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Research Article

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Field Evaluation of Clay Candle Filters Modified with Rice Husk Ash Zeolite for Drinking Water Purification in Ugwueke, Abia State, Nigeria

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Abstract

Though clay-based water filtration technology has been in use as a natural means of water purification for years, but continuous improvement on the filtration efficacy is needed. We report the improvement of the physicochemical and microbial properties of a rural community water treated with water filtration candles produced from pure clay and clay impregnated with rice husk derivatives (rice husk ash RHA, rice husk zeolite RHZ). RHA was produced by carbonization and RHZ was synthesized by hydrothermal method. Candle shape was formed with clay using casting method, and fired to temperature of 900^0C. Four filtration candles with the following design: A (100% clay), B (90%, 10% RHZ), C (90% clay, 5% RHZ, 5% RHA), D (90% clay, 10% RHA) were produced. Physical characteristics (porosity, water absorption, apparent density, bulk density, linear shrinkage) of the test pieces were evaluated according to standard methods. Pre- and post- treated water sample from a rural community River was evaluated for physicochemical parameters (pH, turbidity, conductivity, total dissolved solid, total hardness) and microbial load, following standard methods. Results showed improvement in all the parameters with B candle showing significant improved filtration efficacy than others and is therefore, suitable for development of simple household water filtration unit.

Keywords: Clay candle filter, Rice husk ash, zeolite, Drinking water quality, Microbial contamination, Rural water supply.

Introduction

Like majority of Nigerian citizens, the people of Ugwueke, a community in Bende Local Government Area of Abia State, lack access to potable water and this contributes to the high incidences of water-borne diseases among the population. The borehole sunk by the Niger Delta Development Commission (NDDC) is hard, odourous and epileptic, and therefor grossly unfit for domestic use. Thus, individuals' resort to self-help efforts utilizing surface water resources for their water needs. Natural water features include proximity to streams and tributaries, including the Eze River, that feed into the broader Imo River basin, providing seasonal water availability amid the undulating topography. This riverine influence helps to moderate local microclimates and supports hydrological flow toward the Atlantic, though the hilly terrain can exacerbate runoff during intense wet-season rains, often resulting to pollution of the Eze River (Figure1) when it overflows its banks. The safety of these water resources is not guaranteed and require treatment to improve on the quality. The conventional treatment using synthetic chemicals pose health challenges because of their implications in myriads of non-communicable diseases. Though reports [1,2] on clay-based filtration technology in water treatment are available locally and internationally, but some of the treated water still failed to meet required water treatment standards. There is the need for improved clay-based water treatment technology with broader antimicrobial, physicochemical modifying potentials and sustained bioavailability.



Figure 1: Eze River in Early Rainy Season

Biochar such as rice husk ash (RHA and zeolite have both antimicrobial and cation exchanging capabilities [3,4] that make them very interesting options in the fight against water pollution, disposing them as a veritable water treatment agent. Interestingly, rice husk derivatives would be very cheap and affordable, while reducing the nuisance of environmental pollution, being that rice husk mounds (Figure 2) abound in many rice processing areas of some states in the country, including Abakaliki rice mill cluster in Ebonyi state, and are even posing environmental concerns. We hypothesize that incorporation of zeolite or rice husk ash into a clay-based filtration candle will improve its physical properties and enhance its water filtration efficacy.



Figure2: Rice Husk Mounds and Scavengers at the Abakaliki Mill Cluster

Methodology:

Description of the Study Area

The study took place at Ugwueke, in Bende Local government Area, Abia State. Located within 5º44'N,7º36'E, Ugwueke, often taunted as the food basket of Abia state, is a predominantly agro based economy with the cultivation of staple food crops such as yam, rice, cassava as a major activity. Palm oil processing is also an emerging occupation with oil mills dotting some parts of each five autonomous communities that make up the larger Ugwueke Ibinaeze Ancient Kingdom. Notable establishments include the Santa Paulo Palm Oil Processing Mill in Ndielu Ugwueke and the Chikwendu Palm Oil Processing Mill in Isieke Amaba Ugwueke, which process raw palm fruits into oil for local sale and export to regional markets. Other essential services include multiple public and private schools like Ugwueke Secondary School and Delight Academy, healthcare facilities such as the Amaba Ugwueke Primary Health Center and Royal Cross. Hospital, and periodic markets including Nkwo Ndielu Market and Orie Amaba Market. These services underscore Ugwueke's role as a self-sustaining rural settlement in Abia State. The Eze river crisscrosses all the autonomous communities that make up the larger Ugwueke Ibinaeze Ancient kingdom and serves as a major source of water for the citizens.

Extraction of Rice husk Ash, Zeolite and Production of Filtration Candles

Extraction of Rice husk ash and rice husk zeolite followed the method described in Ibezim *et al* [5]. Water filtration candles were produced by the Casting method [1] to form candle shape with Ukpo clay sample obtained from the Ceramic Research Department, Project Development Agency (PRODA), Enugu and subjected to atmospheric drying and fired to temperature of 900^0C, following the method reported in Agbo *et al* [1]. Briefly, the clay sample was sieved through a mesh size of 210 µm to get a clay powder particle of < 210 µm and mixed with water to produce homogenous colloidal slurry. The slurry was sieved through a 200 µm sieve and successively decanted to obtain a silt of clay. The silt was then poured into a Plaster of Paris mould to remove the excess water and dried in air, ground with pestle and mortar to fine powder which was sieved through 210 µm sieves.

Four filtration candles with the following design matrix: A (100% clay), B (90% clay, 10% zeolite), C (90% clay, 5% zeolite, 5% rice husk ash), D (90% clay, 10% rice husk ash) were produced by pouring each combination into basin with 500 mls of water to dissolve; immediately deflocculated with 5 ml of sodium silicate to produce a slip. The slip was stirred with a motorized stirrer for uniformity of the materials in the slip and then poured into the POP moulds and excess water was absorbed by the mould. The moulds were allowed to undergo atmospheric drying to remove the water content which the mould did not absorb and subsequently the candles were dried in an oven at a temperature of 150^oC for further demoisturization. They were fettled to remove the outline of the mould that

appeared on the candle and then were packed into a kiln and fired to temperature of 900^{o}C.

Determination of some Physical Properties of the Candles

Some physical properties **(**porosity, water absorption, apparent density, bulk density and linear shrinkage**)** of a test piece from each design matrix were tested before compounding into a candle

Porosity

The porosity of the test pieces was determined as reported in Bulta and Michael [2]. The candles were weighed when dry in air and then saturated in distilled water at room temperature for 20 hours (Wsaturated). The water with the candle was boiled for two hours and allowed to cool to room temperature for another 20 hours to ensure that the air in the open pores of the candle filter was replaced by the distilled water. The soaked sample was weighed suspended with wire in distilled water (Wunderwater) after which it was removed from the water, its surface wiped with tissue paper and was reweighed in air (Wdry). The weight of the wire was subtracted from the value obtained while determining the weight of the sample suspended in water. Apparent porosity (P) was calculated according to D'ujanda (2015):

$P = 100[\frac{Wsaturate-Wdry}{Wsaturate-Wunderwater}]$, where; Wsaturated was the weight of the specimen when saturated in water, Wdry was the weight of the dry specimen and Wunderwater was the weight of the sample underwater

Water Absorption

The water absorption was calculated based on the difference between the dry weight and the saturated weight of the fired test pieces, according to the procedures in American Standard for Test Materials (ASTM) C373-88). Briefly**, t**he test piece was dried at 105 ^{o}C for 3hrs to remove all moisture, weighed to determine the dry mass (M1) and soaked in water for 6 hours for saturation. The candle was removed, surface-dried to remove excess surface water, and immediately weighed to obtain the soaked mass (M2). The percentage of water absorption was calculated using the following formula:

Water Absorption (%) = $\frac{100\ [M2 - M1]}{M1}$ Where; M1 = Fired weight and M2 = Soaked weight

Apperent and Bulk Densities

The density terms were determined accurding to the method in ASTM C20-00, 2015

Apparent Density (g/cm^3) = M1/ [M1 – M3], Where; M1 = Fired weight, M3 = Suspended Weight

Bulk Density (BD)

The BD was determined by dividing the test sample mass by the exterior volume thus;

Bulk Density (g/cm^3) = M1/ [M2 – M3], Where; M1 = Fired weight, M2 = Soaked Weight, M3 = Suspended Weight

Linear Shrinkage

Immediately after molding of the test pieces, a vernier caliper was used to insert a 5m mark on each of them, this was recorded as the original length *Lo* (cm). The test pieces were then air dried for 7days and then dried in an oven at 105^0C until a constant weight was obtained. The shrinkage from the 5cm mark was then determined and recorded as the dried length, *Ld* (cm). Afterwards, the dried samples were fired to 900^0C. The shrinkage of the test pieces from the 5cm mark were then determined and recorded as the fired length, *Lf* (cm). The shrinkage was then calculated:

$$\text{Wet-Dry Shrinkage (\%)} = \frac{100\,[Lo - Ld]}{Lo}$$

Where; L_O = Original Length, Ld = Dry Length

(Dry- Fired) Linear Shrinkage (%) = $\frac{100\,[Ld - Lf]}{Ld}$, Where; Ld = Dry Length , Lf = Fired Length

(Total) Fired Linear Shrinka**ge (%) =** $\frac{100\,[Lo - Lf]}{Lo}$, Where; L_O = Original Length, Lf = Fired Length

Sample Collection and Analysis

Water sample for the study was collected from the Eze River by 07:00 hrs on 6th April, 2026. Two plastic water bottles of 2L capacity each, were used. The bottles were previously thoroughly washed with detergent and tap water from Enugu water corporation and rinsed with distilled water. The container used to collect water sample for microbiological analysis was further sterilized with hydrogen peroxide. At the point of sample collection, each container was again rinsed with the Eze River water and then filled, closed, labelled and stored in icebox, for transportation to the laboratory for further activities.

Physicochemical Assessment

Some physicochemical parameters (pH, turbidity, conductivity, total dissolved solid, colure, microbial load) of the water sample were determined before and after filtration, to

assess the effects of the treatment. These parameters were determined according to the methods reported in Association of Analytical Chemists [7] in Official Methods of Analysis.

Microbiological Analysis

The microbial load of the water samples was determined by surface agar diffusion technique according to the method reported in American Health Association (APHA, AWWA 1995) [8]

Results and Discussion

The results of the study are presented in figures 3 and 4 (I-V) and table 1

Figure 3 represents the four filter candles produced: A (100% clay), B (90% clay, 10% zeolite), C (90% clay, 5% zeolite, 5%rice husk ash) and D (90% clay, 10% rice husk ash).

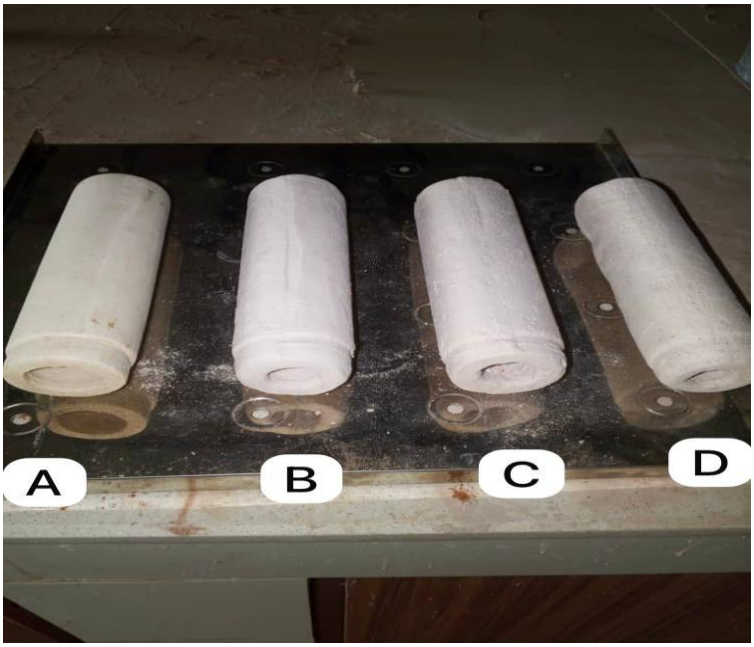


Figure 3: Filter Candles.

The produced filters are ash coloured, probably because of loss in moisture, organic matter and carbon (IV) oxide, during firing.

Figure 4 (I-V) represents some physical properties of the filter candles produced.

Porosity ranged from 32.59±0.32 in A to 37.23±0.46 in D. There was significant difference ($p < 0.005$) when the modified candles (C, $p<0.01$; D, $p<0.01$) were compared with pure clay (A), and 10% zeolite impregnated clay candle (B) was compared with 10% rice husk ash impregnated clay candle (D)($p<0.01$).

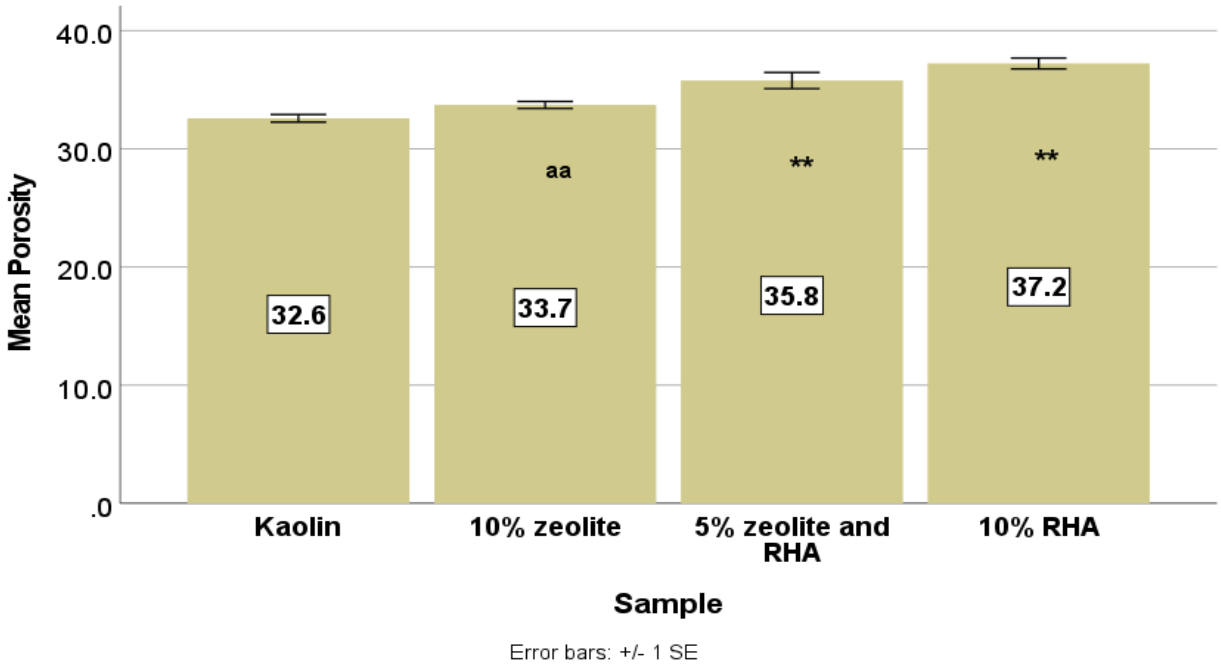


Fig4(i): Mean Porosity of the Test Pieces

* represents comparison with kaolin: *** P <0.001, ** p<0.01

a represents comparison with 10% RHA: aa $p<0.01$

The high firing temperature possibly caused some of the clay particles to fuse, destroyed the original clay structure and binding the mass together, while creating pores due to burnt-off materials. This aligns with the report of Gadzama [9]. The porosity of the pure Ukpo clay in this study agrees favorably with other studies [10; 11]. Impregnation of the clay with the rice husk derivatives (RHA, RHZ) increased the apparent porosity. Studies [12;13] reported that the porosity of a ceramic filter candle, typically ranging from 36% to over 60%, was enhanced by adding combustible materials (burn-out materials) to clay before it was fired in a kiln. Combustible materials such as sawdust, rice husks, or maize cobs burn out during the firing process leaving behind interconnected pore structures that allow for water flow while trapping contaminants. The final apparent porosity is reportedly [14] directly proportional to the amount of burn-out material added. Thus, increased burn-out material (RHA) led to higher porosity, higher water absorption and lower bulk density in D.

Mean porosity plays a critical, often inverse, role in the filtration efficiency of ceramic filters, particularly in water treatment applications. Studies [15] on ceramic water filters (CWFs) have shown that lower porosity correlates with higher efficiency in removing microbial organisms and turbidity. Filters with lower porosity (≤50%) were found to be more efficient than those with higher porosity (>50%), as the smaller pores enable better size exclusion of contaminants. However, in the present study the lesser porous clay filter (A) did not remove turbidity and microbial load much as B and D, probably because of the

rice husk additives. Okechukwu *et al* [16] reported that a water filter made with dry buckweed plant removed turbidity better than that of charcoal, even though the porosity of the former was slightly higher than the later. According to Keiken [17], the granular structure of zeolites traps solid and suspended particles between grains. The porous texture also causes organic and mineral colloid particles to be extracted from the water. The capability for solid particle removal is up to 45 percent more than that of sand with a comparable particle size distribution [17]. This is evidently so in this study where in the treatment with candle filters, turbidity reduction was more pronounced in B and C than in A even though they recorded more porosity. According to Ibezim *et al* [5] the zeolite produced from Abakiliki rice husk possess the characteristic features of large volume of free space and a high degree of crystallinity which are good qualities of adsorbents and would mean that the Abakaliki rice husk derived-zeolite would make a good adsorbent material for the development of water filtration candle and other industrial uses.

Similarly, D with the highest turbidity value recorded higher total microbial viable count; this is explained from the fact that turbidity and microbial load are often directly related [18]. High microbial load generally increases turbidity by introducing suspended particulate matter that scatters light. Bacteria, plankton, and associated bioflocculants (organic matter) raise turbidity levels, often showing a positive correlation with bacterial concentration [19]. The difference in turbidity reduction between pre- and post- treatment was statistically significant ($p<0.005$) across the entire candles, but more so in B -D,

lending more credence on the fitness of the modified clay candle filters for the treatment of Eze river.

Water absorption ranged between 20.83 in B to 23.04 in D, without a significance difference ($p > 0.05$).

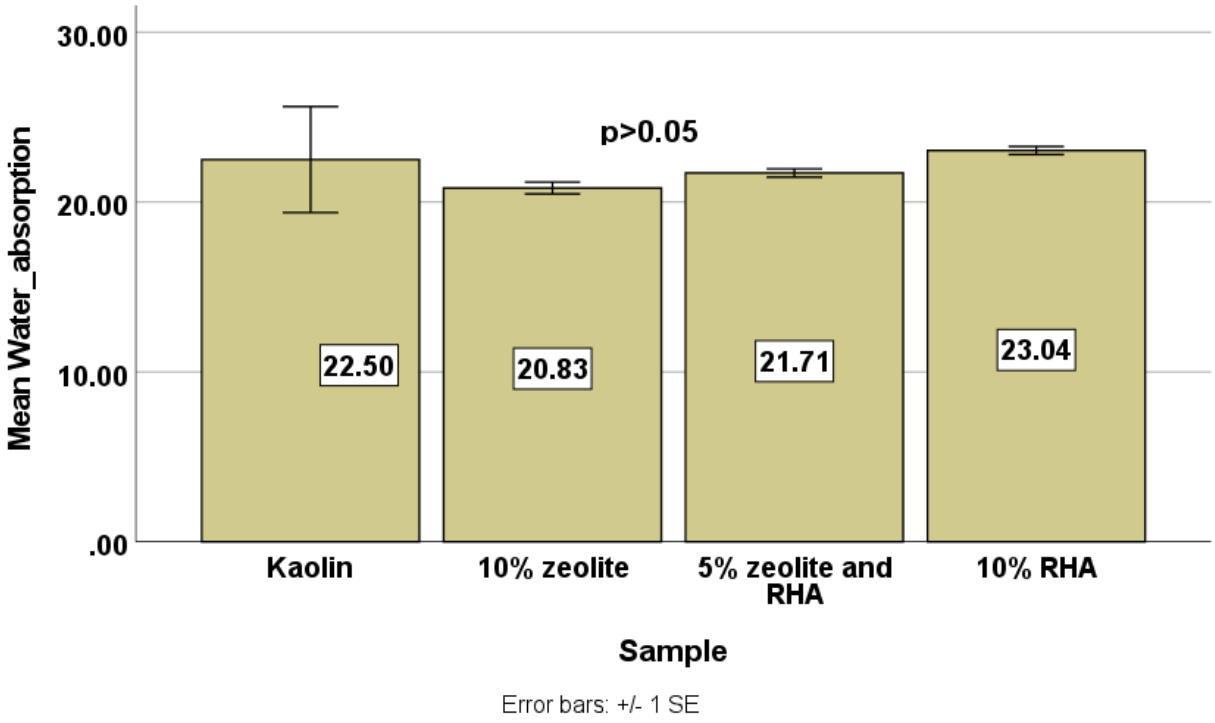


Fig 4(ii): Mean Water Absorption of the Test Pieces

Water absorption tests determined how much water was absorbed by the wet surface of the test samples, which also measured the water content, swell ability, and porosity of the

clay filters. Candle water filters (CWFs) typically require high water absorption (porosity) to function effectively, often exceeding 20 - 30%) depending on the proportion of combustible materials used, which create pores upon firing (Saheed *et al.,* 2021). High water absorption indicates high porosity, which improves flow rates and contaminant removal. The water absorption of a fired clay filter is directly related to the ratio of combustible materials mixed into the clay; higher amounts of combustibles result in higher porosity and water absorption, creating more pathways for water to pass through. Thus, the highest value of water absorption was recorded in D with the highest combustible additive (10% RHA). Increased water absorption correlates to a faster, higher flow rate and higher porosity, but can decrease the material's compressive strength and turbidity removal efficacy.

Apparent density was highest (2.67±0.05) in D, followed by (2.66±0.09) in C.

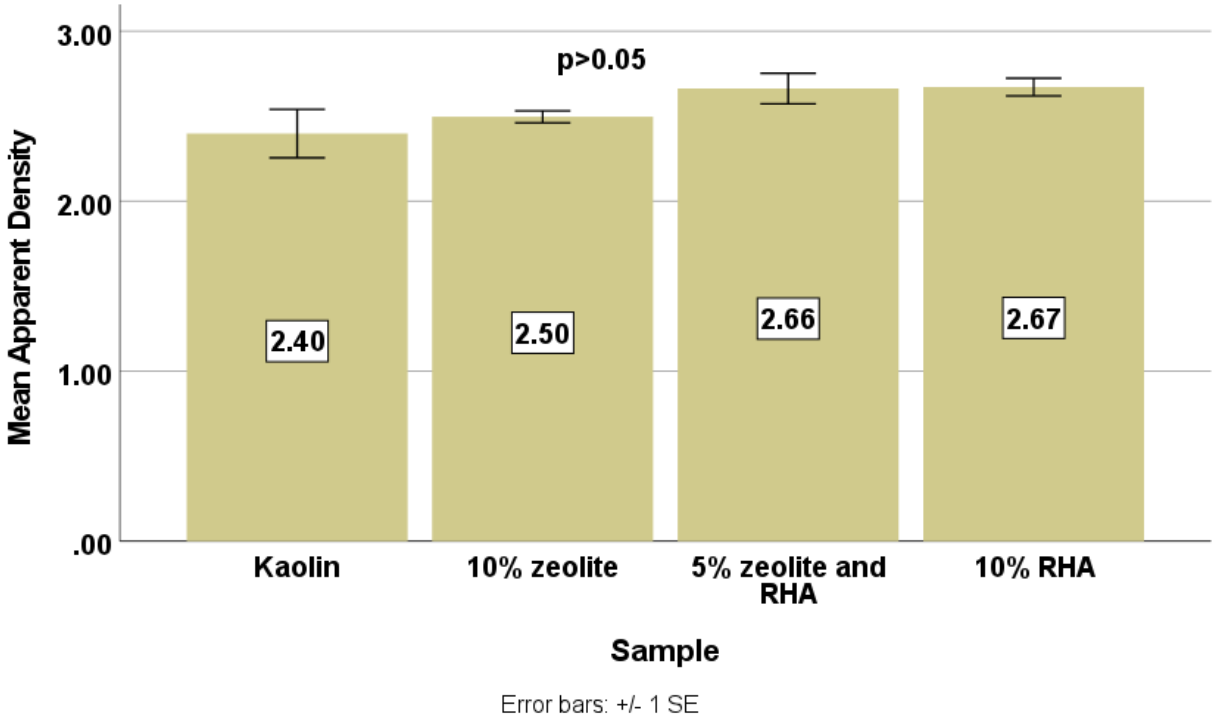


Fig 4(iii): Mean Apparent Density of the Test Pieces

The apparent density of a ceramic filter which is a measure of the compactness of the clay materials is a critical factor in determining its filtration efficiency. In the present study, the apparent density of the clay increased with addition of rice husk derivatives (RHA, RHZ), which invariably would mean an increased porosity as reported above. This is somehow contradictory since compactness reflects less porosity, especially so in this study where in the treatment with candle filters, turbidity reduction was more pronounced in B with 10% zeolite impregnation and least in D with 10% combustible material (RHA).

Bulk density was highest (1.85±0.17) in B and least in A (1.64±0.21)

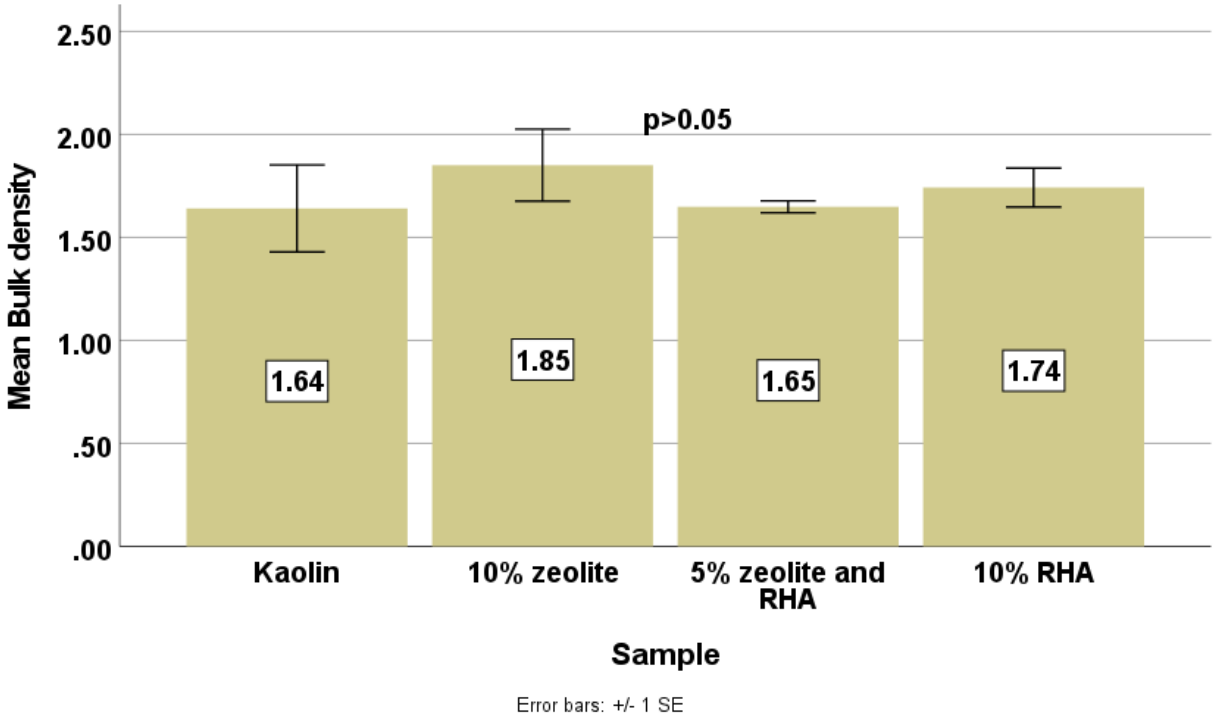
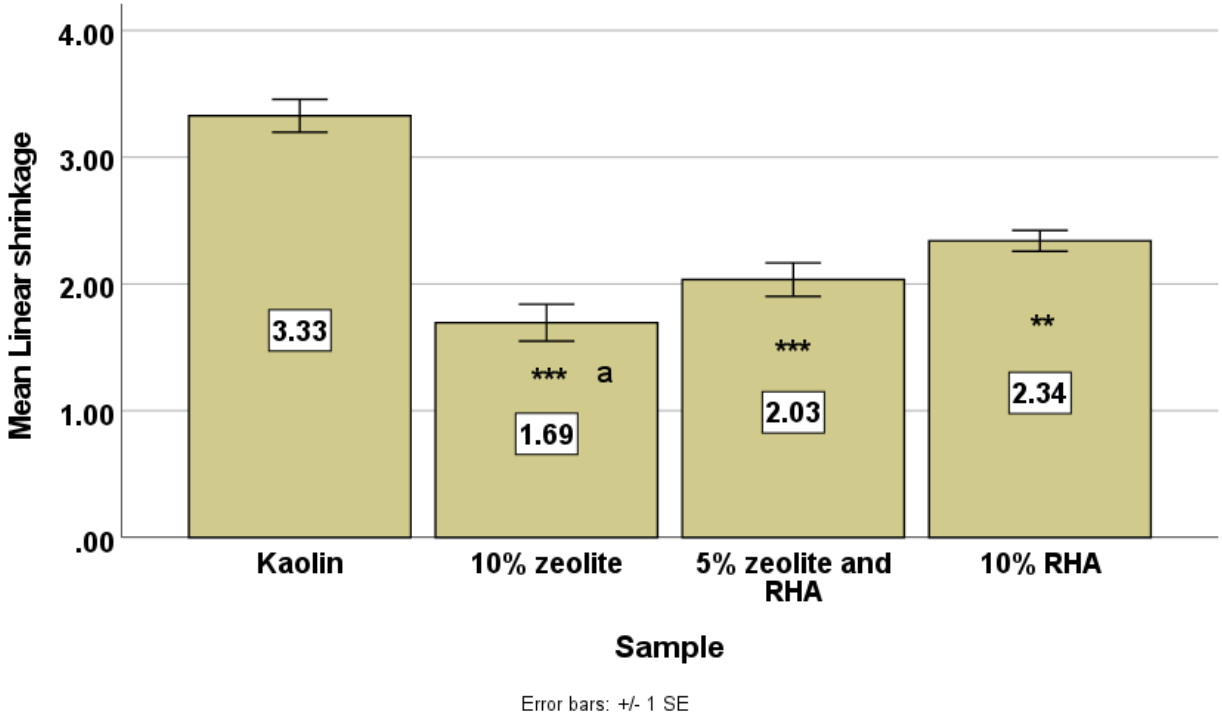


Fig 4(iv): Mean Bulk Density of the Test Pieces

Bulk density is a critical physical parameter in the production of clay filter candles, as it directly relates to the material's compaction, porosity, and ultimately, its ability to filter water effectively. Higher bulk density implies a denser structure, which may provide better microbial straining, explaining why turbidity and microbial load were significantly reduced in B than in other filter candles.

Linear shrinkage value was recorded least (1.69±0.15) in B with a significance difference ($p < 0.001$) when compared with A, C, D.



* Represents comparison with kaolin: *** P < 0.001, ** p<0.01

a represents comparison with 10% RHA: a p<0.05

Fig 4 (V)Mean Linear Shrinkage of the Test Pieces

The linear shrinkage of the test pieces falls within the desired range (< 8%) for good water filtration material [19]. Addition of rice husk derivatives (RHA, RHZ) to the pure clay reduced its linear shrinkage significantly in B-D. Report [20] associated lower linear

shrinkage with pore formers which help to maintain high open porosity required for a consistent flow. In the present study, B with highest content of zeolite recorded lowest linear shrinkage. According to Ibezim *et al* [5] zeolite possess a complex three-dimensional arrangement of tetra hydrous SiO_4 and AlO_4 which create microporous cavities with the ability to adsorb ionic pollutants and organic molecules. No wonder that B was more effective in microbial reduction than others.

Table 1 represents the data on some physicochemical parameters of the pre and post filtered river water samples. The initial pH of the untreated water was 8.26. Treatment with filter candles resulted in a gradual but significant increase in pH, reaching 9.0±0.03 in D.

The initial EC was 110.50 µS/cm. Treatment with filters caused a significant decrease in EC to 68.53 µS/cm in A, after which it slightly increased. The difference in EC of rice husk derivatives treatments was statistically significant.

The TDS of the control water was77.73±0.84mg/L. The trend for TDS closely mirrored that of EC. Treatment lowered TDS from 77.73 mg/L to 48.67 mg/L in A before increasing slightly to 93.93±2.11mg/L in D.

From the initial total hardness of 21.63 mg/L, treatment with B and C was highly effective in reducing hardness, completely eliminating it (0.00 mg/L).

Treatment with candle filters reduced turbidity to a minimum of 81.13 NTU in B, from its initial value of 173.10±1.10 NTU. The difference in turbidity reduction between pre and post treatment was statistically significant across the entire candles ($p<0.005$).

Treatment with the candle filters significantly reduced the TVC in all cases with more effect in B. The difference in microbial reduction between pre and post treatments was statistically significant across the entire candles ($p<0.005$).

Table 1: Physicochemical parameters of the pre and post filtered river water samples

	Untreated water	**A**	**Treated water B**	**C**	**D**
pH	8.26±0.16	8.21±0.11c	8.73±0.04c	8.84±0.21**c**	9.0±0.03**c**
EC	110.50±0.98	68.53±0.27***c	91.53±0.15***c	96.57±0.23**c**	102.40±0.44
TDS	77.73±0.84	48.67±0.24***c	66.00±1.42***c	71.60±0.84***c	73.93±2.11***c
TH	21.63±1.02	12.50±0.46***b	0.00±0.00***c	0.00±0.00***c	8.50±37***c
Turbidity	173.10±1.10	100.41±0.07***b	81.13±0.09***c	92.63±1.55***c	102.80±0.72***c

TVC	2.25±0.15	0.78±0.01***c	0.26 ±0.02***c	0.37±0.02***c	0.48±0.01c***

*p<0.05, **p<0.01 and ***p<0.001 compared with normal water control

b represents p<0.01, c represents p<0.001 (comparison with clay filter treated water)

Although the physicochemical parameters of the Eze river fall within the acceptable standard for domestic water, except for the microbial load, treatment with the filter candles improved the parameters

The pH of the river was within the World Health Organization drinking water standard (6.50-8.50) but increased after filtration with the modified clay candles. This is in tandem with the report of Agbo *et al* [1] on modified Nsu clay filter candle. The pH increase could be explained from the fact the filters probably contained alkaline qualities that neutralized the acidic components in the river, raising the pH. Studies [21, 22] showed that zeolite possess buffering capability that cause pH stability by absorbing or releasing hydrogen ions, limiting substantial pH changes. It is also reported [23, 24] that clay minerals and agro-waste materials have ion-exchange capabilities. This probably caused hydrogen ions in the river water to exchange with metal ions, resulting in a shift in pH. It was also possible that the filters contributed to the pH rise by reducing organic acids through degradation or adsorption. The study has demonstrated the efficiency of the modified clay filters in stabilizing the pH of Eze river. The changes in pH control the majority of chemical

processes in the aquatic environment. Aquatic organisms are sensitive to pH fluctuations; hence, pH control or monitoring is required during biological activity.

The electrical conductivity (EC) is an effective indicator of the salinity or total salt content of water body which is simply a function of the amount of soluble ionic salt in the water. The reduced conductivity of the filtrate across the candles with candle A recording least value would mean that A was more effective in dissolved ion reducing capacity than others. The reduction in the conductivity by clay-based filter could be through a variety of mechanisms, including ion adsorption, particle filtration, ion exchange, electrostatic interaction, organic compound adsorption, flocculation, and metal ion binding.

Total dissolved solid (TDS) concentration in water is also an important water quality parameter. TDS is made up of inorganic matter and dissolved components such as carbonates, bicarbonates, sulfates, chlorides, phosphates, calcium, magnesium, sodium, potassium, iron, and manganese nitrates. A high TDS concentration impacts water density, osmoregulation of freshwater in organisms, gas solubility (such as oxygen), and the usability of water for drinking, irrigation, and industrial uses. Thus, high TDS concentrations in water are undesirable. The TDS content of the treated water reduced across the filters, with the filtrate from A having significantly lower TDS (48.67±0.24mg/l) than the other filtrates. This is expectedly so because both TDS and EC

are related in the sense that they are indicators of dissolved organic and inorganic compounds in water

The improvement of total hardness in filters B and C could be as a result of the adsorption ability of zeolite to remove divalent cations (Ca++, Mg++ and/or iron++). According to Nazarenko and Zarubina [25], zeolite can be used for water softening through Ca^{2+} removal and replacement with Na+. Zeolite is known for its hardness reduction capability through ion exchange, particularly for calcium and magnesium ions, leading to a decrease in total hardness as the water passed through the zeolite impregnated clay filters. This result is due to zeolite's primary function as an ion-exchanger, efficiently removing calcium and magnesium ions (the primary causes of hardness) from the water.

That the treatment of Eze river with the candle filters significantly reduced the TVC in all cases with more effect in B aligns with previous studies [1, 26]. The difference in microbial reduction between pre and post treatments was statistically significant across the entire candles ($p<0.005$), emphasizing the efficacy of the filters in ameliorating microbial contamination of surface water treatment in line with another study elsewhere [27].

Conclusion

The treatment of Eze river with various filters of different compositions (clay, zeolite and rice husk ash) revealed notable improvements in water quality parameters. The filters

exhibited varying levels of efficiency in the modulation of pH, electrical conductivity (EC), total dissolved solids (TDS), total hardness (TH), turbidity and microbial load (TVC) of the treated water. These followed from the varying physical characteristics which significantly influenced their ability to remove contaminants and enhance water quality. Among the filters, Filter B, composed of clay and zeolite, demonstrated exceptional performance in improving most of the physicochemical parameters and microbial load. These findings underscore the potential of clay and rice husk - additives clay filters as an environmentally friendly and sustainable treatment alternative for rural community surface water.

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Conflict of Interest:

The authors declare no conflict of interest.

Author’s Declaration

The authors hereby declare that the work presented in this article is original and any liability for claims relating to the content of this article will be borne by us.

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Ethics, Consent to Participate, and Consent to Publish declarations: not applicable.

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