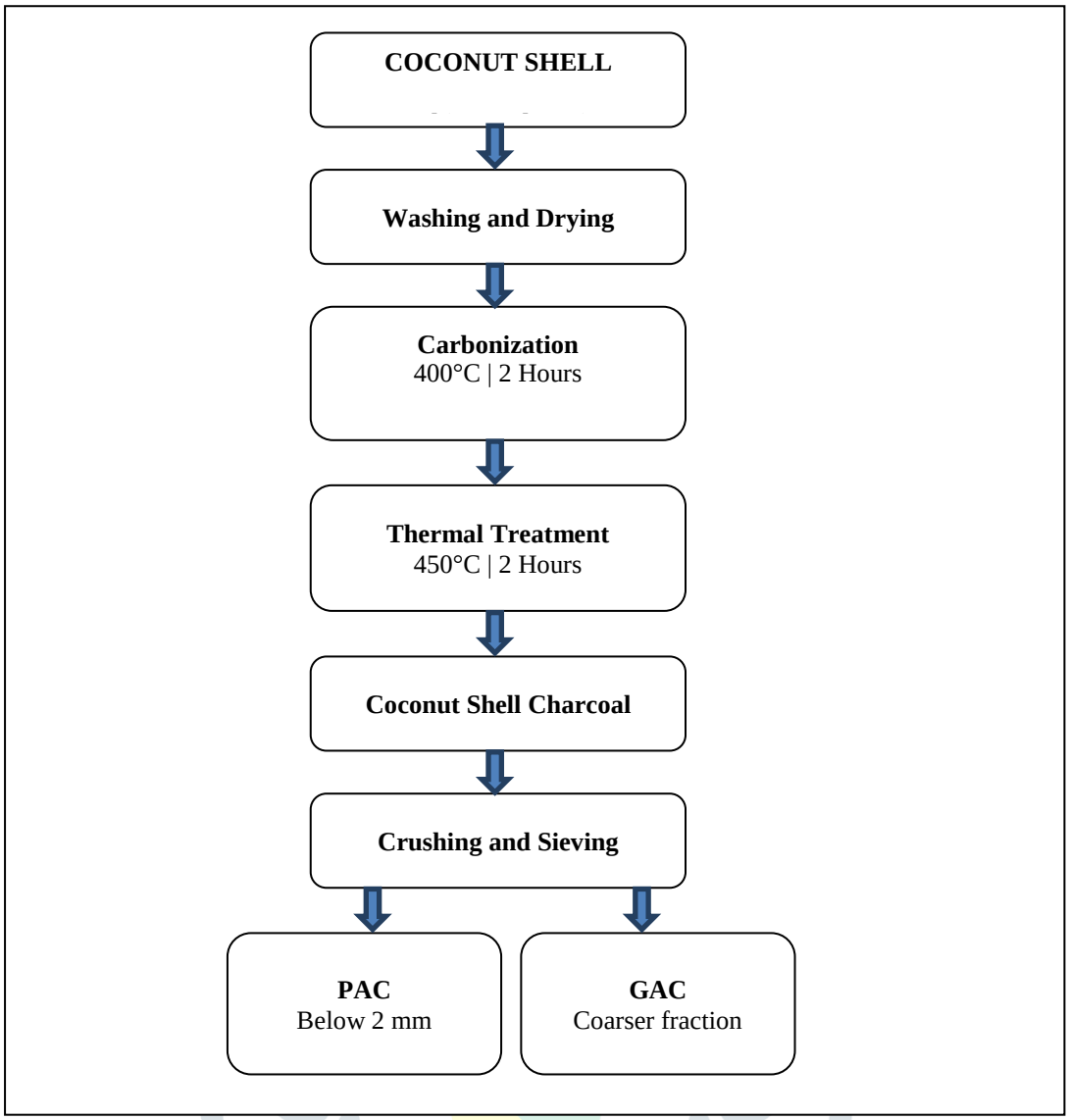


Figure 1. Flowchart showing the preparation of PAC and GAC from coconut shell.

2.4 Dosage experiment for GAC and PAC

The removal experiments were carried out using the batch method. Each experiment was conducted in a 100 mL conical flask containing 50 mL of water sample. Five different dosages were tested for both PAC and GAC. The dosages were 0.25, 0.50, 0.75, 1.00 and 1.25 g. The samples were labelled PAC 1 to PAC 5 and GAC 1 to GAC 5, respectively (Rolence et al., 2014).

The mixtures were shaken using an orbital shaker at 150 ± 1.5 hr. After shaking, the samples were filtered through Whatman No. 42 filter paper. The filtrates were collected in 100 mL airtight bottles. Some headspace was left in each bottle. The samples were stored for further analysis.

The treated water samples were analysed for temperature, pH, electrical conductivity (EC), total dissolved solids (TDS) and turbidity. The instruments used included a Systronics µ-pH System 361, a Systronics Conductivity Meter 306 and a µP multiparameter analyser.

The PAC and GAC samples were also examined using scanning electron microscopy (SEM) and energy-dispersive X-ray spectroscopy (EDS). SEM analysis was performed using a JEOL microscope (Model: JSM-6510). EDS analysis was carried out using an INCAx-act system (Model: 51-ADD0076).

3. RESULTS AND DISCUSSION

3.1. Initial Water Quality Parameters

The initial water sample was analysed before the treatment process. The temperature was recorded as 20.8°C, while the pH was 7.9. The electrical conductivity)EC(was 813.1 µS/cm. The total dissolved solids)TDS(were 323 mg/L, and the turbidity was 0.8 NTU)Telgote and Patil, 2022(. These readings were considered as the baseline values for evaluating the treatment performance of coconut shell-based powdered activated carbon)PAC(and granular activated carbon)GAC(. The initial water quality parameters are presented in Table 1.

Table 1. Initial water quality parameters of the sample

Sr. No.	Water Parameter	Initial Reading	Unit
1	Temperature	20.8	°C
2	pH	7.9	-
3	Electrical Conductivity	813.1	µS/cm
4	Total Dissolved Solids	323	mg/L
5	Turbidity	0.8	NTU

3.2 Dose Effect on GAC and PAC

The dosage study plays an important role in the adsorption process during batch experiments. In the present study, different dosages of coconut shell-based activated carbon were used to evaluate their treatment performance. Five dosages ranging from 0.25 to 1.25 g were tested for both PAC and GAC. Each experiment was conducted using 50 mL of water sample. The treated samples were analysed for physical water quality parameters, including temperature, pH, electrical conductivity)EC(, total dissolved solids)TDS(and turbidity. The results were used to examine the effect of adsorbent dosage on the quality of the treated water.

3.2.1. Temperature

The temperature of the treated water samples was measured using a digital thermometer. The initial temperature of the water sample was 20.8°C. After PAC treatment, the recorded temperatures were 20.3°C, 24.3°C, 22.4°C, 23.4°C and 21.5°C for PAC 1, PAC 2, PAC 3, PAC 4 and PAC 5, respectively. The maximum temperature of PAC was 24.3°C, while the minimum was 20.3°C. The average temperature was 22.38°C.

Similarly, the temperatures recorded after GAC treatment were 21.7°C, 22.4°C, 22.5°C, 22.1°C and 21.6°C for GAC 1, GAC 2, GAC 3, GAC 4 and GAC 5, respectively. The maximum temperature of GAC was 22.5°C, the minimum was 21.6°C and the average was 22.06°C.

The analysis of temperature readings presented in Table 2 shows that the values varied slightly after PAC and GAC treatment compared with the initial reading. These variations may be associated with differences in sample handling and laboratory conditions during the experiments.

Table 2. Temperature readings during analysis of PAC and GAC

Sr. No.	Vol. (g)	Variable	Initial Reading (°C)	PAC (°C)	GAC (°C)	Volume of Sample	Analytical Method
1	0.25	Temperature (°C)	20.8	20.3	21.7	50 mL	Digital thermometer
2	0.50			24.3	22.4		
3	0.75			22.4	22.5		
4	1.00			23.4	22.1		
5	1.25			21.5	21.6		
Maximum				**24.3**	**22.5**		
Minimum				**20.3**	**21.6**		
Average				**22.38**	**22.06**		

3.2.2. pH

The pH of water indicates its acidic or alkaline nature. It is an important parameter for assessing drinking water quality (Dandge and Patil, 2022). The pH of drinking water is generally maintained within the range of 6.5 to 8.5 as specified in BIS IS 10500:2012.

The pH of the treated water samples was measured using the electrometric method. The initial pH of the water sample was 7.9. After PAC treatment, the recorded pH values were 7.6, 7.5, 7.4, 7.3 and 7.4 for PAC 1, PAC 2, PAC 3, PAC 4 and PAC 5, respectively. The maximum pH of PAC was 7.6, while the minimum was 7.3. The average pH was 7.44.

Similarly, the pH values recorded after GAC treatment were 7.7, 7.6, 7.6, 7.5 and 7.5 for GAC 1, GAC 2, GAC 3, GAC 4 and GAC 5, respectively. The maximum pH of GAC was 7.7, the minimum was 7.5 and the average was 7.58.

The analysis of pH readings presented in Table 3 shows a slight decrease in pH after both PAC and GAC treatment. All recorded values remained within the permissible range of 6.5 to 8.5. PAC showed a slightly greater reduction in pH than GAC.

Table 3. pH readings during analysis of PAC and GAC

Sr. No.	Vol. (g)	Variable	Initial Reading	PAC	GAC	Volume of Sample	Standards as per BIS & CPCB	Analytical Method
1	0.25	pH	7.9	7.6	7.7	50 mL	6.5–8.5	Electrometric
2	0.50			7.5	7.6			
3	0.75			7.4	7.6			
4	1.00			7.3	7.5			
5	1.25			7.4	7.5			
Maximum				**7.6**	**7.7**			
Minimum				**7.3**	**7.5**			
Average				**7.44**	**7.58**			

3.2.3. Electrical Conductivity (EC)

Electrical conductivity (EC) indicates the ability of water to conduct electric current. It is directly related to the concentration of dissolved ions present in water. Higher concentrations of dissolved salts generally result in higher electrical conductivity (Dandge and Patil, 2022; EPA, 2012).

The electrical conductivity of the treated water samples was measured using the electrometric method. The initial EC of the water sample was 813.1 µS/cm. After PAC treatment, the recorded EC values were 785.0, 765.0, 745.0, 730.0 and 715.0 µS/cm for PAC 1, PAC 2, PAC 3, PAC 4 and PAC 5, respectively. The maximum EC of PAC was 785.0 µS/cm, while the minimum was 715.0 µS/cm. The average EC was 748.0 µS/cm.

Similarly, the EC values recorded after GAC treatment were 800.0, 785.0, 770.0, 755.0 and 740.0 µS/cm for GAC 1, GAC 2, GAC 3, GAC 4 and GAC 5, respectively. The maximum EC of GAC was 800.0 µS/cm, the minimum was 740.0 µS/cm and the average was 770.0 µS/cm.

The analysis of EC readings presented in Table 4 shows a gradual decrease in electrical conductivity with increasing adsorbent dosage. PAC showed a greater reduction in EC than GAC. The lowest EC value was recorded at a PAC dosage of 1.25 g. These results indicate better reduction of dissolved ionic content with PAC treatment under the simulated conditions.

Table 4. Electrical conductivity readings during analysis of PAC and GAC

Sr. No.	Vol. (g)	Variable	Initial Reading (µS/cm)	PAC (µS/cm)	GAC (µS/cm)	Volume of Sample	Standards as per BIS & CPCB (µS/cm)	Analytical Method
1	0.25	Electrical Conductivity (µS/cm)	813.1	785.0	800.0	50 mL	2000	Electrometric
2	0.50			765.0	785.0			
3	0.75			745.0	770.0			
4	1.00			730.0	755.0			
5	1.25			715.0	740.0			
Maximum				**785.0**	**800.0**			
Minimum				**715.0**	**740.0**			
Average				**748.0**	**770.0**			

3.2.4 Total Dissolved Solids (TDS)

The total dissolved solids (TDS) of the treated water samples were estimated in relation to the corresponding electrical conductivity (EC) values. The initial TDS concentration was 323 mg/L. Based on the initial EC and TDS readings, a conversion factor of approximately 0.397 was considered for estimating the TDS values.

The estimated TDS values after PAC treatment were 312, 304, 296, 290 and 284 mg/L for PAC 1, PAC 2, PAC 3, PAC 4 and PAC 5, respectively. The maximum TDS value was 312 mg/L, while the minimum was 284 mg/L. The average TDS value was 297.2 mg/L.

Similarly, the estimated TDS values after GAC treatment were 318, 312, 306, 300 and 294 mg/L for GAC 1, GAC 2, GAC 3, GAC 4 and GAC 5, respectively. The maximum TDS value was 318 mg/L, while the minimum was 294 mg/L. The average TDS value was 306 mg/L.

The results indicate a gradual reduction in TDS with increasing adsorbent dosage. PAC showed a greater reduction in TDS than GAC under the estimated conditions. The TDS results obtained after PAC and GAC treatment are presented in Table 5.

Table 5. Relationship Between PAC and GAC Dosage and Total Dissolved Solids (TDS)

Sr. No.	Vol. (g)	Variable	Initial Reading (mg/L)	PAC (mg/L)	GAC (mg/L)	Volume of Sample	Standard as per BIS & CPCB (ppm)	Analytical Method
1	0.25	Total Dissolve Solids (ppm)	323	312	318	50 mL	500	Electrometric
2	0.50			304	312			
3	0.75			296	306			
4	1.00			290	300			
5	1.25			284	294			
Maximum				**312**	**318**			
Minimum				**284**	**294**			
Average				**297.2**	**306.0**			

3.2.5 Turbidity

The turbidity of the treated water samples was measured using the nephelometric method. The initial turbidity of the water sample was 0.8 NTU. After PAC treatment, the estimated turbidity values were 0.01, 0.02, 0.01, 0.02 and 0.01 NTU for PAC 1, PAC 2, PAC 3, PAC 4 and PAC 5, respectively. The average turbidity value for PAC-treated samples was 0.014 NTU. Similarly, the estimated turbidity values after GAC treatment were 0.08, 0.10, 0.08, 0.07 and 0.06 NTU for GAC 1, GAC 2, GAC 3, GAC 4 and GAC 5, respectively. The average turbidity value for GAC-treated samples was 0.078 NTU.

The results indicate a reduction in turbidity after both PAC and GAC treatment. PAC showed a greater reduction than GAC under the simulated conditions. All estimated values were below the BIS acceptable limit of 1 NTU. The turbidity results obtained after PAC and GAC treatment are presented in Table 6.

Table 6. Turbidity Readings During Analysis of PAC and GAC

Sr. No.	Vol. (g)	Variable	Initial Reading (NTU)	PAC (NTU)	GAC (NTU)	Volume of Sample	Standard as per BIS (NTU)	Analytical Method
1	0.25	Turbidity	0.8	0.01	0.08	50 mL	1	Nephelometric method
2	0.50			0.02	0.10			
3	0.75			0.01	0.08			
4	1.00			0.02	0.07			
5	1.25			0.01	0.06			
Maximum				**0.02**	**0.10**			
Minimum				**0.01**	**0.06**			
Average				**0.014**	**0.078**			

4. SEM AND EDS ANALYSIS

4.1 SEM Analysis

Scanning Electron Microscopy (SEM) is widely used to examine changes in the surface morphology of solid materials (Pandey et al., 2021). In the present study, SEM analysis was performed to investigate the surface morphology of coconut shell-derived carbon materials. The SEM micrographs of powdered activated carbon (PAC) and granular activated carbon (GAC) revealed irregular and porous surface structures. The presence of macropores on the carbon surface may provide suitable sites for the adsorption of pollutants (Jadhav et al., 2021).

The PAC sample showed several visible pores and cavities distributed across the surface. The surface appeared rough, with irregular openings and variations in pore dimensions. These features indicate the development of a porous surface structure during thermal treatment.

Similarly, the GAC sample exhibited an irregular surface with visible pores and cavities. Its surface showed a rough and uneven structure with several openings of different shapes and dimensions. These morphological features indicate the presence of accessible surface regions in the prepared carbon material.

Overall, the SEM observations confirmed the presence of porous surface features in both PAC and GAC samples. Such structures may provide sites for interaction with dissolved substances during the water treatment process. Representative SEM micrographs of PAC and GAC are presented in Figure 2)a(and Figure 2)b(, respectively.

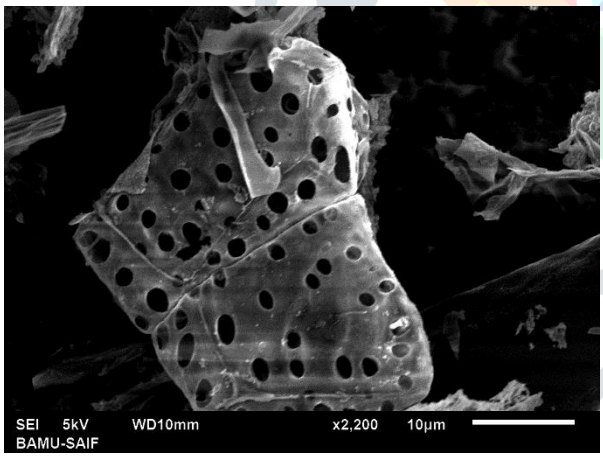


Figure 2(a). Scanning Electron Micrograph of Coconut Shell-Derived Powdered Activated Carbon (PAC).

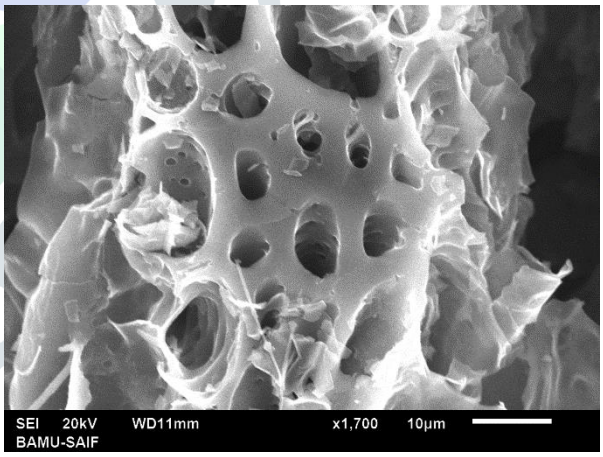


Figure 2(b). Scanning Electron Micrograph of Coconut Shell-Derived Granular Activated Carbon (GAC).

4.2 EDS Analysis

Energy Dispersive X-ray Spectroscopy (EDS) was carried out to identify the elemental composition of the prepared coconut shell-derived carbon materials. Representative EDS spectra of PAC (Site 3) and GAC (Site 5) were selected for the analysis.

The EDS results showed that carbon was the predominant detected element in both samples. The PAC sample contained 95.59 Atomic % carbon and 4.41 Atomic % oxygen. Similarly, the GAC sample showed 91.90 Atomic % carbon and 8.10 Atomic % oxygen.

The higher proportion of carbon indicates the carbon-rich elemental composition of both prepared materials. Oxygen was also detected in both samples, which may be associated with oxygen-containing surface components. PAC showed a higher carbon proportion than GAC in the analysed regions.

The elemental composition obtained from the representative EDS spectra is presented in Table 7. The corresponding EDS spectra of PAC and GAC are shown in Figure 3(a), 3 (b) and Figure 4(a), 4 (b) respectively.

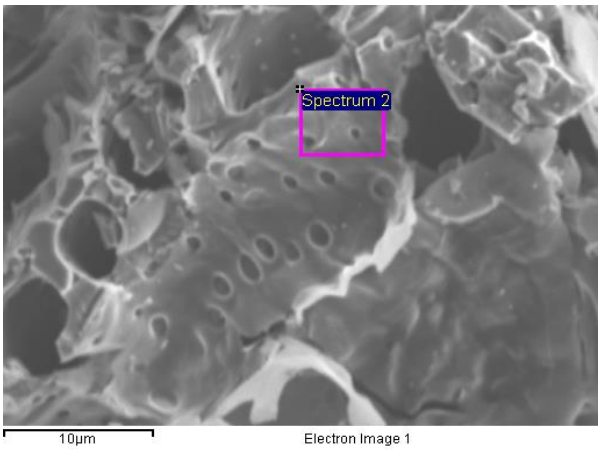


Figure 3(a). SEM Micrograph Showing the Selected Area for EDS Analysis of Coconut Shell-Derived PAC.

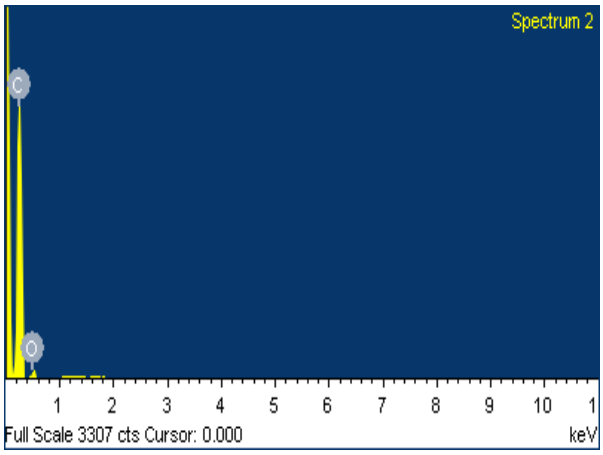


Figure 3(b). EDS Spectrum of Coconut Shell-Derived PAC (Site 3).

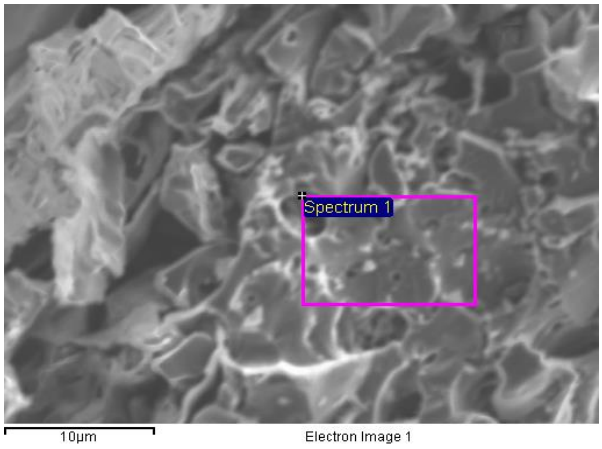


Figure 4(a). SEM Micrograph Showing the Selected Area for EDS Analysis of Coconut Shell-Derived GAC.

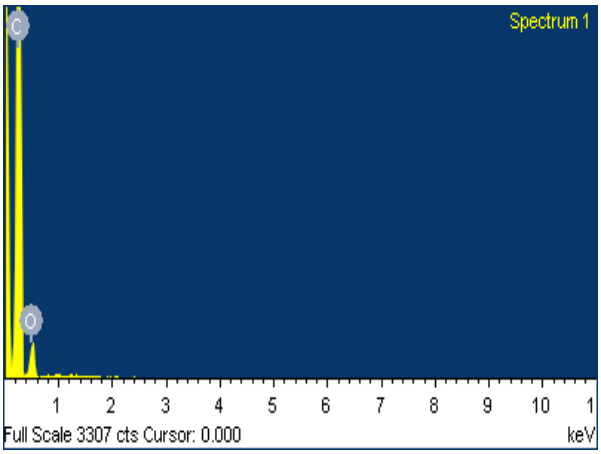


Figure 4(b). EDS Spectrum of Coconut Shell-Derived GAC (Site 5).

Table 7. Elemental Composition of Coconut Shell-Derived PAC and GAC Based on EDS Analysis

Sr. No.	Element	PAC (Atomic %)	GAC (Atomic %)
1	Carbon (C)	95.59	91.90
2	Oxygen (O)	4.41	8.10
	Total	**100.00**	**100.00**

The EDS analysis confirmed that carbon was the major detected element in both PAC and GAC samples. These findings support the carbon-rich nature of the prepared coconut shell-derived materials.

5. STATISTICAL AND GRAPHICAL ANALYSIS OF PAC AND GAC RESULTS

5.1 Statistical Methodology

A one-sample t-test was applied to compare the initial water quality readings with the mean values obtained after PAC and GAC treatment. The analysis was performed separately for each water quality parameter. The level of significance was set at 5% (α=0.05). A p-value below 0.05 indicates a statistically significant difference between the treatment mean and the initial reading.

The t-statistic was calculated using the following formula:

$$t = \frac{\bar{x} - \mu}{s/\sqrt{n}}$$

Where,

$\bar{x}$ -Sample mean
μ- Population mean (claimed value)
s- Sample standard deviation
n- Sample size
t- Test statistic

5.2. T-Test Analysis

To test the significance of PAC and GAC treatment, the initial values of the water quality parameters were compared with the corresponding values obtained after PAC and GAC treatment. For this comparative statistical analysis, a one-sample t-test was performed using Equation (1). The analysis was carried out separately for PAC and GAC using five dosage readings. The t-test results are presented in Tables 8 and 9.

Table 8. t-test results for PAC

Water Parameter	Initial Value	Mean Value	BIS/CPCB Standard	t-test Statistic	p-value
Temperature (°C)	20.8	22.38	20–25	2.25	0.0873
pH	7.9	7.44	6.5–8.5	-9.02	0.0008
Electrical Conductivity (µS/cm)	813.1	748.00	2000	-5.25	0.0063
Total Dissolved Solids (mg/L)	323	297.20	500	-5.20	0.0065
Turbidity (NTU)	0.8	0.014	1	-320.88	<0.0001

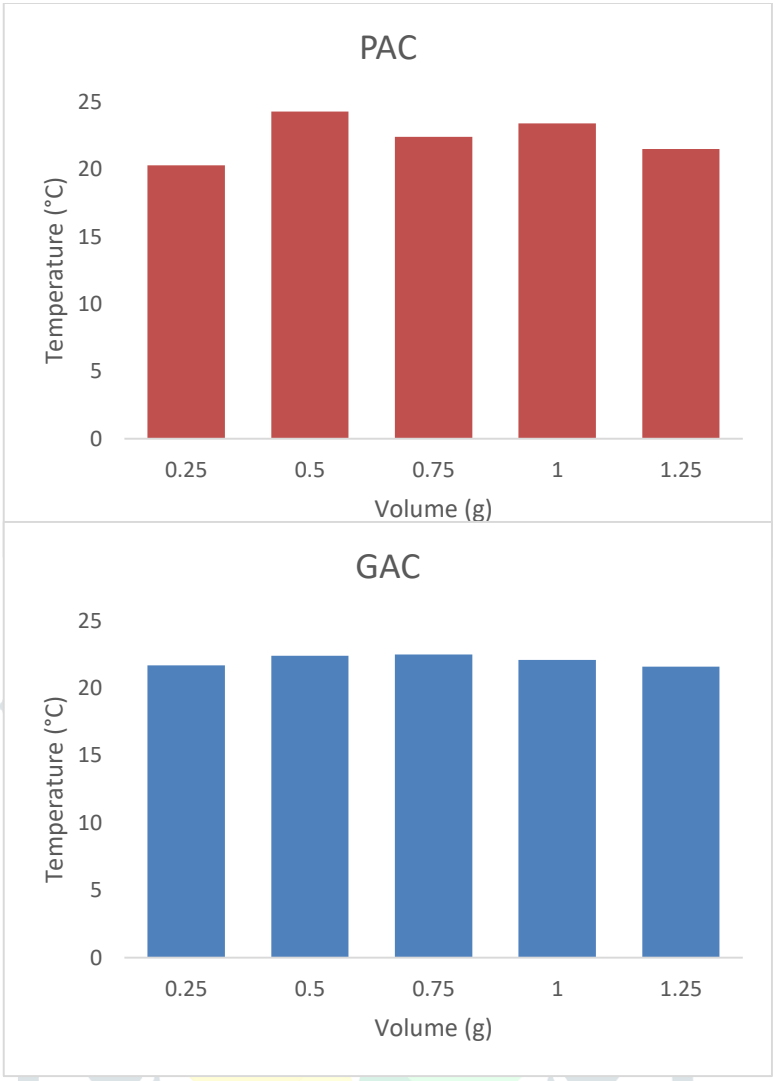
Table 9. t-test results for GAC

Water Parameter	Initial Value	Mean Value	BIS/CPCB Standard	t-test Statistic	p-value
Temperature (°C)	20.8	22.06	20–25	6.98	0.0022
pH	7.9	7.58	6.5–8.5	-8.55	0.0010
Electrical Conductivity (µS/cm)	813.1	770.00	2000	-4.06	0.0153
Total Dissolved Solids (mg/L)	323	306.00	500	-4.01	0.0160
Turbidity (NTU)	0.8	0.078	1	-108.85	<0.0001

5.2.1. Temperature

From the test results in Table 8 and Figure 5, the p-value for PAC was 0.0873, which was greater than 0.05 (level of significance). Therefore, the null hypothesis could not be rejected at the 5% level of significance. It is concluded that there was no statistically significant difference between the initial temperature and the mean temperature after PAC treatment.

From the test results in Table 9 and Figure 5, the p-value for GAC was 0.0022, which was less than 0.05. Therefore, the null hypothesis was rejected at the 5% level of significance. This indicates a statistically significant difference between the initial temperature and the mean temperature after GAC treatment. The mean temperature values after PAC and GAC treatment were 22.38°C and 22.06°C, respectively. Both values were within the reference temperature range of 20–25°C.



H_{o1}: There is no significant difference between the initial temperature reading and the mean temperature after PAC treatment.

Vs

H_{a1}: There is a significant difference between the initial temperature reading and the mean temperature after PAC treatment.

H_{o1}: There is no significant difference between the initial temperature reading and the mean temperature after GAC treatment.

Vs

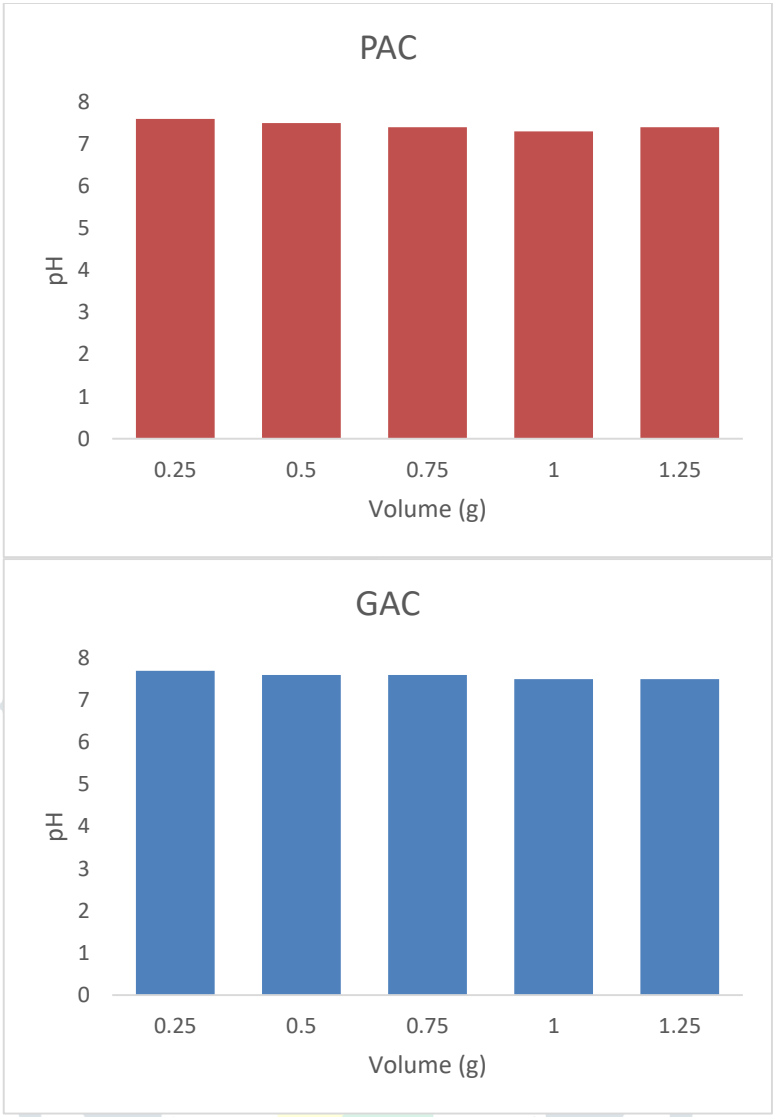
H_{a1}: There is a significant difference between the initial temperature reading and the mean temperature after GAC treatment.

Figure 5. Graphical Representation of Temperature during Analysis of PAC and GAC

5.2.2. pH

From the test results in Table 8 and Figure 6, the p-value for PAC was 0.0008, which was less than 0.05. Therefore, the null hypothesis was rejected at the 5% level of significance. This indicates a statistically significant difference between the initial pH and the mean pH after PAC treatment.

From the test results in Table 9 and Figure 6, the p-value for GAC was 0.0010, which was also less than 0.05. Therefore, the null hypothesis was rejected. A statistically significant difference was observed between the initial pH and the mean pH after GAC treatment. The mean pH values after PAC and GAC treatment were 7.44 and 7.58, respectively. Both values were within the BIS acceptable range of 6.5–8.5.



H_{02}: There is no significant difference between the initial pH reading and the mean pH after PAC treatment.

Vs

H_{a2}: There is a significant difference between the initial pH reading and the mean pH after PAC treatment.

H_{02}: There is no significant difference between the initial pH reading and the mean pH after GAC treatment.

Vs

H_{a2}: There is a significant difference between the initial pH reading and the mean pH after GAC treatment.

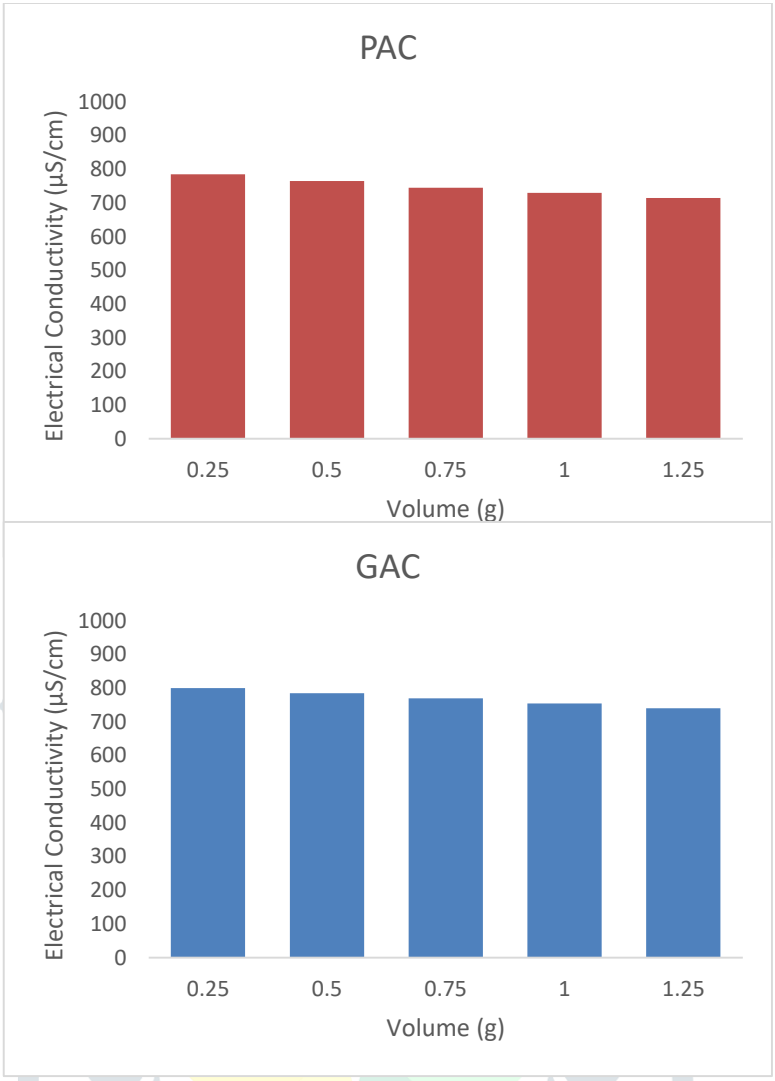
Fig. 6. Graphical Representation of pH during Analysis of PAC and GAC

5.2.3. Electrical Conductivity (EC)

From the test results in Table 8 and Figure 7, the p-value for PAC was 0.0063, which was less than 0.05. Therefore, the null hypothesis was rejected at the 5% level of significance. It is concluded that the mean electrical conductivity decreased significantly after PAC treatment compared with the initial reading.

From the test results in Table 9 and Figure 7, the p-value for GAC was 0.0153, which was also less than 0.05. Therefore, the null hypothesis was rejected.

This indicates a statistically significant decrease in the mean electrical conductivity after GAC treatment compared with the initial reading. The mean EC values after PAC and GAC treatment were 748.00 µS/cm and 770.00 µS/cm, respectively. PAC showed a greater decrease in EC than GAC.



H_{03}: There is no significant difference between the initial Electrical Conductivity reading and the mean Electrical Conductivity after PAC treatment.

Vs

H_{a3}: The mean Electrical Conductivity after PAC treatment is significantly lower than the initial Electrical Conductivity reading.

H_{03}: There is no significant difference between the initial Electrical Conductivity reading and the mean Electrical Conductivity after GAC treatment.

Vs

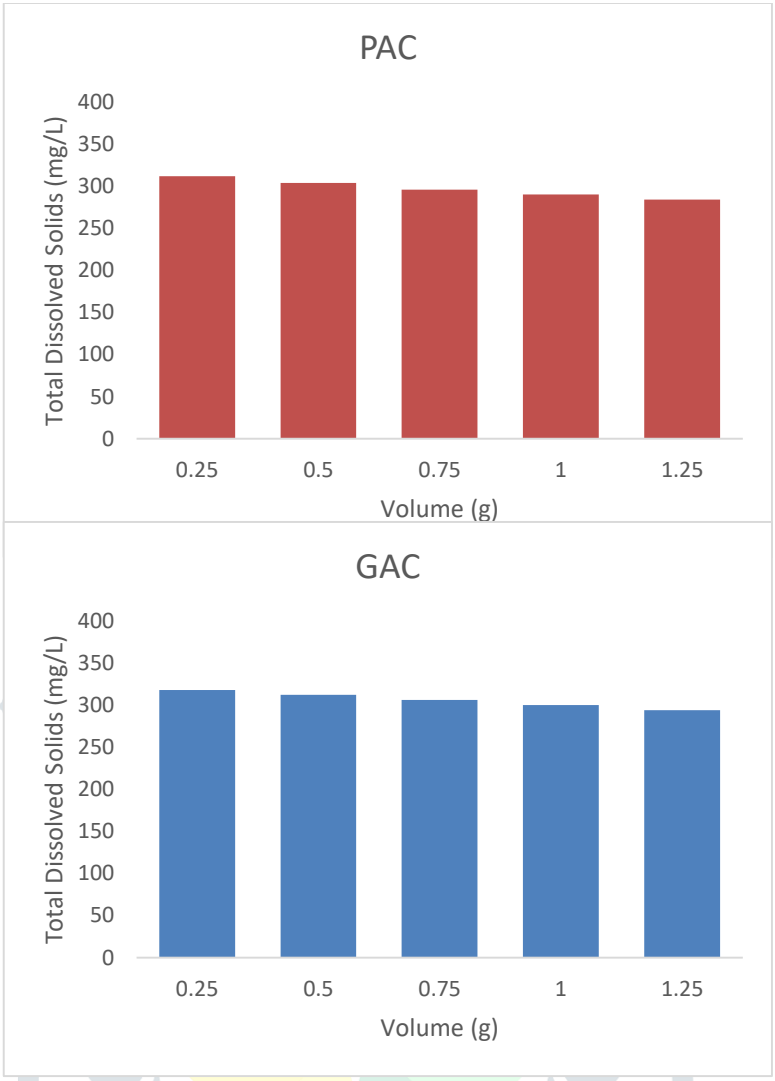
H_{a3}: The mean Electrical Conductivity after GAC treatment is significantly lower than the initial Electrical Conductivity reading.

Fig 7. Graphical Representation of Electrical Conductivity during Analysis of PAC and GAC

5.2.4. Total Dissolved Solids (TDS)

From the test results in Table 8 and Figure 8, the p-value for PAC was 0.0065, which was less than 0.05. Therefore, the null hypothesis was rejected at the 5% level of significance. The estimated mean TDS value decreased from the initial reading of 323 mg/L to 297.20 mg/L after PAC treatment.

From the test results in Table 9 and Figure 8, the p-value for GAC was 0.0160, which was also less than 0.05. Therefore, the null hypothesis was rejected. The estimated mean TDS value after GAC treatment was 306.00 mg/L. PAC showed a greater estimated decrease in TDS than GAC. Both estimated mean values were below the BIS acceptable limit of 500 mg/L.



H_{04}: There is no significant difference between the initial Total Dissolved Solids reading and the mean Total Dissolved Solids after PAC treatment.

Vs

H_{a4}: The mean Total Dissolved Solids after PAC treatment is significantly lower than the initial Total Dissolved Solids reading.

H_{04}: There is no significant difference between the initial Total Dissolved Solids reading and the mean Total Dissolved Solids after GAC treatment.

Vs

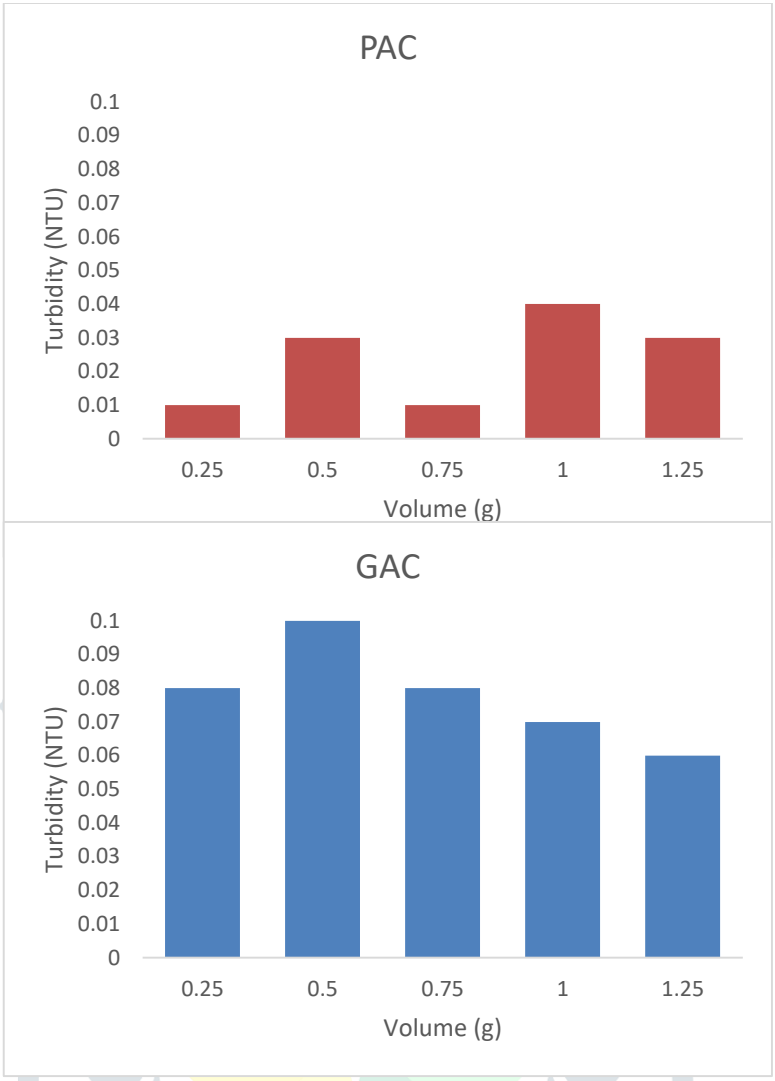
H_{a4}: The mean Total Dissolved Solids after GAC treatment is significantly lower than the initial Total Dissolved Solids reading.

Fig 8. Graphical Representation of Total Dissolved Solids during Analysis of PAC and GAC

5.2.5. Turbidity

From the test results in Table 8 and Figure 9, the p-value for PAC was less than 0.05. Therefore, the null hypothesis was rejected at the 5% level of significance. It is concluded that the mean turbidity value differed significantly from the initial reading after PAC treatment.

From the test results in Table 9 and Figure 9, the p-value for GAC was also less than 0.05. Therefore, the null hypothesis was rejected. A statistically significant difference was observed between the initial turbidity and the mean turbidity after GAC treatment. The mean turbidity values after PAC and GAC treatment were 0.014 NTU and 0.078 NTU, respectively. PAC showed a greater decrease in turbidity than GAC. Both mean values were below the reference limit of 1 NTU.



H_{o5}: There is no significant difference between the initial Turbidity reading and the mean Turbidity after PAC treatment.
Vs
H_{a5}: The mean Turbidity after PAC treatment is significantly lower than the initial Turbidity reading.
H_{o5}: There is no significant difference between the initial Turbidity reading and the mean Turbidity after GAC treatment.
Vs
H_{a5}: The mean Turbidity after GAC treatment is significantly lower than the initial Turbidity reading.

Figure 9. Graphical Representation of Turbidity during Analysis of PAC and GAC

6. CONCLUSION

The present study examined the preparation and application of coconut shell-derived carbon materials for water treatment. A chemical-free thermal treatment method was used to prepare powdered activated carbon (PAC) and granular activated carbon (GAC). Both materials were evaluated at five different dosages ranging from 0.25 to 1.25 g using a batch treatment process.

The results presented in this study indicate changes in selected water quality parameters after PAC and GAC treatment. The pH values decreased slightly from the initial value of 7.9, while remaining within the BIS acceptable range of 6.5–8.5. PAC showed a greater reduction in EC and TDS than GAC in the presented dataset. Both materials also showed a reduction in turbidity, with PAC exhibiting lower values than GAC. Overall, PAC showed comparatively better performance than GAC for the selected parameters under the conditions considered in this study.

The SEM analysis revealed irregular and porous surface structures in both PAC and GAC samples. These surface features may provide potential sites for adsorption. The EDS analysis further showed that carbon was the predominant detected element, accounting for 95.59 Atomic % in PAC and 91.90 Atomic % in GAC. This confirms the carbon-rich composition of the prepared materials.

The findings indicate that coconut shell is a promising cost effective raw material for preparing carbon-based adsorbents for water treatment. The use of this agricultural residue also offers an opportunity for waste utilization. Further studies involving validated experimental measurements, detailed pore characterization, adsorption capacity and removal efficiency for specific contaminants are required to establish the treatment potential and practical applicability of these materials.

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