Research Article

Utilization of Biomass Waste as Absorbents for Groundwater Purification

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Abstract
Calcium carbonate ($CaCO_3$) in groundwater is a major concern, as it can cause scaling in pipes and potentially pose health risks, particularly in rural areas. Developing innovative groundwater filtration systems capable of reducing $CaCO_3$ content is therefore essential for improving water quality. This study investigated the use of biomass waste from candlenut shells and corn cobs as sources of activated carbon adsorbents for portable groundwater filtration in the Sumbawa Region, Indonesia. A portable filter system was designed using varying amounts of adsorbent (150, 250, and 500 g), and its performance was evaluated based on several water quality parameters, including temperature, total dissolved solids (TDS), pH, taste, odor, turbidity, and $CaCO_3$ concentration. The results showed that the groundwater temperature remained stable (31–33 °C) with no significant changes observed. Both candlenut shell and corn cob adsorbents effectively reduced TDS, pH, taste, odor, turbidity, and $CaCO_3$ content. Corn cob adsorbents generally performed better, likely due to their more developed microporous structure, while candlenut shells reduced carbon release more slowly. Corn cob adsorbents achieved the highest reductions in TDS, $CaCO_3$, and pH, while candlenut shells showed better performance in sensory quality by reducing taste scores and odor intensity. Turbidity decreased by up to 91% using candlenut shells (to 0.24 NTU) and 90% using corn cobs (to 0.28 NTU). These findings highlight the potential of converting agricultural biomass waste into low-cost activated carbon absorbents for sustainable groundwater purification in rural communities.

Keywords: Absorbent, Biomass, Biorefinery, Candlenut shells, Corn cob, Water filter

1 Introduction

The presence of calcium carbonate ($CaCO_3$) in groundwater poses challenges in certain regions. Commonly known as lime, excessive $CaCO_3$ levels may threaten human health, as long-term consumption can harm internal organs and contribute to calculus formation, a key concern in dental and oral health [1]. In addition, calcium buildup in household water systems can cause scaling, which clogs pipes and reduces the lifespan of plumbing infrastructure, leading to costly maintenance [2], [3].

Groundwater in Sumbawa Island contains a high concentration of $CaCO_3$ as the natural condition of the land in Sumbawa that is predominantly made up of limestone mountains, and may directly affect the composition of the groundwater [4]. As rainwater seeps through these geological formations, it dissolves calcium carbonate, increasing its presence in the underground water supply. This makes the development of an effective and affordable filtration system an urgent need for local communities.

One innovative solution is the use of portable water filters equipped with micro-materials such as activated carbon absorbents derived from local agricultural waste. These filters are not only affordable but also practical for household use in rural and remote areas. By incorporating activated carbon materials, the filters can effectively reduce calcium content and improve water quality [5].

The use of agricultural residues such as corn cobs and candlenut shells for groundwater filtration promotes a circular economy by turning waste materials into valuable resources [6], [7]. This approach not only reduces environmental pollution but also provides a sustainable, low-cost solution for improving water quality. Some studies reported that agricultural residues can be economically valorized into biomaterials, briquette and other carbon products, which may serve as effective functional materials in downstream processes (including adsorption and catalysis), reinforcing the technical feasibility of using candlenut shells or corn cobs for water treatment [8]–[11].

Corn cob-based activated carbon is a particularly promising absorber material. Corn cobs have a naturally high surface area and large pore volume, which enhances their capacity to trap contaminants [12]. Corn cob powder has been investigated as a natural adsorbent for various applications such as the purification of used cooking oil [13], dye removal [14], effluent treatment and removal of lead and cadmium from wastewater [15]. On the other hand, there are several strategies to reduce or prevent calcium $CaCO_3$ scaling in water systems, which are generally classified into chemical and non–chemical methods [15], [16]. Chemical treatments, such as the use of chlorine or brominated compounds, have traditionally been effective but face drawbacks including high costs, strict environmental regulations, and potential risks of chemical residues or spills [16]. To address these limitations, non-chemical or physical water treatment (PWT) methods have been developed, employing techniques such as magnetic or electric fields, membranes, and ultrasounds. Although this technique shows effectiveness, the applications remain debated due to high cost [17]–[19].

Furthermore, Sumbawa is the largest corn-producing region in West Nusa Tenggara (NTB), generating an abundance of corn cob waste [20]. According to data from BPS Sumbawa, the region has significant potential for corn production, reaching 467,240 tons from a planted area of 1,685 hectares. Most of the corn is sold in the form of kernels, leaving behind waste such as stalks, leaves, husks, and cobs. Corn cobs represent the largest portion of this waste, accounting for about 30% of the corn fruit. Based on the 2024 production volume, the region has the potential to generate approximately 116.810 tons of corn cob waste [21]. Utilizing this agricultural byproduct for water filtration supports waste reduction while providing a cost–effective, locally sourced solution. In addition to corn cobs, candlenut shells also serve as an excellent source of carbon–rich absorber material [22]. Candlenut shells have been extensively developed as effective adsorbents for various synthetic dyes, including methyl orange, methylene blue, and rhodamine B [23]–[25]. Beyond their application in dye removal, candlenut shell-derived activated charcoal has also been explored as a promising electrode material for Capacitive Deionization (CDI) technology in seawater desalination [26]. These shells are also widely available agricultural waste products in Sumbawa, with high carbon content suitable for activated carbon production. By turning local waste into useful filter materials, this approach not only improves water quality but also promotes environmental sustainability and economic efficiency for the people of Sumbawa.

This study aims to develop a portable water filtration system employing activated carbon–based adsorbents derived from agricultural residues, specifically corn cobs and candlenut shells. The research evaluates the influence of varying adsorbent dosages on key physicochemical parameters of water quality, including temperature, total dissolved solids (TDS), pH, taste, odor, turbidity, and $CaCO_3$ concentration. Water samples were collected from three distinct locations within Sumbawa Regency, Indonesia, to assess the filtration performance across different groundwater characteristics.

2 Method

2.1 *Materials*

The portable filter was constructed using both primary and supplementary materials. The primary materials were agricultural biomass waste, specifically corn cobs and candlenut shells. Corn cobs were collected directly from maize farmers in Sumbawa Regency, while candlenut shells were sourced from nearby local farmers. Supplementary materials included gravel with an average diameter of 2 cm and a commercially available polyethylene–based sponge, which served as supporting filter media. For the activation process, technical-grade sodium hydroxide (NaOH) supplied by Merck, Germany, was used.

2.2 *The design of a portable filter*

A portable filter unit was constructed using a PVC pipe as the main chamber, with a diameter of 3 inches and a length of 50 cm (Figure 1). The system was equipped with inlet and outlet connections made from 0.5–inch PVC piping. This design was adapted from previous research [9], with modifications focused on the configuration and dimensions. Unlike the earlier design, which included components such as a sedimentation pond, the system developed in this study was engineered to be portable, community–friendly, and easily deployable in various locations.

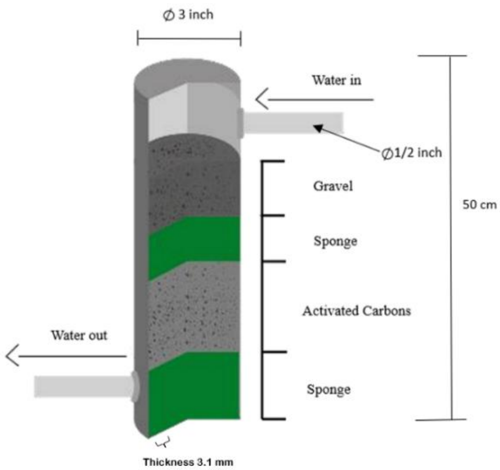

Figure 1: The design of a biomass-based water filter.

The absorbent material was prepared by carbonizing agricultural wastes, corncobs and candlenut shells, through a pyrolysis process in a sealed chamber. Carbonization was carried out at approximately 400 °C, monitored using a handheld infrared thermometer, and terminated once the raw materials were fully converted into charcoal. A total of 3 kg of corn cob charcoal and 3 kg of candlenut shell charcoal were then chemically activated by soaking in a 20% sodium hydroxide (NaOH) solution (0.5 M), as adopted from previous research [10]. The activation was performed with 5 L of NaOH solution, following a 3:5 (w/w) charcoal-to-solution ratio, for a duration of 24 h. After soaking, the samples were rinsed with distilled water until a neutral pH (7) was achieved, followed by drying to a moisture content of 3–8%, after which the activated carbon was ready for use.

The filter chamber was assembled in several layers, as shown in Figure 1. The bottom layer consisted of a 3–inch diameter polyethylene sponge with a height of approximately 4 cm. Above this, the second layer was filled with activated carbon, either from candlenut shells or corn cobs, in varying amounts of 0, 150, 250, and 500 g. A second sponge was placed above the activated carbon to secure the material. The top layer was filled with gravel, which served as a physical pretreatment medium to retain larger suspended materials such as mud and sand, thereby enhancing the performance of the activated carbon layer.

During operation, raw groundwater entered the system through the inlet, flowed from the top of the chamber to the bottom, and passed sequentially through the gravel, sponge, and activated carbon layers before exiting through the outlet. This configuration allowed suspended solids to be retained in the upper section, enabling the activated carbon layer to absorb dissolved and fine contaminants more effectively.

2.3 *Sampling and analysis*

This study began with a preliminary analysis of groundwater collected from three locations in Sumbawa Regency, Indonesia. The first source was located at the Residential College of Sumbawa University of Technology (8°34'09.5"S 117°25'35.8"E), the second at Sumbawa Town (8°29'56.1"S 117°26'41.7"E), and the third at Penyaring Village (8°27'46.1"S 117°31'51.4"E). A total of 10 liters of water was drawn from each source at a flow rate of 0.5 cm³/s, and the sampling sites are shown in Figure 2. The collected raw groundwater was first evaluated against established groundwater quality standards, presented in Table 1.

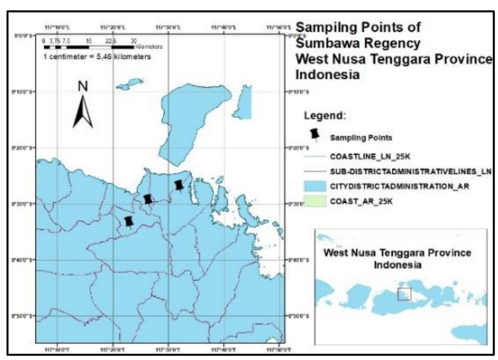

Figure 2: Sampling sites.

Table 1: The water ground quality standard [27].

Test Parameters	Results
Water Temperature, °C	-
Total Dissolved Solid (TDS), ppm	≤ 1000
Water pH	6.5-8.5
Taste	-
Turbidity, NTU	≤ 5
Odor	-
$CaCO_3$, ppm	≤ 500
Nitrate (as NO_3^-), ppm	≤ 50

For the filtration process, the groundwater was passed through the portable filter unit at a constant flow rate. The filtrate was then collected as a test sample, with 10 mL taken for each variable, and each measurement was conducted in triplicate to ensure validity and reliability. The collected water samples were stored in plastic tubes for further physical and chemical analysis. Both the initial condition and the post–filtration quality of the water were evaluated to determine the effectiveness of the filter system. The analysis of water quality included temperature, pH, total dissolved solids (TDS), odor, taste, turbidity, and $CaCO_3$ concentration. Several instruments were used: a digital pH meter (EUTECH) for pH measurement, an EUTECH TN 100 turbidimeter for turbidity, and a TDS meter (Mediatech PH/TDS/EC/Temp Waterproof Auto–Calibrate ATC 9908, Merahabu–B1900134) for total dissolved solids (TDS). The surface area of activated carbon absorbents derived from corn cobs and candlenut shells was tested using a Surface Area Analyzer (SAA). The concentration of $CaCO_3$ in water was measured using X-ray Diffraction (XRD). Soil water sampling and preparation were carried out by taking soil water samples from representative locations using sterile polypropylene bottles. The $CaCO_3$ sediment was then ground into a fine powder using a mortar and pestle. It is then sieved with a 200 mesh to obtain uniform particle sizes. The powder was then put in an XRD holder and flattened the surface for optimal diffraction. The XRD parameters used in this experiment were Cu-Kα (λ = 1.5406 Å), 2θ range: 10°–80°, step size: 0.02°, scan rate: 1–2°/min.

The taste evaluation followed the guidelines issued by the Ministry of Health of the Republic of Indonesia No. 2 of 2023 [12], using the organoleptic method with the assistance of 15 trained panelists. The indicators for the taste test results are presented in Table 2, while the odor evaluation standards are provided in Table 3. The requirements for odor and taste panelists were determined in accordance with the Indonesian Standard (SNI 01–2346–200). These criteria include: a) being physically healthy and free from defects that may interfere with organoleptic assessments; b) having no judgment or bias regarding the product being tested; c) having the ability to make free and independent comparisons; and d) possessing interest and curiosity in evaluating the organoleptic properties under study. All analysis was conducted in three replicates.

Table 2: Test indicator of groundwater taste standard.

Score	Taste Description
1	No Taste
2	Sour Taste
3	Bitter Taste
4	Metallic Taste
5	Salty Taste
6	Chalky Taste

Table 3: Test indicator of groundwater odor standard.

Score	Odor Description
1	Odorless
2	Fishy Odor
3	Muddy Odor
4	Chemical Odor
5	Metallic and Iron Odor

2.4 *Experimental design*

This study used a two-factor Complete Randomized Design (CRD). In this study, the testing was conducted using the Analysis of Variance (ANOVA) method to determine the effect of two fixed variables on the observed results. The fixed variables used were: a) Type of absorbents (candlenut and corn cob); b) Mass of absorbents (0 g, 150 g, 250 g, 500 g). The significance level to determine the difference between treatments was conducted using the Duncan test.

3 Results and Discussion

3.1 *Characteristics of groundwater*

The quality of groundwater in Sumbawa Regency is presented in Table 4. The results indicate that the Total Dissolved Solids (TDS) level was 570 ppm. This value exceeds the World Health Organization (WHO) standard of 500 ppm [28]. This suggests that the groundwater contains a considerable amount of dissolved minerals that may impact its suitability for direct consumption.

Table 4: The initial values of groundwater test in Sumbawa regency.

Parameters	Results
Water Temperature, °C	32
Total Dissolved Solid (TDS), ppm	570
Water pH	8.5
Taste	4.1
Turbidity, NTU	2.8
Odor	4.2
$CaCO_3$, ppm	531
Nitrate (as NO_3^-), ppm	None

The pH of groundwater was measured at 8.5, although this value remains within the acceptable limit— it indicates a basic nature of the water. The elevated pH suggests a significant presence of calcium hydroxide ($Ca(OH)_2$), a strong base that contributes to the formation of calcium carbonate ($CaCO_3$) in groundwater. Since $CaCO_3$ itself possesses mildly basic properties, its presence further increases the alkalinity of the water [29]. The initial concentration of $CaCO_3$ was determined to be 531 ppm. The organoleptic evaluation had a taste score of 4.1, indicating the detection of a metallic taste, most likely caused by the presence of heavy metals such as manganese (Mn) and iron (Fe), which are common contributors to such sensory characteristics [30]. Regarding odor, the score of 4.2 suggests a chemical-like odor, potentially arising from the combination of $CaCO_3$ and other acidic or basic compounds in the water matrix. Meanwhile, turbidity measurements yielded a value of 2.8 NTU, which is still below the acceptable limit for drinking water. The subsequent sections present the performance of the portable filter, comparing the effectiveness of candlenut shell and corn cob absorbents across different amounts in reducing TDS, pH, taste, odor, turbidity and $CaCO_3$ level.

3.2 *The effect of absorbents on water temperature*

Figure 3 shows the water temperature measurement from the groundwater filtration process in Sumbawa Regency with different types and various amounts of active carbon.

The results of the ANOVA test indicate that both the type of activated carbon source and the amount of absorbent used significantly affect temperature changes, as demonstrated by a p-value of less than 0.001. However, detailed analysis reveals that certain aspects do not significantly influence the differences in groundwater temperature produced. For instance, Figure 3 shows no temperature change among the various types of absorbent sources when no absorbent is added (0 grams). This lack of change is expected since no absorbent is involved in the filtration process. This phenomenon is likely due to minimal heat exchange during the process [31]. This assumption is in line with the theory stated in Equation 1.

$$Q = m\ Cp\ dT \tag{1}$$

Where Q is heat, m is the mass of the object, and dT is the change in temperature. If $Q = 0$, then dT will also be 0. This means that there will be no change in the system temperature if there is no change in the heat that occurs [32], [33]. In addition, temperature does not have much influence because there are no exothermic or endothermic reactions that can change the temperature of the environment [32].

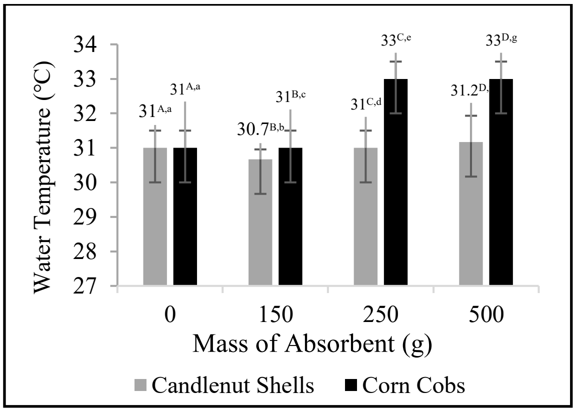

Figure 3: The effect of type and mass of absorbents on the water temperature. Superscripts indicate the data were statistically different at p-value < 0.001.

When using activated carbon derived from candlenut shells at three different mass levels (150 g, 250 g, and 500 g), statistical calculations showed a significant effect on the water temperature produced (p-value < 0.001). Although the observed increase in temperature was not substantial, this indicates that the material has minimal thermal interaction with water [34]. In contrast, filtration using activated carbon made from corn cobs consistently resulted in a slightly higher water temperature of 33 °C. The ANOVA results indicated that variations in the amount of corn cob raw material used as an absorbent had a significant effect on the temperature of the water passing through the filter. This consistent increase in temperature may be attributed to the physical or chemical properties of the corn cobs; however, further research is needed to confirm this observation [35]. Overall, the findings indicate that there is a significant effect on the temperature of filtered groundwater, both in terms of the type of absorbent source and the amount of absorbent used.

3.3 *The effect of absorbents on water TDS*

Different types and quantities of absorbents influenced the TDS of groundwater in Sumbawa Regency, as shown in Figure 4. The initial TDS of groundwater before the filtration process was 570 ppm (Table 4). When the water was passed through the filter without any absorbent, the TDS decreased to 428 ppm. This reduction may be explained by the role of gravel and sponge in the filter column, which were able to trap or adsorb part of the dissolved and suspended solids, even in the absence of additional absorbent material [36].

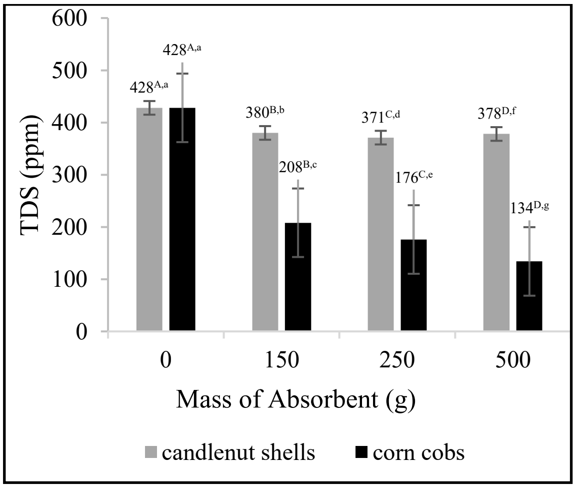

Figure 4: The effect of the type and mass of the absorbent in TDS. Superscripts indicate the data were statistically different at p-value < 0.001.

A more significant reduction occurred with the addition of activated carbon absorbents derived from candlenut shells and corn cobs. This can also be seen from the ANOVA test results, which give a p-value <0.001, meaning that there is a significant result in TDS absorption with the addition of the amount of absorbent used. The improvement can be attributed to the increase in surface area provided by activated carbon, which enhances its ability to adsorb suspended and dissolved materials from groundwater [37]. In the case of candlenut shell waste, the TDS values obtained for absorbent masses of 150, 250, and 500 grams were 380 ppm, 371 ppm, and 378 ppm, respectively.

In contrast, the use of corn cob absorbents resulted in a much greater reduction in TDS. This can also be seen from the ANOVA test results, which give a p-value <0.001, meaning that there is a significant result in TDS absorption with the addition of the amount of absorbent used. At absorbent masses of 150, 250, and 500 grams, the TDS values decreased significantly to 208 ppm, 176 ppm, and 134 ppm, respectively. The difference in performance based on the type of absorbent is also supported by the conclusion of the ANOVA results, which states that there is a significant effect on TDS absorption in groundwater with different types of absorbents used (p-value <0.001). This marked difference in performance may be explained by the structural characteristics of the two materials. Corn cobs generally possess a larger pore size, which allows for more efficient adsorption of dissolved solids. The results of SAA analysis, the surface area of the activated carbon from corn cobs was 352 m^2/gram, whereas the activated carbon from candlenut shells had a significantly lower surface area of 32 m^2/gram. Meanwhile, candlenut shells have a higher lignin content. Based on the previous research, the lignin content of corn cobs is 19.6%-22.7% [38]–[40]. Meanwhile, the lignin content of candlenut shells is 22.4%–33.1% [41]–[43]. During the carbonization and activation process, this high lignin content makes it more difficult to release carbon and develop large pores. As a result, the activated carbon produced from candlenut shells tends to have smaller pores and lower adsorption capacity compared to that from corn cobs. These findings are consistent with the results reported in previous studies [44].

3.4 *The effect of absorbents on water pH*

The effect of different types and amounts of activated carbon on groundwater pH is shown in Figure 5. Before filtration, the pH of groundwater was 8.5. When passed through the filter without any absorbent, the pH remained unchanged at 8.5. This indicates that a filter without absorbent material does not influence groundwater pH, as it only provides physical filtration through gravel and rocks without inducing any chemical reactions [45].

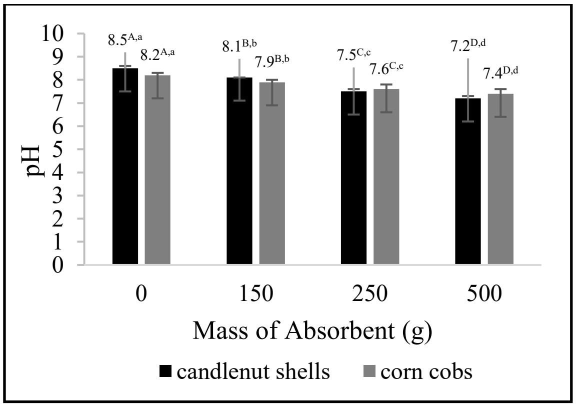

Figure 5: The effect of the type and mass of absorbents on the pH of the water sample. Superscripts indicate the data were statistically different at p-value < 0.001.

The addition of activated carbon absorbents, however, resulted in a noticeable decrease in pH. Corn cob absorbents at masses of 150, 250, and 500 grams reduced the pH to 7.9, 7.6, and 7.4, respectively. Similarly, candlenut shell absorbents at the same masses decreased the pH to 8.1, 7.5, and 7.2, respectively. These results suggest that increasing the amount of absorbent enhances the reduction in pH, as more active sites become available on the activated carbon surface to adsorb basic compounds. This is confirmed by the ANOVA test results, which give a p-value of less than 0.001, meaning that the difference in the amount of absorbent has a significant effect on the pH of the soil water. Substances such as $CaCO_3$ and $Ca(OH)_2$, which contribute to higher pH, are increasingly captured by the absorbent when larger amounts are used [44].

According to the results of the ANOVA test, there was no significant difference between the two types of adsorbents—corn cobs and candlenut shells (p-value > 0.001). This outcome is likely due to the absorption of $CaCO_3$, a weak base compound. However, this absorption is accompanied by the release of compounds from the adsorbent, which may neutralize the effects of pH reduction [46].

3.5 *The effect of absorbents on water taste*

Taste is an important parameter in assessing the acceptability of groundwater for consumption, as it is directly perceived by consumers. The initial groundwater sample from Sumbawa Regency had a slightly bitter and alkaline taste, which corresponds to its relatively high TDS and pH values observed before filtration. Such taste characteristics are commonly associated with the presence of dissolved minerals, particularly calcium carbonate ($CaCO_3$), magnesium, and other alkaline compounds [47]. Figure 6 shows the effect of absorbents on water taste in Sumbawa Regency.

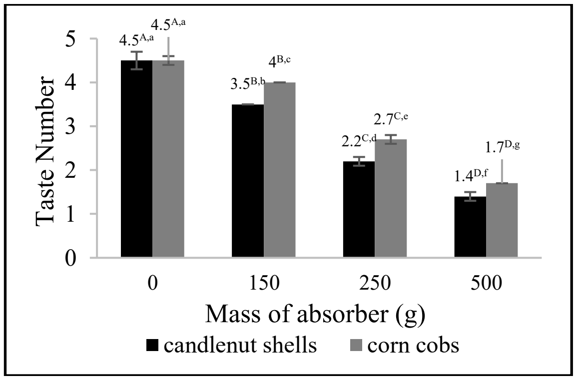

Figure 6: The effect of type and mass of absorbents on water taste. Superscripts indicate the data were statistically different at p-value < 0.001.

The initial taste score of groundwater in Sumbawa Regency before filtration was 4.1, which reflects a slightly bitter and alkaline taste. Interestingly, after the water was passed through the filter without any absorbent, the taste score increased to 4.5 (Figure 6). This means that the water quality became worse in terms of taste, shifting into the "metallic taste" category. The increase in taste score is most likely due to the release of metallic ions, such as Fe, from the gravel and other filter media that were not completely clean. Since this condition involved only physical filtration without any chemical interaction or adsorption, the suspended particles may have been removed, but additional soluble metallic compounds entered the water, intensifying its metallic aftertaste [48].

When activated carbon absorbents were added, a very different trend was observed. Corn cob absorbent at doses of 150, 250, and 500 g reduced the taste score to 4.0, 2.7, and 1.7, respectively. Similarly, the candlenut shell absorbent reduced the score to 3.5, 2.2, and 1.4 for the same amounts of absorbent. These results clearly show that increasing the mass of absorbents leads to a progressive reduction in the taste score. Based on the ANOVA results, differences in the amount of absorbent significantly affect the taste of groundwater, as seen from the p-value being less than 0.001. In other words, the more activated carbon used, the more effective the system was in removing compounds that cause unpleasant taste, with the water moving from a metallic taste toward nearly tasteless at higher doses.

This trend can be explained by the adsorption process occurring on the activated carbon surface. Activated carbon contains a highly porous structure with numerous active sites, which makes it effective at adsorbing dissolved organic and inorganic compounds. Compounds such as $CaCO_3$, $Ca(OH)_2$, and Fe, which are known contributors to alkaline or metallic taste, are gradually removed as the amount of activated carbon increases [49]. The adsorption mechanism involves both physical trapping in the pores and chemical interactions at the surface, leading to the reduction of taste–causing ions and minerals.

A comparison between the two absorbents reveals an interesting difference. While both types improved the taste, candlenut shell–based activated carbon produced slightly lower taste scores than corn cob–based activated carbon. This suggests that candlenut shells were more effective in improving the sensory quality of groundwater, even though previous sections showed that corn cobs generally performed better for parameters such as TDS and pH. Based on the ANOVA results, the type of absorbent affects the taste of groundwater, as indicated by a p-value of <0.001. One possible explanation is that activated carbon from corn cobs is more brittle, and during use, fine carbon particles or certain compounds may leach into the water, slightly increasing the taste score. Candlenut shells, although they tend to produce activated carbon with smaller pore sizes and lower surface area than corn cobs, may release fewer soluble compounds, resulting in cleaner-tasting water. This interpretation is consistent with findings from other studies, which report that differences in the raw material of activated carbon influence not only adsorption performance but also the stability of the carbon itself in water treatment [50].

3.6 *The effect of absorbent on water odors*

Odor is another important sensory parameter that determines the acceptability of groundwater for daily use. The initial groundwater sample from Sumbawa Regency had a noticeable odor, which is commonly associated with the presence of dissolved organic matter, metallic ions, or sulfur–containing compounds. Such odors not only reduce consumer acceptance but can also indicate contamination that affects overall water quality [51]. Figure 7 shows the effect of absorbents on water odor in Sumbawa Regency.

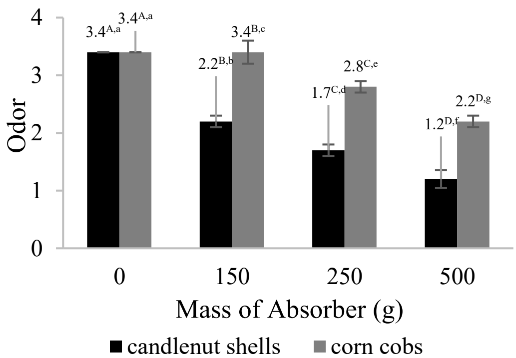

Figure 7: The effects of the type and mass of absorbent on water odors. Superscripts indicate the data were statistically different at p-value < 0.001.

Based on the initial test results presented in Table 3, the groundwater from Sumbawa Regency had an odor score of 4, which corresponds to the chemical odor category. This type of odor is most likely dominated by the presence of inorganic compounds such as calcium carbonate ($CaCO_3$) and other minerals dissolved in the water [26]. Such odors not only reduce the sensory quality of the water but may also indicate the presence of compounds that influence taste and pH.

When the groundwater was passed through a filter without any absorbent, the odor score decreased slightly from 4.0 to 3.4, shifting from the chemical odor category to the muddy odor category. This minor improvement suggests that physical filtration through gravel and sponge was able to remove some suspended materials. However, the persistence of unpleasant odor indicates that chemical compounds remained in the water. Moreover, the presence of residual impurities in the gravel and sponge may have contributed to an additional muddy odor, rather than fully improving water quality [52].

The addition of activated carbon absorbents showed a more significant impact. With corn cob–based activated carbon, the odor score decreased progressively with increasing mass of absorbent: 3.4 (150 g), 2.8 (250 g), and 2.2 (500 g). This change shifted the odor category from muddy to fishy odor, indicating that the activated carbon was effective in adsorbing some odor–causing compounds, though not completely eliminating them. Interestingly, the results also suggest that corn cob absorbent may release certain volatile compounds into the water, contributing to the persistence of a fishy smell [52]. Based on the ANOVA results, differences in the amount of absorbent significantly affect the odor of groundwater, as seen from the *p*-value being less than 0.001.

On the other hand, candlenut shell–based activated carbon produced a more consistent reduction in odor intensity. Based on the ANOVA results, the type of absorbent affects the odor of groundwater, as indicated by a *p*-value of <0.001. At doses of 150 g, 250 g, and 500 g, the odor scores were 2.2, 1.7, and 1.2, respectively. This corresponds to an improvement from fishy odor to odorless water. The superior performance of candlenut shells compared to corn cobs may be explained by differences in material characteristics. Corn cobs have a high carbon content (up to 78.46%) and large porosity, which enhances adsorption capacity but may also facilitate the release of compounds that increase odor [53]. In contrast, candlenut shells produce activated carbon with smaller but more stable pore structures, leading to effective adsorption of odor–causing substances such as $CaCO_3$, Fe, and organic matter without contributing secondary odors [53].

3.7 *The effect of absorbent on water turbidity*

Turbidity is a critical parameter that reflects the clarity of water and is strongly influenced by the presence of suspended solids, colloids, organic matter, and metal oxides. High turbidity not only reduces the aesthetic quality of water but also indicates the potential presence of contaminants that can interfere with disinfection processes and pose health risks. The results of the water turbidity test after filtration can be seen in Figure 8.

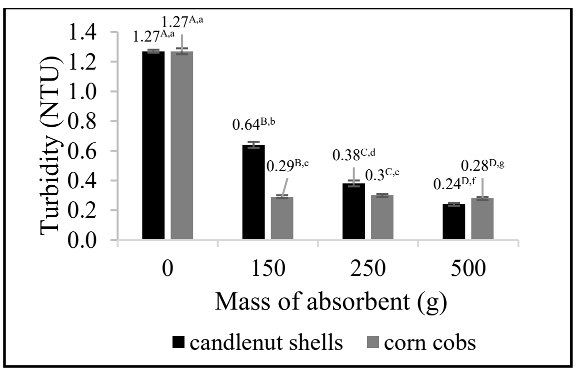

Figure 8: The effect of type and mass of absorbents on water turbidity. Superscripts indicate the data were statistically different at *p*-value < 0.001.

As shown in Table 3 and Figure 7, the initial turbidity of groundwater in Sumbawa Regency was 2.8 NTU, which is still within the permitted standard for clean water. After filtration without absorbents, the turbidity decreased to 1.27 NTU, indicating that the gravel and sponge layers were effective in removing some mud, sand, and other particulates. However, this reduction relies mainly on physical straining, and over time, the permeability of gravel tends to decrease as pores become saturated with trapped material [2].

The addition of activated carbon absorbents provided a more significant reduction in turbidity. These results are supported by ANOVA results, which state that adding absorbent significantly changes groundwater turbidity values (*p*-value < 0.001). With corn cob–based activated carbon, turbidity decreased to 0.29, 0.30, and 0.28 NTU for absorbent masses of 150, 250, and 500 g, respectively. These results demonstrate that corn cob activated carbon can efficiently adsorb suspended solids, leading to water clarity well below the initial level. The slight fluctuation across different dosages indicates that even at lower amounts, corn cob absorbent already provides a high adsorption efficiency due to its large surface area and porous structure [54].

For candlenut shell–based activated carbon, turbidity values were 0.64, 0.38, and 0.24 NTU at 150, 250, and 500 g, respectively. This shows a consistent decrease in turbidity with increasing absorbent dosage, highlighting that more active sites in the activated carbon result in greater particle and chemical adsorption. Although effective, candlenut shells produced slightly higher turbidity values compared to corn cobs at equivalent dosages. This difference can be attributed to material characteristics: corn cobs have higher porosity and greater adsorption capacity, while candlenut shells, due to their higher lignin content, tend to form less developed pore structures during carbonization and activation [55]. Overall, based on the results of the ANOVA test, the type of absorbent used in this experiment significantly affected the turbidity of the filtered groundwater (*p*-value < 0.001).

3.8 *The effect of absorbents on $CaCO_3$ removal*

Calcium carbonate ($CaCO_3$) is one of the dominant inorganic compounds in groundwater and plays an important role in determining pH, hardness, and taste. Elevated concentrations of $CaCO_3$ can increase alkalinity, produce a chalky or metallic taste, and contribute to scaling in household appliances and pipelines. Therefore, its removal is a key target in water treatment processes. The effect of the type and amount of absorbent on the reduction of $CaCO_3$ from filtration in groundwater in Sumbawa Regency can be seen in Figure 9.

As shown in Figure 9, the initial $CaCO_3$ concentration in Sumbawa groundwater was 531 ppm. After filtration without any activated carbon absorbent, the concentration decreased only slightly to 530 ppm, or just 1 ppm lower than the original level. This minimal reduction indicates that physical filtration through gravel and sponge layers had almost no effect on dissolved $CaCO_3$, though it may have trapped a very small fraction of suspended carbonate particles [2].

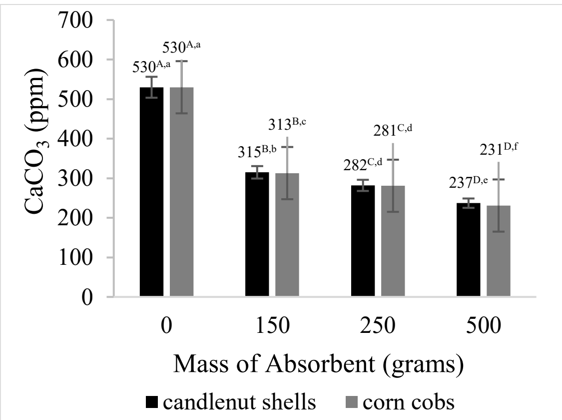

Figure 9: The effect of mass and type of absorbents on $CaCO_3$ removal. Superscripts indicate the data were statistically different at p-value < 0.001.

Table 4 and Figure 9 indicate that the $CaCO_3$ content in groundwater remained relatively unchanged following filtration without the use of an adsorbent. This is likely due to the limited adsorption capacity of gravel and sponge materials, which lack the active sites necessary for $CaCO_3$ binding [56]. In contrast, the incorporation of activated carbon derived from corn cobs or candlenut shells significantly reduced $CaCO_3$ levels. Notably, increasing the amount of activated carbon corresponded with a greater reduction in $CaCO_3$ concentration, suggesting effective adsorption. The activated carbon likely facilitates $CaCO_3$ removal through chemical interactions. $CaCO_3$ can react with NaOH to form $Na_2CO_3 \cdot H_2O$ or Na_2CO_3, compounds that effectively bind CO_2. Previous SEM–EDX analyses have demonstrated the migration of Na^+ ions into $CaCO_3$ particles, enhancing their dissolution and promoting binding. These findings support the hypothesis that NaOH-impregnated activated carbon enables the capture of Ca^{2+} and CO_3^{2-} ions via surface functional groups [54]. Furthermore, increasing the amount of adsorbent expands the available surface area and active sites, thereby improving $CaCO_3$ adsorption efficiency. These results show the significant effect of the amount of absorbent on the absorption capacity of $CaCO_3$ in groundwater. This is supported by statistical test results using ANOVA, which show that variations in the amount of absorbent significantly affect the effectiveness of $CaCO_3$ absorption in groundwater, both using candlenut shells and corn cobs. This conclusion is supported by a p-value of less than 0.001.

Based on the ANOVA test results, differences in absorbent sources (candlenut shells and corn cobs) produced significant differences in terms of $CaCO_3$ absorption effectiveness in groundwater. This can be seen in the p–value <0.001 results. However, visually, the differences are not very significant. The type of biomass used to produce activated carbon—whether corn cobs or candlenut shells—did not result in significant differences in $CaCO_3$ removal performance in groundwater from Sumbawa Regency. This is likely because both materials were treated with the same NaOH concentration, leading to comparable active site formation. Previous studies have shown that the concentration of activating agents and the polarity of the solvent influence the dispersion of active components and the development of functional sites on activated carbon [57]. Higher concentrations and solvent compatibility enhance dispersion, reduce particle size, and increase the number of active sites [58].

The use of activated carbon absorbents derived from corn cobs has proven to be effective in reducing calcium carbonate ($CaCO_3$) levels in groundwater. This innovative approach offers a cost–efficient solution for water purification, as it utilizes corn waste, which is inexpensive and often considered worthless. In contrast, reverse osmosis is a much more expensive method of water treatment.

According to the correlation observed between the levels of $CaCO_3$ in groundwater and the pH of the produced water, lower levels of $CaCO_3$ in groundwater correspond to lower pH test results (Figure 5). This relationship occurs because $CaCO_3$ is a basic compound; therefore, as the levels of $CaCO_3$ decrease, the pH also decreases. Furthermore, activated carbon derived from corn cobs absorbs more $CaCO_3$ compared to activated carbon obtained from candlenut shells (Figure 9). This finding is consistent with the pH values, which also decline when the source of activated carbon shifts from candlenut shells to corn cobs (Figure 5). However, the difference in the type of adsorbent does not result in a significant difference in pH (Figure 5).

4 Conclusions

This study demonstrated the effectiveness of activated carbon derived from corn cobs and candlenut shells in improving groundwater quality in Sumbawa Regency, West Nusa Tenggara Province, Indonesia. The groundwater initially contained $CaCO_3$ at 570 ppm, exceeding the allowable standard, while the water temperature remained stable during the filtration process (33 °C with corn cob-based adsorbents and 31 °C with candlenut shell–based adsorbents), indicating no significant thermal effect from filtration.

The addition of activated carbon significantly improved several physicochemical parameters. Total dissolved solids (TDS) decreased from 570 ppm to as low as 134 ppm when 500 g of corn cob-based adsorbent was applied, compared to 370 ppm with the same dosage of candlenut shells. Similarly, turbidity decreased from 2.8 NTU to 0.28 NTU with corn cobs and 0.24 NTU with candlenut shells, both values well below the permissible standard. Calcium carbonate ($CaCO_3$) concentrations declined from 570 ppm to 231 ppm with 500 g of corn cob adsorbent and to 237 ppm with candlenut shells, showing that corn cobs provided slightly better removal efficiency. In terms of pH, the groundwater shifted from an initial value of 8.5 to 7.4 with 500 g of corn cobs and 7.2 with candlenut shells, indicating a moderate reduction in alkalinity.

Improvements were also evident in organoleptic properties. The taste score, which initially increased to 4.5 after simple filtration without absorbent (metallic taste), was reduced to 1.7 with 500 g of corn cobs and 1.4 with candlenut shells, indicating nearly tasteless water. Similarly, odor intensity decreased from 4.0 (chemical odor) to 2.2 with corn cobs and to 1.2 with candlenut shells, transitioning the groundwater from unpleasant odor categories to nearly odorless. These findings confirm that while corn cob-based activated carbon performed better in reducing TDS, turbidity, and $CaCO_3$, candlenut shell–based adsorbents were more effective in improving taste and odor.

Overall, this research highlights the potential of agricultural by-products, such as corn cobs and candlenut shells as low-cost, sustainable, and effective absorbents for groundwater purification. Their application not only enhances physicochemical properties but also improves sensory quality, offering a practical solution for clean water provision in rural communities.

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Author Contributions

S.A: conceptualization, investigation, methodology, data analysis, writing—original draft; M.S: Writing—review and editing; W.R.: conceptualization, investigation, data curation, writing—review and editing; S.A. and W.R are the main contributors of this manuscript. All authors have read and agreed to the published version of the manuscript.

Conflict of Interest

The authors declare no conflict of interest.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work, the authors used ChatGPT to improve the readability and language of the manuscript. After using this tool, the authors reviewed and edited the content as needed and took full responsibility for the content of the published article.

References

[1] S. Amalia, Sudarmadji, and H. Qaimamunazzala, "The correlation between the levels of fluoride, $CaCO_3$, and pH in clean well water with the calculus index," *BKM Public Health and Community Medicine*, vol. 40, no. 6, p. e10964, 2024, doi: 10.22146/bkm.v40i06.10964.

[2] M. Simoni et al., "Decarbonisation of calcium carbonate in sodium hydroxide solutions under ambient conditions: effect of residence time and

mixing rates," *Physical Chemistry Chemical Physics*, vol. 24, no. 26, pp. 16125–16138, 2022, doi: 10.1039/d2cp01412b.
[3] L. Yu, L. Zihao, J. He, and Guowei, "Experimental Study on the Permeability Damage Mechanism of Gravel Pack Sand Control Medium in Mud Hydrate Reservoirs," *Journal of Coastal Research*, vol. 38, no. 6, pp. 1104–1115, 2022.
[4] A. A. S. Rianda, D. P. E. Putra, and W. Wilopo, "Groundwater flow modeling at Sejorong Watershed, Sumbawa, West Nusa Tenggara, Indonesia," *Journal of Applied Geology*, vol. 4, no. 2, p. 43, 2019, doi: 10.22146/jag.53200.
[5] W. Chen, Y. Chen, Y. Wang, and N. Zhao, "Combining activated carbon adsorption and CO_2 carbonation to treat fly ash washing wastewater and recover high-purity calcium carbonate," *Water (Switzerland)*, vol. 16, no. 20, 2024, doi: 10.3390/w16202896.
[6] R. J. P. Latiza and R. V. Rubi, "Circular economy integration in 1G+2G sugarcane bioethanol production: Application of carbon capture, utilization and storage, closed-loop systems, and waste valorization for sustainability rich," *Applied Science and Engineering Progress*, vol. 18, no. 1, 2025, Art. no. 7448, doi: 10.14416/j.asep.2024.07.005.
[7] Y. S. Cheng et al., "Recent situation and progress in biorefining process of lignocellulosic biomass: Toward green economy," *Applied Scence and Engineering Progress*, vol. 13, no. 4, pp. 299–311, 2020, doi: 10.14416/j.asep.2020.08.002.
[8] A. B. D. Nandiyanto, N. N. Azizah, and G. C. S. Girsang, "Optimal design and techno-economic analysis for corncob particles briquettes: A literature review of the utilization of agricultural waste and analysis calculation," *Applied Scence and Engineering Progress,* vol. 15, no. 3, pp. 1–16, 2022, doi: 10.14416/j.asep.2021.10.006.
[9] A. H. R. Gowda, G. Goud, S. Karthik, and M. Puttegowda, "Influence of water absorption on mechanical and morphological behaviour of roystonea-regia banana hybrid polyester composites," *Applied Science and Engineering Progress*, vol. 17, no. 1, 2024, Art. no. 7074, doi: 10.14416/j.asep.2023.10.003.
[10] N. T. V. Anh, N. N. Hoa, N. T. Thuy, N. L. T. And, and N. N. Huy, "Utilization of rice husk and alum sludge to produce an efficient adsorbent composite for recovery of nutrients from wastewater," *Applied Scence and Engineering Progress,* vol. 17, no. 1, 2024, Art. no. 6898, doi: 10.14416/j.asep.2023.08.002.
[11] E. Santolini, M. Bovo, A. Barbaresi, D. Torreggiani, and P. Tassinari, "Turning agricultural wastes into biomaterials: Assessing the sustainability of scenarios of circular valorization of corn cob in a life-cycle perspective," *Applied Sciences*, vol. 11, no. 14, 2021, doi: 10.3390/app11146281.
[12] H. S. Kiridena, S. I. Thenuwara, M. M. Kandage, N. Peiffer, M. Marszewski, and D. Isailovic, "Evaluation of carbonized corncobs for removal of microcystins and nodularin-r from water," *Separations*, vol. 11, no. 3, p. 84, 2024, doi: 10.3390/separations11030084.
[13] B. Haryanto, I. T. Nasution, A. F. Polem, R. Tambun, and V. Alexander, "Natural adsorbent of corncob (*Zea mays* L.) powder capability in purification of used cooking oil with shaking operation based on turbidity," *Results in Engineering*, vol. 19, 2023, Art. no. 101233, doi: 10.1016/j.rineng.2023.101233.
[14] G. Yan et al., "Sustainable approaches for dye removal using enzymatic hydrolysis residue of corncob as an adsorbent," *Desalination and Water Treatment*, vol. 300, pp. 192–198, 2023, doi: 10.5004/dwt.2023.29716.
[15] R. Amen et al., "Lead and cadmium removal from wastewater using eco-friendly biochar adsorbent derived from rice husk, wheat straw, and corncob," *Clean Engineering and Technology*, vol. 1, no. May, 2020, doi: 10.1016/j.clet.2020.100006.
[16] C. B. Panchal and J. G. Knudsen, "Mitigation of water fouling: technology status and challenges," *Advanced in Heat Transfer*, vol. 31, pp. 431–474, 1998.
[17] M. Naderi, V. Past, and A. H. Mahvi, "Magnetic treatment as a suppressive method for $CaCO_3$ scale deposition in hard waters in the presence of air bubbles," *Desalination and Water Treatment*, vol. 318, 2024, Art. no. 100249, doi: 10.1016/j.dwt.2024.100249.
[18] L. D. Tijing, H. Y. Kim, D. H. Lee, C. S. Kim, and Young I. Cho, "Physical water treatment using RF electric fields for the mitigation of CaCO3 fouling in cooling water," *International Journal of Heat and Mass Transfer*, vol. 53, no. 7–8, pp. 1426–1437, 2010.
[19] J. Xu et al., "$CaCO_3$-Enhanced cleaning in tubular Membrane: Mechanism and application

in Polymer-Flooding produced water treatment," *Separation and Purification Technology*, vol. 379, no. 1, 2025, Art. no. 134883.

[20] A. Yakin, H. F. Putri, and Amiruddin, "Profitability and profit risk analysis of corn farming in District of Utan, Sumbawa Regency: A cross-sectional study," *IOP Conference Series: Earth and Environmental Science*, vol. 1107, no. 1, 2022, doi: 10.1088/1755-1315/1107/1/012049.

[21] BPS-Sumbawa. "Produksi Jagung Kabupaten Sumbawa (Ton), 2016." Badan Pusat Statistika. Accessed: Sept. 15, 2025. [Online]. Available: https://sumbawakab.bps.go.id/

[22] A. Azis, A. Sukasri, Z. Darajat, H. Hilma, and P. N. Resqi, "Characterization of candlenut shell activated carbon based on the reflux method in H_3PO_4 solution," *AIP Conference Proceedings*, vol. 3140, no. 1, p. 060006, 2024, doi: 10.1063/5.0221066.

[23] S. Muliani, M. Zakir, and S. Fauziah, "Surface modification of activated carbon derived from Candlenut Shell (*Aleurites moluccana*) by HNO_3 and its application as an adsorbent of methyl orange dyes," *Egyptian Journal of Chemistry*, vol. 66, no. 9, pp. 27–36, 2023, doi: 10.21608/EJCHEM.2022.149651.6476.

[24] Buhani, S. N. Halimah, Suharso, and Sumadi, "Utilization of activated carbon from Candlenut Shells (*Aleurites Moluccana*) as methylene blue adsorbent," *Rasayan Journal of Chemistry*, vol. 15, no. 1, pp. 124–131, 2022, doi: 10.31788/RJC.2022.1516538.

[25] Rahmi, I. Lestari, L. Marlinda, Y. W. Mirzayanti, and M. A. Muttaqii, "Sunan candlenut shells activated carbon: Preparation, characterization, and application adsorption of Rhodamine B," *Indian Journal of Chemical Technology*, vol. 29, no. 1, pp. 54–61, 2022, doi: 10.56042/ijct.v29i1.47544.

[26] M. Anas et al., "The utilization of candlenut shell-based activated charcoal as the electrode of capacitive deionization (CDI) for seawater desalination," *Science and Technology Indonesia*, vol. 9, no. 1, pp. 86–93, 2024, doi: 10.26554/sti.2024.9.1.86-93.

[27] R. W. Herschy, "Water quality for drinking: WHO guidelines," in *Encyclopedia of Lakes and Reservoirs*, Dordrecht. Netherlands: Springer, 2012, doi: 10.1007/978-1-4020-4410-6_184.

[28] World Health Organization, *Guidelines for Drinking-Water Quality*, 4th ed., Geneva, Switzerland: WHO Library, 2025.

[29] R. Ramadania, S. Samsunarb, and M. Utamia, "Analisis kandungan minyak dan lemak pada limbah outlet pabrik kelapa sawit di aceh tamiang," *Quimica Jurnal Kimia Sains dan Terapan*, vol. 4, no. 1, pp. 15–19, 2022, doi: 10.33059/jq.v4i1.4318.

[30] B. Krishnakumari, V. M. Abhishek, T. E. Puneeth, S. Vignesh, and M. K. M. Irfan, "Removal of iron and manganese from ground water," *International Journal of Engineering Research and Technology*, vol. V6, no. 02, pp. 6–9, 2018, doi: 10.17577/ijertcon008.

[31] X. Bai, I. J. T. Dinkla, and G. Muyzer, "Microbial ecology of biofiltration used for producing safe drinking water," *Applied Microbiology and Biotechnology*, vol. 106, no. 13–16, pp. 4813–4829, 2022, doi: 10.1007/s00253-022-12013-x.

[32] G. Sullivan and C. Edmondson, "Heat and temperature," *Continuing Education in Anaesthesia, Critical Care and Pain*, vol. 8, no. 3, pp. 104–107, 2008, doi: 10.1093/bjaceaccp/mkn014.

[33] A. Herlambang, S. Amrullah, D. Daniyanto, Y. S. Pradana, Rochmadi, and A. Budiman, "The effect of temperature and biomass pre-treatment on non-catalytic gasification of Indonesian sugarcane bagasse," *AIP Conference Proceedings*, vol. 2026, no. 1, 2018, doi: 10.1063/1.5064992.

[34] J. He et al., "Joule heating-driven sp2-C domains modulation in biomass carbon for high-performance bifunctional oxygen electrocatalysis," *Nano-Micro Letters*, vol. 17, no. 1, pp. 1–16, 2025, doi: 10.1007/s40820-025-01725-0.

[35] M. Wróbel, M. Jewiarz, J. Krilek, and L. Dmochowska-Kuc, "Material properties changes caused by high temperature drying—Corn cobs case study," *Materials*, vol. 18, no. 10, 2025, doi: 10.3390/ma18102302.

[36] C. O. Ataguba and I. Brink, "Design and construction of laboratory-scale activated carbon, gravel and rice husk filter columns for the treatment of stormwater runoff from automobile workshops," *Journal of The South African Institution of Civil Engineering*, vol. 63, no. 1, pp. 61–66, 2021, doi: 10.17159/2309-8775/2021/V63N1A6.

[37] M.A. Zadeh, A. Daghbandan, and B. Abbasi Souraki, "Removal of iron and manganese from

groundwater sources using nano-biosorbents," *Chemical and Biological Technologies in Agricultural*, vol. 9, no. 1, pp. 1–14, 2022, doi: 10.1186/s40538-021-00268-x.

[38] M. A. Hasani and A. P. Siswanto, "Effect of delignification process on cellulose, hemicellulose, and lignin content on liquid glucose production from a mixture of Corn Cobs (*Zea mays*) and Sugar Cane Bagasse (*Saccharum officinarum*)," *Equilibrium Journal of Chemical Engineering*, vol. 7, no. 1, p. 23, 2023, doi: 10.20961/equilibrium.v7i1.64558.

[39] P. K. Gandam, M. L. Chinta, A. P. Gandham, N. P. P. Pabbathi, S. Konakanchi and A, Bhavanam, "A new insight into the composition and physical characteristics of corncob substantiating its potential for tailored biorefinery objectives," *Fermentation*, vol. 8, no. 12, 2022, doi: 10.3390/fermentation8120704.

[40] R. Sharma, D. Vaidya, M. Kaushal, A. Gupta, C. Thakur, and J. Garg, "Compositional changes in corn cob and sheath across developmental stages: Implications for industrial use," *International Journal of Research and Agronomy*, vol. 8, no. 7, pp. 14–22, 2025, doi: 10.33545/2618060x.2025.v8.i7a.3171.

[41] R. Hasibuan et al., "Characteristics of bio-briquettes from candlenut shells as a renewable energy: Selection of adhesive type, adhesive concentration, and biochar particle size," *Journal of Ecological Engineering*, vol. 26, no. 10, pp. 316–327, 2025, doi: 10.12911/22998993/204924.

[42] Syahidah, S. H. Larekeng, and M. M. M. A. Nur, "Analysis of lignin content and bioinformatics of lignin overexpression for the quality improvement of Candlenut wood (Aleurites moluccana)," *IOP Conference Series: Earth and Environmental Science*, vol. 1430, no. 1, 2024, doi: 10.1088/1755-1315/1430/1/012023.

[43] A. P. Klein, E. S. Beach, J. W. Emerson, and J. B. Zimmerman, "Accelerated solvent extraction of lignin from aleurites moluccana (*candlenut*) nutshells," *Journal of Agricultural and Food Chemistry*, vol. 58, no. 18, pp. 10045–10048, 2010, doi: 10.1021/jf1019856.

[44] R. Ganjoo, S. Sharma, A. Kumar, and Daouda, "Activated carbon: Fundamentals, classification, and properties," in *The Royal Society of Chemistry*, C. Verma and M. A. Quraishi, Eds. UK: The Royal Society of Chemistry, 2023, pp. 1–22.

[45] A. Z. Ranaivoson and J. F. Moncrief, "Filtration capacity of a gravel inlet system under low accumulation conditions," *International Journal of Hydrology*, vol. 4, no. 5, pp. 257–268, 2020, doi: 10.15406/ijh.2020.04.00253.

[46] S. Adesokan, A. R. Giwa, and I. Bello, "Negative adsorption phenomenon: adsorbent, adsorbates reaction, and ph as contributing factors," *Letters in Appled NanoBioScience*, vol. 12, no. 4, pp. 1–7, 2023, doi: 10.33263/LIANBS124.154.

[47] S. Gugulothu, N. Subbarao, R. Das, and R. Dhakate, "Geochemical evaluation of groundwater and suitability of groundwater quality for irrigation purpose in an agricultural region of South India," *Applied Water Science*, vol. 12, no. 6, pp. 1–13, 2022, doi: 10.1007/s13201-022-01583-w.

[48] I. Meshram, V. Kanade, N. Nandanwar, and P. Ingle, "Super-absorbent polymer: A review on the characteristics and application," *International Journal of Advanced Research and Chemical Science*, vol. 7, no. 5, pp. 8–21, 2020, doi: 10.20431/2349-0403.0705002.

[49] Y. Yang et al., "Research advances in superabsorbent polymers," *Polymers (Basel)*, vol. 16, no. 4, p. 501, 2024, doi: 10.3390/polym16040501.

[50] M. Marlina and A. Putra, "Preparation and characterization of activated carbon from Waste of Corn Cob (Zea mays L)," *International Journal of Scientific Research and Engineering Development*, vol. 2, no. 4, pp. 221–228, 2019.

[51] H. Kolya and C.W. Kang, "Toxicity of metal oxides, dyes, and dissolved organic matter in water: Implications for environment and human health," *Toxics*, vol. 12, no. 2, p. 111, 2024, doi: 10.3390/toxics12020111.

[52] M. S. Muzarpar and A. M. Leman, "The adsorption mechanism of activated carbon and its application-A review," *International Journal of Advanced Technology in Mechanical, Mechatronics and Materials*, vol. 1, no. 3, pp. 118–124, 2021, doi: 10.37869/ijatec.v1i3.37.

[53] R. Farma et al., "Corn cob based activated carbon preparation using microwave assisted potassium hydroxide activation for sea water purification," *Journal of Physics: Conference Series*, vol. 1120, pp. 1-6, 2018, doi: 10.1088/1742-6596/1120/1/012017.

[54] Z. Heidarinejad, M.H. Dehghani, M. Heidari, G. Javedan, I. Ali, and M. Sillapan, "Methods for preparation and activation of activated carbon: a

review," *Environmental Chemistry Letters*, vol. 18, pp. 393–415, 2020, doi: 10.1007/s10311-019-00955-0.

[55] X. He, X. Chen, X. Wang, and L. Jiang, "Optimization of activated carbon production from corn cob using response surface methodology," *Frontiers in Environmental Science*, vol. 11, pp. 1–11, 2023, doi: 10.3389/fenvs.2023.1105408.

[56] G. L. Kyriakopoulos, K. Tsimnadis, I. Sebos, and Y. Charabi, "Investigating the effect of pore size distribution on the sorption types and the adsorption-deformation characteristics of *Porous Continua*: The case of adsorption on carbonaceous materials," *Crystals*, vol. 14, no. 8, 2024, doi: 10.3390/cryst14080742.

[57] T. Goto, Y. Amano, M. Machida, and F. Imazeki, "Effect of polarity of activated carbon surface, solvent and adsorbate on adsorption of aromatic compounds from liquid phase," *Chemical and Pharmaceutical Bulletin*, vol. 63, no. 9, pp. 726–730, 2015, doi: 10.1248/cpb.c15-00039.

[58] Z. Xu et al., "Solvent effects in the preparation of catalysts using activated carbon as a carrier," *Nanomaterials*, vol. 13, no. 3, pp. 1–10, 2023, doi: 10.3390/nano13030393.