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Evaluation of the potential of activated palm fruit bunch biochar (aPFBB) on groundwater hardness reduction

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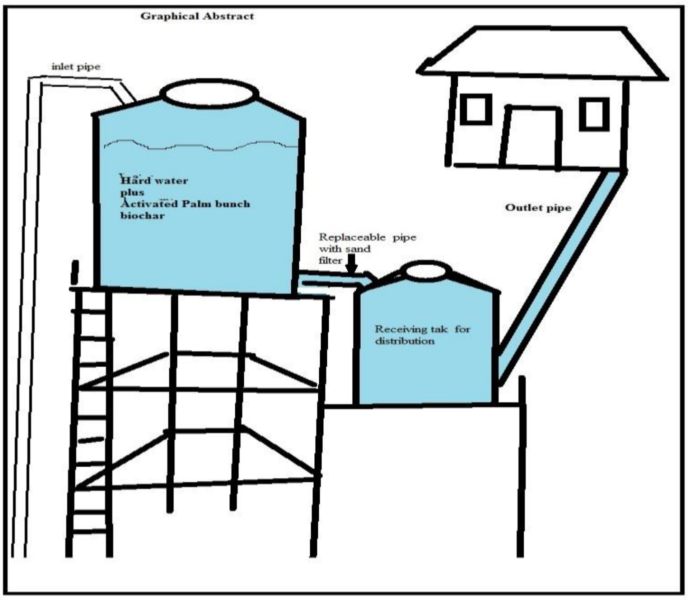
Abstract

The potential of aPFBB in water hardness reduction was evaluated in 25 borehole water samples collected from five residential clusters within Abakaliki, Ebonyi State, Nigeria. During sample collection for determination of the hardness level in the laboratory, temperature, pH, TDS, and Conductivity were measured using standard equipment and procedures. One hundred milliliter of water samples from each borehole was treated with 1 gram of aPFBB in the laboratory and the physico-chemical parameters as well as hardness level measured after 1 hour and 24 hours. The results showed that mean total hardness decreased from 1100.00 mg/L to 503.00 mg/L in samples from PRESCO cluster. Percentage reduction in total hardness was highest (67.11%) in samples from CAS after 24 hours of treatment. The study revealed that aPFBB had good potential for water hardness reduction, hence could be used as alternative to the existing methods because it is cheaper and safer.

Graphical Abstract



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Keywords: Activated Biochar; Abakaliki; Borehole; Water Hardness

1. Introduction

Groundwater represents the world's largest and most important source of fresh potable water [1], due to pressures from anthropogenic activities and climate change on surface water. It provides potable water to an estimated 1.5 billion people worldwide daily and has proved to be the most reliable resource for meeting rural water demand in the sub-Saharan Africa [2]. Due to inadequate supply of water from pipe borne water in developing and underdeveloped countries as a result of government failure, there has been an increase in the drilling of boreholes to meet the water need of the growing population especially among rural dwellers where boreholes serve as alternative to well, pond or stream water in the dry season [3].

Generally, the quality of groundwater varies from place to place and may depend on seasonal changes, soil types, rocks formation, nature of human activities and the waste management practices in an area [3]. As groundwater flows through bedrocks and sediments, metals such as iron and manganese are dissolved and may later be found in high concentrations in the water, while calcium and magnesium may occur as salts [4]. The salts of calcium and magnesium at high concentration are the principal cause of hard water [5], which alter the quality of the water for domestic use. Presence of metals or their ions in groundwater could be by mineralization of bedrocks during weathering and leachates from mining activities. In addition, human activities can alter the natural composition of groundwater through the disposal of untreated waste or injection of wastes directly into groundwater [3]. Calcium and magnesium are present in many sedimentary rocks such as limestone and chalk [5], which form part of the earth crust. They are also common essential mineral constituents of food.

According to the report of the World Health Organization, there is convincing evidence that hardness of water cause no adverse effects to human health [6]. Hard water has rather been found to pose serious problems to industrial setting and some household products by forming lime scales on boilers, cooling towers, water heaters, kettles and other equipment that handle water. Calcium at normal concentration in the body is vital in increasing the bone mass thereby reducing the risk of fracture [5]. However, excess intake of calcium can increase the risks of osteoporosis, nephrolithiasis (kidney stones), colorectal cancer, hypertension and stroke, coronary artery disease, insulin resistance and obesity in some individuals [7]. The body of an adult human is reported to contain about 25 gram of magnesium of which 50 to 60 per cent are stored in the skeletal system [8]. At normal concentration in healthy individuals, magnesium play important role in healthy bone formation [9], glucose control and insulin metabolism [10], maintenance of healthy cardiovascular tissue [11], prevent or relieves headache [12], reducing anxiety and depression [13]. According to [14], high doses of magnesium in food does not pose any health risk in healthy individuals as the kidney eliminate the excess amount in urine. However, high doses of magnesium from dietary supplements or medications can cause diarrhea with nausea and abdominal cramping [15].

Water hardness is caused by a variety of dissolved polyvalent metallic ions mainly calcium and magnesium cations while other cations such as aluminum, barium, iron, manganese, strontium and zinc may contribute [5]. The sum of calcium and magnesium hardness in water is equivalent to the total hardness. Water hardness is most commonly expressed as milligrams of calcium carbonate per liter and water containing below 60 mg/L of calcium carbonate is said to be soft, from 60 mg/L – 120 mg/L calcium carbonate is moderately hard, above 120 mg/L to 180 mg/L is hard and above 180 mg/L of calcium carbonate is very hard [5, 16]. Some researchers reported that groundwater within Abakaliki area of Ebonyi State is hard due to high concentration of calcium and magnesium salts [3, 17, 18, 19]. [1] classified groundwater samples from Mile 50 area of Abakaliki urban as moderately hard based on the concentrations of calcium and magnesium salts they recorded. The reports of these researchers affirmed that water hardness is a major problem associated with the use of groundwater for various purposes where it subsist [19].

Various methods including nanofiltration, electro-dialysis, chemical precipitation, reverse osmosis, lime soda process and ion exchange process have been employed in the removal of hardness in water [21], but these methods have huge cost implications [22], and the residual element in some of the chemical processes may be harmful to human. Hence, studies have been carried out on the use of some locally available plant products in the removal of water hardness. [23] used activated Coconut shell activated carbon (CSAC), wheat husk ash (WHA) and *Amorphophallus campanulatus* (YAM) for removal of hardness in water. They reported that the efficiency of YAM was 84.38% at the end of 180 minutes, CSAC was 62% while WHA was 25% at 2 hours and 1 hour, respectively. [24] used palm kernel shell biochar activated with different concentrations of hydrochloric acid for the removal of contaminants (methyl blue) in water and confirmed it was effective. [25] studied the potential of activated biochar of cashew nut shell in the removal of water hardness at different pH and the result showed that the adsorption of the hardness ion was maximum at the pH of 9 with efficiency of 96%. The researcher stated that the efficiency of removal of hardness at pH 7 was 94 % and that was preferred for the safety of the water for domestic use. Similarly, [26] conducted a study on the use of banana peel for the removal/reduction of total and calcium hardness in groundwater samples from Abakaliki urban. Meanwhile, none of these studies was on the use of activated palm fruit bunch biochar although they are all targeted at the removal or reduction of water hardness. The reason for the use of various raw materials in the various studies conducted could be due to availability and to identify the one that may be most effective.

Hence, this study was carried out to evaluate the potential of activated palm fruit bunch biochar on the reduction of hardness in groundwater from Abakaliki urban of Ebonyi State, Nigeria and we hypothesize that there might/might not be a reduction in the hardness level of the treated samples. If the hardness is reduced, the study becomes a source of useful information on the best approach to handling water hardness problem to the public especially those residing in areas with similar issues.

2. Materials and Methods

2.1. Study Area

The study was carried out in Abakaliki urban, Ebonyi State, Southeastern Nigeria. The town is one of the new growing cities in Southeastern Nigeria and is made of several residential clusters. Five cluster were selected for sample collection based on observed level of groundwater hardness in the areas and the selected residential clusters include Mile 50 layout, College of Agriculture campus of Ebonyi State University, St Mulumba, Mechanic village, and PRESCO campus of Ebonyi State University (Figure 1). Residents of the selected areas depend mainly on groundwater (borehole) water for domestic purposes such as cooking, washing, bathing and in some cases drinking. The level of hardness of groundwater within Abakaliki urban has been a setback to the availability of drinking making sachet/bottle water business one of the most ventured into by small scale business operators.

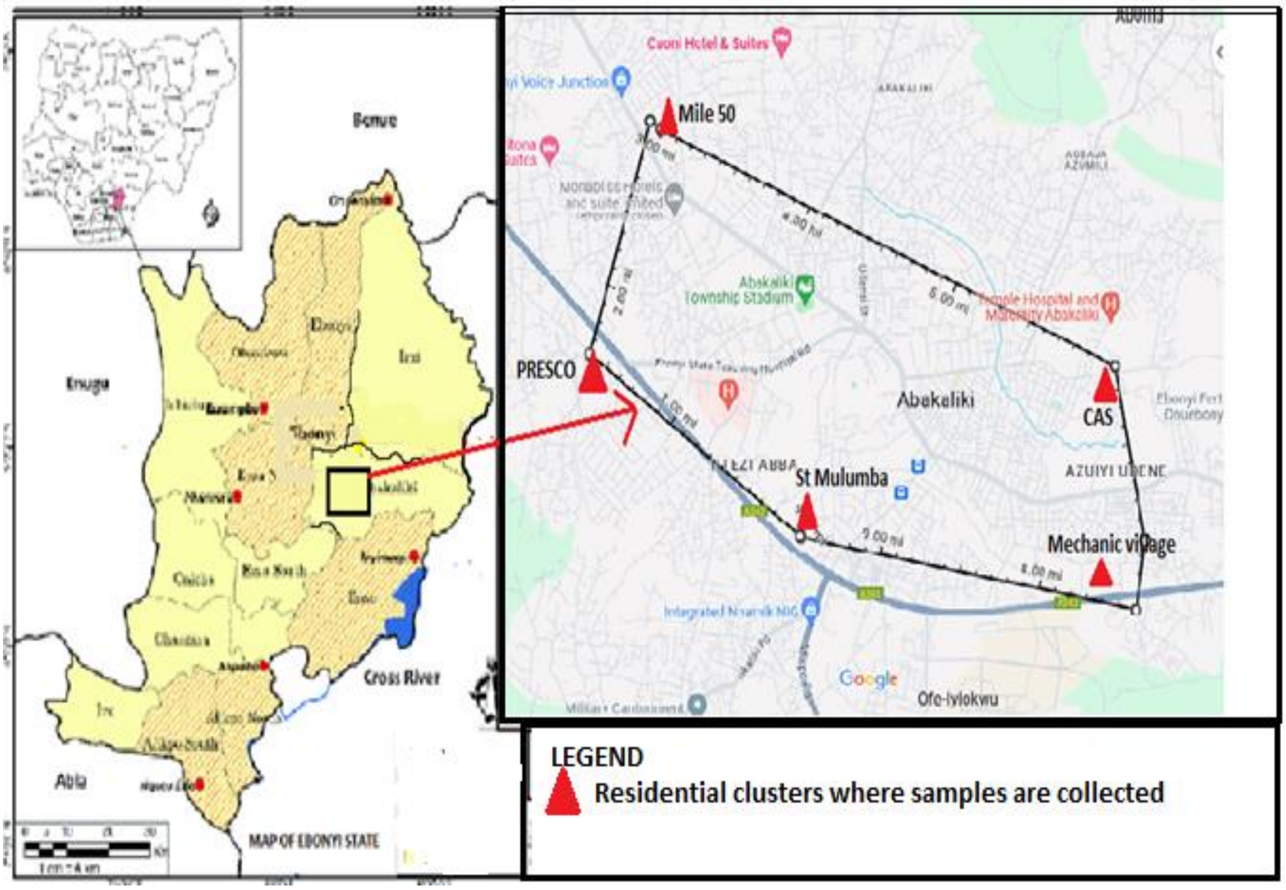

Figure 1 Map of Nigeria (inset), and Ebonyi State showing the Study area.

Source: Modified after [27].

2.2. Sample Collection

Water samples were collected from five boreholes within each residential clusters using a clean plastic container. During sample collection, some water quality parameters including temperature, total dissolved solids, conductivity and pH were measured *in situ* using Hanna digital thermometer, TDS (Model 98108), conductivity (Model: HI 98303) and pH meters, respectively while the sample in containers were taken to the laboratory for determination of alkalinity, calcium and magnesium hardness level using standard methods according to [28].

2.3. Preparation of palm bunch biochar/treatment of Water samples

Fresh palm fruit bunch were gathered from the rural area and the biochar prepared by pyrolysis as described by [29]. Thereafter, water samples collected from the selected residential clusters with sterile containers were treated with activated palm bunch biochar. The treatment was at the ratio of 1.0 gram of the activated palm bunch biochar to 100 milliliter of the water samples. Hardness was measured in the untreated samples, at 1 hour and 24 hours after treatment.

2.4. Estimation of total Water hardness

Total water hardness was estimated from the calcium and magnesium hardness of the water samples which was the concentration of calcium and magnesium ions expressed as equivalent of calcium carbonate [30]. The ratio of the molar mass of calcium carbonate to calcium and magnesium ions were calculated and the results multiplied by the concentration of calcium and magnesium ions to get the calcium and magnesium hardness of the water samples as shown below;

Molar mass of calcium carbonate ($CaCO_3$) = 100.1 g/mol
Molar mass of calcium = 40.1 g/mol
Molar mass of magnesium = 24.3 g/mol
Ratio of molar mass of $CaCO_3$ to Ca = 100.1/40.1 = 2.5
Ratio of molar mass of $CaCO_3$ to Mg = 100.1/24.3 = 4.1

Hence, total hardness in milligram per liter (mg/L) of $CaCO_3$ = 2.5 x Ca^{2+} in water sample + 4.1 x Mg^{2+} in water sample [31].

2.5. Data analysis

Data obtained were summarized using descriptive statistics and presented in a table. Mean values were compared using one sample t test and values were considered significant at $p < 0.05$. All statistical analysis was carried out using statistical package for social science (SPSS) version 22.

3. Results

The mean values of some physico-chemical parameters, calcium ion, magnesium ion and total hardness of the sampled boreholes from the selected residential clusters are showed in Table 1. Water temperature ranged from 28.50° C to 32.00° C in the untreated samples to 28.00° C in the treated samples. pH increased from 6.94 (slightly acidic) in the untreated sample to 8.26 (alkaline) in the treated sample from St Mulumba after 24 hours. Total dissolved solids was highest (426.00 mg/L) in the untreated sample from Mechanic village and lowest (298.00 mg/L) in sample from Mile 50 after 24 hours of treatment. Conductivity was highest (864.00 µS/cm) in the untreated sample from Mechanic village and decreased in the treated samples with lowest value (602.00 µS/cm) recorded in a sample from Mile 50. Highest (252 mg/L) and lowest (100.00 mg/L) alkalinity was recorded in the untreated and treated sample from PRESCO campus of Ebonyi State University, Abakaliki. Calcium concentration was highest (222.00 mg/L) in untreated sample from PRESCO and lowest (40.00 mg/L) in treated sample from College of Agricultural Science (CAS) campus of Ebonyi State University, Abakaliki. Similarly, magnesium ion concentration was also highest (134 mg/L) in untreated sample from PRESCO and lowest (24 mg/L) in a sample from CAS after 24 hour of treatment. Total hardness recorded was highest (1100.00 mg/L) in the sample from PRESCO and decreased to 503.00 mg/L after 24 hours of treatment but the lowest total hardness (198.00 mg/L) recorded after 24 hours of treatment in sample from CAS. Percentage reduction in total water hardness recorded after 24 hours of treatment was highest (67.11%) in sample from CAS and lowest (28.25%) in sample from St Mulumba residential cluster (Table 1). Meanwhile, difference in the parameters measured in the untreated samples were significant after treatment.

Table 1 Mean values of some physico-chemical parameters and hardness of borehole water of selected residential clusters

Parameters	Treatments (1g/100ml)	Residential Clusters				
		Mile 50	CAS Campus	St Mulumba	Mechanic Village	PRESCO Campus
Temperature (°C)	Untreated	28.50	32.00	31.00	32.00	30.00
	Treated (1hour)	28.00	28.00	28.00	28.00	28.00
	Treated (24 hours)	28.00	28.00	28.00	28.00	28.00
pH	Untreated	7.40	7.16	6.94	7.26	7.49
	Treated (1hour)	7.85	7.91	7.75	7.56	7.49
	Treated (24 hours)	8.26	8.10	8.07	8.17	8.10
P-values		0.0002	0.0003	0.0005	0.0003	0.0002
TDS (mg/L)	Untreated	308.00	325.00	352.00	426.00	390.00
	Treated (1hour)	301.00	311.00	321.00	305.00	415.00
	Treated (24 hours)	298.00	308.00	339.00	389.00	347.00
P-values		0.0001	$2.4x10^{-7}$	$2.1x110^{-5}$	0.0003	$7.7x10^{-5}$
Conductivity (µS/cm)	Untreated	616.00	636.00	697.00	864.00	802.00
	Treated (1hour)	757.00	620.00	642.00	684.00	834.00
	Treated (24 hours)	602.00	618.00	678.00	818.00	694.00
P-values		0.0001	$1.9x10^{-6}$	$1.4x10^{-5}$	0.0001	$9.3x10^{-5}$
Alkalinity (mg/L)	Untreated	190.00	232.00	157.00	232.00	252.00
	Treated (1hour)	202.00	203.00	199.00	194.00	193.00
	Treated (24 hours)	110.00	120.00	120.00	130.00	100.00
P-values		0.001	0.002	0.0008	0.002	0.003
Ca^{2+} (mg/L)	Untreated	161.00	121.00	141.00	161.00	222.00
	Treated (1hour)	121.00	81.00	121.00	121.00	161.00
	Treated (24 hours)	61.00	40.00	101.00	81.00	101.00
P-values		0.003	0.006	0.0004	0.002	0.003
Mg^{2+} (mg/L)	Untreated	97.00	73.00	85.00	97.00	134.00
	Treated (1hour)	73.00	49.00	73.00	73.00	97.00
	Treated (24 hours)	36.00	24.00	61.00	49.00	61.00
P-values		0.005	0.007	0.0005	0.002	0/003
Total Hardness (mg/L) of $CaCO_3$	Untreated	800.00	602.00	701.00	800.00	1100.00
	Treated (1hour)	602.00	403.00	602.00	602.00	800.00
	Treated (24 hours)	300.00	198.00	503.00	403.00	503.00
P-values		0.002	0.003	0.0003	0.001	0.001
Percentage hardness reduction after 24 hours		62.50	67.11	28.25	49.63	54.27
Indication		Hard	Hard	Very hard	Very hard	Very hard

4. Discussion

Groundwater/borehole water has been the major source of water for domestic use within Abakaliki urban due to government's failure to provide portable pipe borne water for domestic use in the past 8 years. In Abakaliki urban, the major problem associated with borehole water is hardness and this may be due to the rock formation and mineral composition of the earth crust underlying the area. Hence, the potential of activated palm bunch biochar on the reduction of water hardness was assessed in water samples collected from five residential clusters within Abakaliki urban, Ebonyi State, Nigeria. The study showed that the water temperature decreased in the treated samples in the laboratory and this could be due to change in environmental temperature. The pH of the water samples became alkaline after treatment for 24 hours. This may be due to the dissociation of the sodium hydroxide used in the activation of the palm bunch biochar thereby increasing the hydroxide ion concentration of the medium. The TDS values recorded in the water during sampling and after I hour of treatment were high which indicated high concentration of dissolved ions[32]. The TDS recorded were similar to that reported by [3, 33] at Kpirikpiri and Amike-Aba area all within the Abakaliki urban, Ebonyi State. However, the TDS decreased in the samples after treatment for 24 hour which indicated that some of the dissolved ions have adsorbed to the biochar, reducing the concentrations in the water samples. Conductivity values recorded at the study sites were also high and are similar to the reports of previous studies within Abakaliki urban by other researchers [3, 33]. High conductivity recorded in the groundwater samples could be due to high concentrations of dissociated ions. The alkalinity level recorded in the water samples collected during the study were high and this could be attributed to high level of carbonate ions present in the bedrock of Abakaliki area. This is evident from the level of calcium ion recorded in the samples collected and had been reported by [34] in his study of the evolution of the Abakaliki and Anambra basin. Concentrations of calcium and magnesium recorded during the study were also high and these could be due to the characteristic sandy limestone, which among other types of formation makes up the bedrock of Abakaliki area [34]. [35] have reported high concentrations of calcium and magnesium ions in borehole water in Abakaliki area of Ebonyi State which they quoted to be above WHO permissible limit for drinking water. High concentrations of calcium and magnesium ions recorded in the water samples were responsible for the high total hardness of the water as the salts of calcium and magnesium are known to be the major causes of water hardness.

The activated palm bunch biochar used in the treatment of the water samples had good potential for hardness reduction. This was evident in the result obtained after 24 hours of treating the groundwater samples from the various residential clusters for 24 hours. There were significant decrease in the total hardness of water samples from all the residential clusters covered during the study. Percentage reduction in total hardness was highest in groundwater sample from CAS campus followed by that of Mile 50 where the hardness was reduced from very hard to hard. Previous studies on water hardness reduction using bio-product was carried out by[26] with alkali extract of banana peels and they recorded decrease in the total hardness of the treated water. Meanwhile, there is yet no report on the use of activate palm bunch biochar in groundwater total hardness reduction to compare with the result of this study. The reason for higher percentage reduction in total hardness recorded in samples from some of the selected residential clusters could not be established as the study did not consider any factor such as pH as did in some other study. pH of the water was not altered for safety reason as the essence of the treatment was to improve the quality of the water for domestic use.

5. Conclusion

This study was carried out to evaluate the potentials of activated palm bunch biochar on the reduction of water hardness in water samples from selected residential clusters within Abakaliki urban. The water samples collected were very hard as indicated in the total hardness values before treatment. There were significant reduction in the total hardness of the samples after 24 hours of treatment from very hard to hard in samples from Mile 50 and CAS residential clusters. This could proffer solution to water hardness problems in affected areas as it might be better alternative to chemical, reverse osmosis, and nanofiltration methods that are expensive and may leave traces of hazardous metals in the treated water.

Compliance with ethical standards

Acknowledgments

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Disclosure of conflict of interest

The authors declare no conflict of interest.

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