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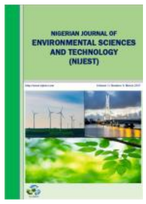

Characterization and Purification of Groundwater Using Carbon Dot Impregnated into Biosand Filters: A Case of Warri and its Environs, Niger Delta, Nigeria

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ABSTRACT

The release of toxic gases and spills into the ecosystem prior to anthropogenic activities can increase the level of pollutants in hydrological systems. This possibly influences the number of harmful substances that percolate into aquifers. The drilling of polluted aquifers for domestic and drinking purposes and consuming such water untreated consequently increases the risk of developing water-related health issues. The study presents the quality and purification of groundwater samples in the Warri metropolis through water-quality analysis and biosand filtration method (Appropriate Technology Enabled Development technique), respectively. The pH results were very low in all the groundwater samples presented with values ranging from 5.16±0.03 to 6.81±0.09, except for table water samples serving as controls. Total iron concentration was above the regulatory limits of 1.00 mg/L in some locations, recording concentrations between 0.758±0.340 mg/L and 1.204±0.740 mg/L. Groundwater samples contaminated with coliform bacteria were recorded in some locations. It suggests that the groundwater quality of the studied locations is relatively poor and unsafe for drinking untreated. This is possibly due to high hydrocarbon exploration and production activities, together with other anthropogenic activities in the area. Nevertheless, the filtration of the groundwater samples with biosand filter effectively improved the taste, reduced the iron content, removed particles, and eliminated microbial contaminations. However, the pH was relatively low after filtration and was further enhanced in the filtration with carbon dots. The carbon dot filtration can be viewed as a better substitute for granites in the filter beds of the biosand filter unit to influence pH conformance.

Keywords: Biosand filter, Carbon dots, Groundwater, Purification, Water quality

1.0. Introduction

The quality of water depends on the physicochemical and biological attributes of the water resources, which in turn depend on the geological setting of the area, and the impacts of human (anthropogenic) activities (Ogeleka et al., 2014; Overare et al., 2016; Eyankware et al., 2021). The significant number of noxious gases, oil spills, and effluent discharge released into the environment as a result of industrial activities, together with other anthropogenic activities generally increase the number of harmful substances in the hydrological systems (Rim-Rukeh *et al*., 2005; Olowoyo, 2011, Isichei *et al*., 2015).

This possibly influences the number of harmful substances that percolate into an aquifer (groundwater). The boring of polluted aquifers for domestic and drinking purposes and consuming such water untreated consequently increases the risk of developing water-related health issues. Safe drinking water is critical to all forms of life despite the fact that it gives no calories or supplements. Access to safe drinking water has improved in the last few decades in most regions of the world; although approximately one billion people still lack access to safe water and over 2.5 billion lack access to adequate sanitation (WHO and

UNICEF, 2021). Safe drinking water is characterized as water with microbial, chemical, and physical qualities that meet the World Health Organization (WHO) benchmarks on drinking water quality (WHO, 2011; Ogeleka and Rukeme, 2018). Kulshreshtha (1998), estimated that by the year 2050, more than half of the world's population will be facing water-based susceptibility. Furthermore, a study by Baroni *et al*. (2007) suggested that by 2030, water demand will be more than supply by 50% in some developing regions of the world. Water plays a crucial role in the world's economy since it functions as a solvent for a myriad of chemical substances, facilitates industrial cooling, and aids transportation, and agricultural applications. Most importantly, humans need potable water for drinking, cooking, and personal cleanliness amongst other domestic uses.

Although water is indispensable, it serves as the commonest route for the transmission of various types of water-related diseases namely cholera, typhoid, diarrhea, dysentery, etc. Consequently, water quality must be guaranteed before utilization, hence, the water we drink must be safe.

The activities of the producing companies with other human activities in the Warri metropolis, induced significant gas flaring, oil spills, and effluent discharges that possibly have impaired the groundwater quality in the study area. To make the borehole water in Warri and its environs potable, it is necessary to carry out a purification routine to make the water safe for consumption. Hence, this study tested a simple method of water purification by using a low cost-effective Appropriate Technology Enabled Development (ATED) technique – carbon dot (class of carbon nanomaterials with particle sizes of < 10 nm) impregnated into a biosand filter to eliminate pollutants in the water before it is used for drinking and domestic applications. Here, the biosand filter is a modification of the traditional slow sand filter that has been essentially used for water treatment.

1.1. Geological and physiographical setting of the area

The sampling areas lie between latitude N05° 34′ 10′ and N05° 34′ 30″ and longitude between E05° 40′ 42″ and E05° 50′ 27″. The area of study comprises Warri, Effurun, and Udu within the western Niger Delta ecological zone of Nigeria (Figure 1).

Warri and its environs where the studied samples were obtained are part of the lower deltaic plain and freshwater swamps deposit physiographic province as described by Odemerho and Ejemeyovwi (2007) (Figure 1). The low province rises gradually from less than 9 m (29.53 ft) above sea-level in the west to about 25 m (82.02 ft) above sea-level at its eastern boundary (Akpoborie, 2011). The work of Akpoborie, (2011), subdivided the province into three distinguishable landform associations: the southern lower Niger flood plain, which is made up of beach ridge, brackish water swamp, and part of the freshwater swamp, characterized by the fluvial landscape and dominated by various streams and oxbow lakes (Figure 1). The second landform association is the north-central (Sombreiro-Warri) deltaic plain that contains numerous freshwater swamps (Figure 1). The third association occupies the northeast which is made up of coastal plain deposits of Benin, Ogwashi-Asaba, and Ameki Formations, and part of the freshwater swamp (Figure 1).

The area of study occupies the southern lower Niger flood plain and the north-central deltaic plain deposits. The freshwater swamp and the Sombreiro-Warri deltaic plain deposit constitute the shallow aquifer of less than 27.43 m (90 ft) depth that is essentially extracted by percussion "hand-drilled" borehole and dug wells. These are major water sources of supply for domestic and industrial use in rural and urban communities, where the deposits underlie the Niger Delta region (Amajor, 1991; Nwajide, 2013). These deposits are of the Holocene age, overlying the Benin formation that constitutes the deep aquifer and is the water-bearing formation of the Niger Delta Basin. Benin Formation is the youngest formation of the basin that is composed of sand-gravel facies and underlain by the alternating sand-shale facies Agbada and shale facies Akata Formations (Short and Stauble, 1967; Nwajide, 2013; Ogbe, 2021).

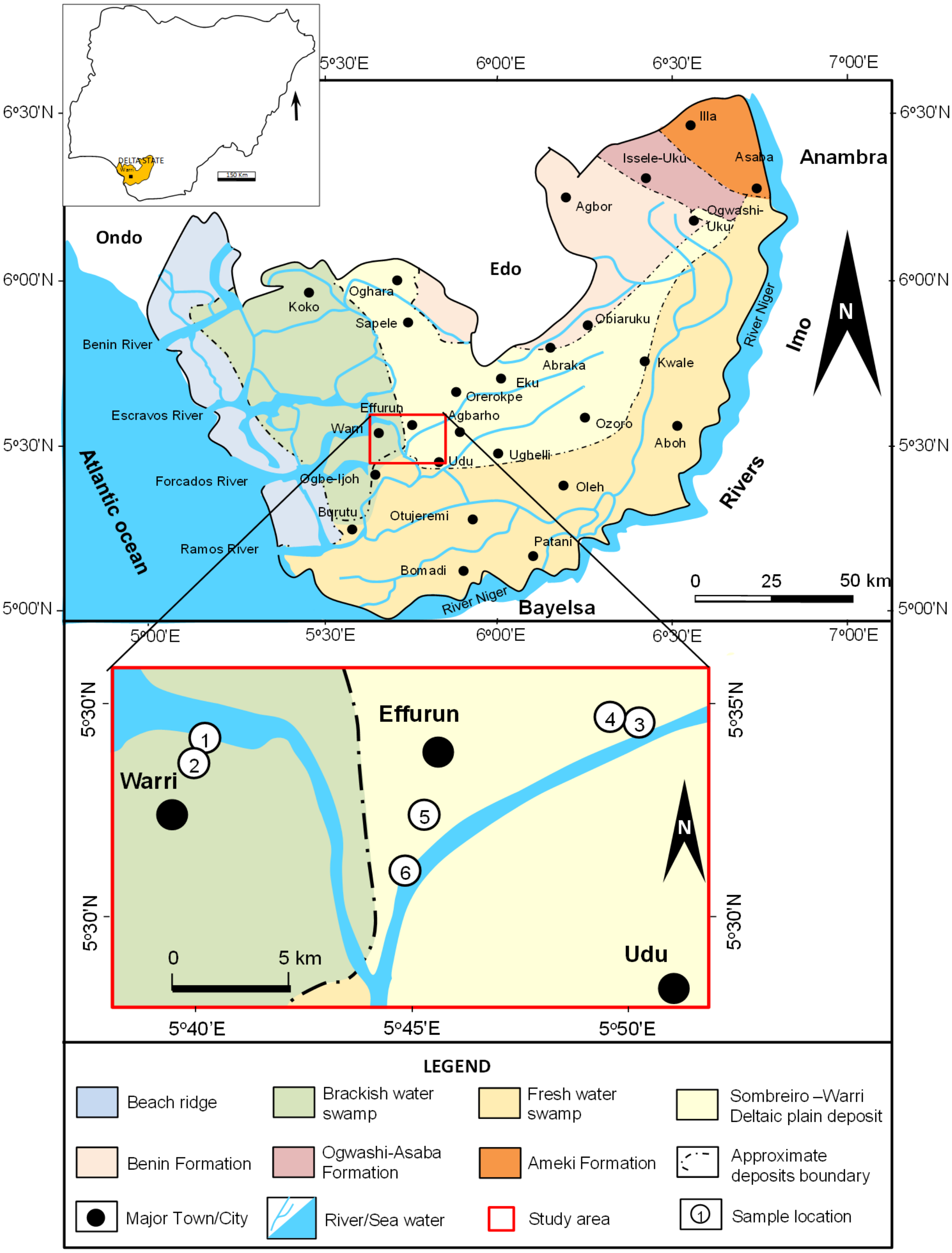

Figure 1: Map of the study area showing the geological and physiographical map of the western Niger Delta Region (Delta State) (Modified from Akpoborie, 2011)

2.0. Methodology

2.1. Water sampling

To ascertain an error-free investigation, sample integrity was maintained, and able to trace possession and handling of the sampling from the collection of samples through analysis to data verification and validation. Samples for ex-situ analysis were delivered to the laboratory in a state free of contamination (APHA, 2017).

A total of 48 water samples were collected from the area of study and each sample is made up of eight (8) replicates (Figure 1). The samples were collected by a cross-sectional mapping of the study area for both the physio-chemical, inorganics and microbial analysis. The water samples from Egbokodo Itsekiri (Aje and Edum Communities) were collected from boreholes (untreated) and biosand filters (treated) by residents already using the biosand filters. In addition, untreated water samples were collected from the premises of the Federal University of Petroleum Resources, Effurun (FUPRE), Nigeria, while table waters were sampled as controls. Plastic containers were used for the different types of samples, using recommended preservation mechanisms as shown in Table 1. The samples' temperature, pH, temperature, electrical conductivity, and total dissolved solids were determined in-situ, while salinity, iron, and microbial analysis were determined ex-situ in the laboratory of the Department of Chemistry, Federal University of Petroleum Resources, Effurun in accordance with APHA standards (Table 2).

Table 1: Sample type, containers, and sample preservation techniques

Sample type	Containers	Preservative
Physico-chemical	Plastic	Cooling at 4ºC
Metals	Plastic	1-2 mL of 1:1 HNO_3
Microbial	Plastic	Sodium thiosulfate ($Na_2S_2O_3$)

Table 2: Analytical methods for parameters determined in this study

Parameters	Analytical Methods
pH	pH, (APHA 4500 H^+
Temperature, ºC	Thermometer (APHA, 2550-B)
Total dissolved solids (TDS), mg/L	TDS (APHA 2540-C)
Salinity (Cl^-), mg/L	Mohr's Argentometric method (APHA 4500 Cl-B)
Conductivity, µS/cm	Conductivity (APHA 2510 B)
Total hardness	EDTA titrimetric method (APHA 2340 C)
Turbidity	Nephelometric Method: (APHA – 2130-B)
Metals	Atomic Absorption Spectrophotometer (AAS) (APHA – 3111-B)
Determination of Total Coliform Bacteria	Multiple Tube Test (APHA 9222A)

2.2. Determination of metals in water samples

The water samples from the different locations were appropriately homogenized and 250 ml was transferred into a beaker and 5 ml of concentrated nitric acid (AR) was added. The samples were digested on a hot plate until the volume was reduced to between 15 and 20 ml. This solution was cooled, filtered, and diluted to 50 ml with double distilled water (APHA, 2017). The metals to be analyzed in the water samples were quantified with the aid of a Schimadzu Flame Atomic Absorption Spectrophotometer (AAS) model AAS-6701F.

2.3. Biosand filter– an Appropriate Technology Enabled Development (ATED)

The biosand filter was inspired by the Canadian model and imported into Nigeria to assist rural communities, who are prone to harm from drinking low-quality water to filter their untreated water and make it safe without resorting to chemicals or other expensive purification methods. A Nigerian model for domestic use was constructed by the Foundation for Partnership Initiatives in the Niger Delta (PIND) and Coastal and Marine Areas Development Initiative (CMADI) with cheap and locally available materials using ATED. The biosand filter design employed in this study is meant to provide potable water for consumption (Figure 2). The design consisted of a 6000 L capacity tank made of plastic. The filtered water from the biosand filter (Figure 2) can only be consumed after a curing period of 21 days to allow non-pathogenous bacteria to grow and predate the harmful bacteria in the water, thus eliminating the disease-causing bacteria (Enamul-Kabir *et al.*, 2016).

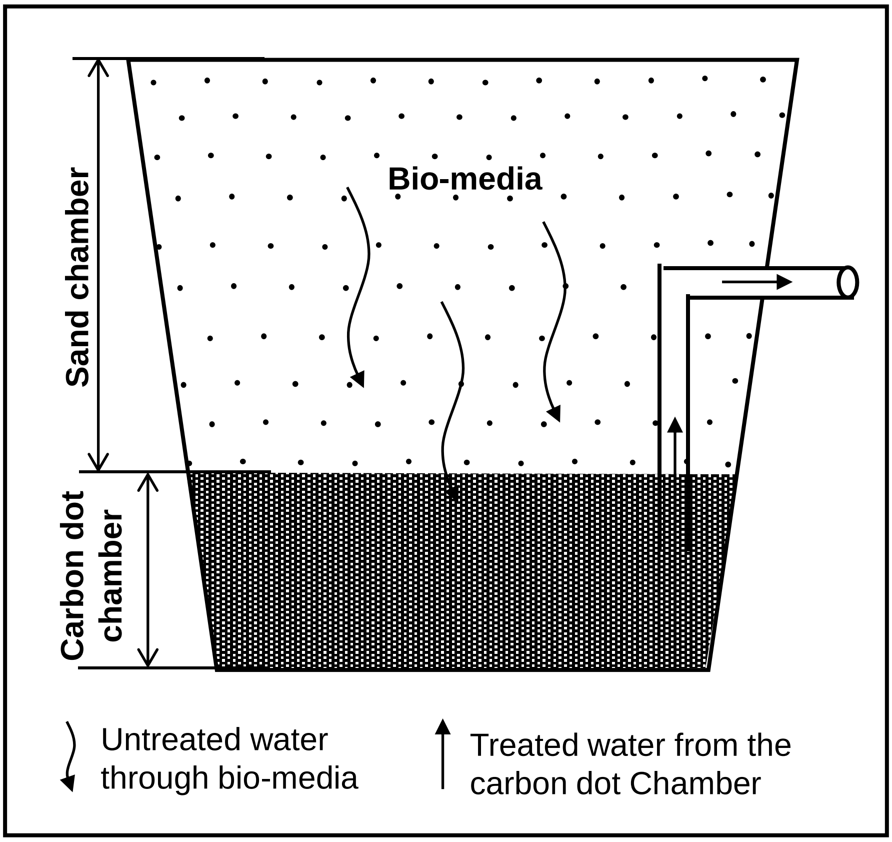

Figure 2: Schematic diagram of the biosand filter (BSF)

2.4. Synthesis and characterization of carbon dots from Daniella ogea

To ensure quality purification of the untreated water samples, carbon dots were used because they have a large surface area and enhance photostability and are chemically inert. A weight of 1.0 kg of *Daniella ogea* (carbon source) was burnt for about 3 hours to get a charcoal bulk, which was crushed using mechanical milling to obtain a fine powder. The crushed particles were carbonized in a furnace at 600°C. This was allowed to cool, and 500 mL of water was added, stirred, and filtered. Using the hydrothermal process, the carbon filtrate was heated on a magnetic stirrer at 400°C for 3 hours in a closed system to further reduce the particle size (Figure 3). The extract was viewed under UV light and blue color was radiated showing the property of carbon dots. Similarly, the extract was centrifuged to get precipitate which was evaporated to obtain the carbons dots (CDs). The carbon dots were stored in a clean dried container until required for characterization using scanning electron microscopy (SEM) and transmission electron microscopy (TEM) (Annan *et al.*, 2018) (Figures 4 and 5).

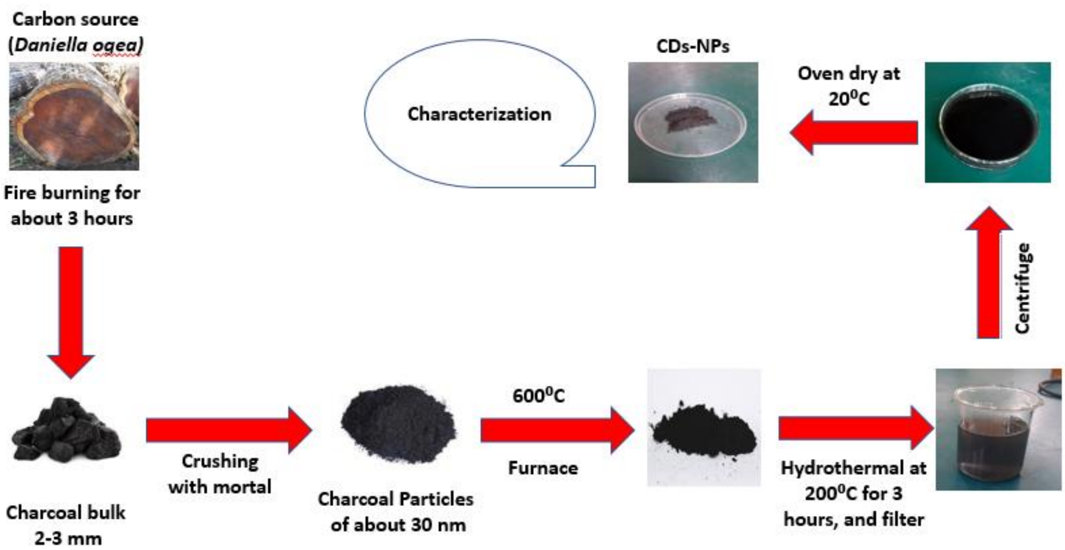

Figure 3: Schematic diagram of the synthesis of carbon dots

Table 3: Characterization techniques for carbon dots

Techniques	Utility	Model	Reference
Scanning electron microscopy (SEM)	Shape and image formation	Quanta FEG 250 SEM	Jelinek, 2017; Annan *et al.*, 2018
Transmission electron microscopy (TEM)	Detect actual shape, size, and identify NPs in matrices	JEOL2100 TEM	Jelinek, 2017; Annan *et al.*, 2018

2.5. Filtration of the water using carbon dots and marble

To establish conformance for pH in this study, two samples were experimented: one from the FUPRE hotel premises and the treated sample from Aje Community, where a non-conformance was reported for pH even after filtration with the biosand filter. The water sample was passed through a carbon dots or marble ($CaCO_3$) filter bed with a reservoir at the base, where the eluate (filtrate) was collected for analysis. The filtrate was then analyzed for pH and some in-situ characteristics to ascertain the effectiveness of the filtration process. This was done as a basic filtration strategy to justify supplanting the biosand channel with carbon dots/nanoparticles rather than granites, which is currently utilized in some biofilters.

2.6. Statistical analysis

Data analysis was performed using Analysis of variance (ANOVA) in Statistical Package for Social Science (SPSS), IBM software (version 22). Column charts and similar graphs were used as a pictorial representation of the water assessment results.

3.0. Results and Discussion

This section contained the results of physicochemical, anions, cations, and microbial analysis for potable water obtained from the study area. The detailed results for the various determinations are presented in Figures 4–9 and Tables 4–6.

3.1. Results of Scanning and Transmission Electron Microscopy for Carbon dots Analysis

The results for SEM and TEM are shown in Figures 4 and 5. The scanning electron microscopy (SEM) image of the synthesized carbon dots indicated spherical morphology typical of carbon dots (Figure 4). Similarly, transmission electron microscopy (TEM) characterization gives information about the size distribution, and shape of any nanomaterial (Figure 5). Figure 5 showed the spotted spherical and monodisperse image of the synthesized C-dots with an average narrow size distribution having a particle of 10 nm, which is typical of the size range for carbon dots (1-10 nm).

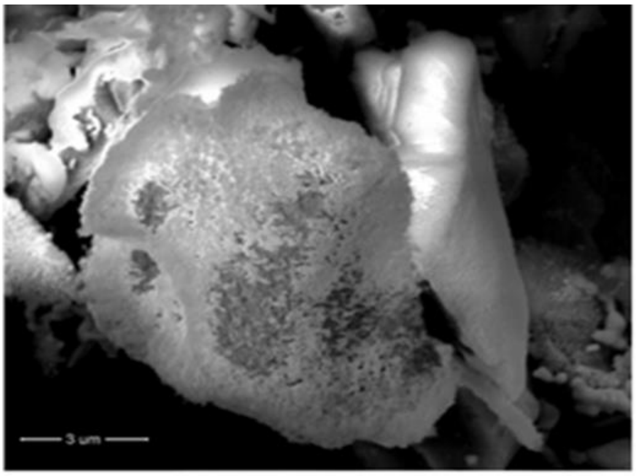

Figure 4: Scanning Electron Microscopy (SEM) image of carbon dots

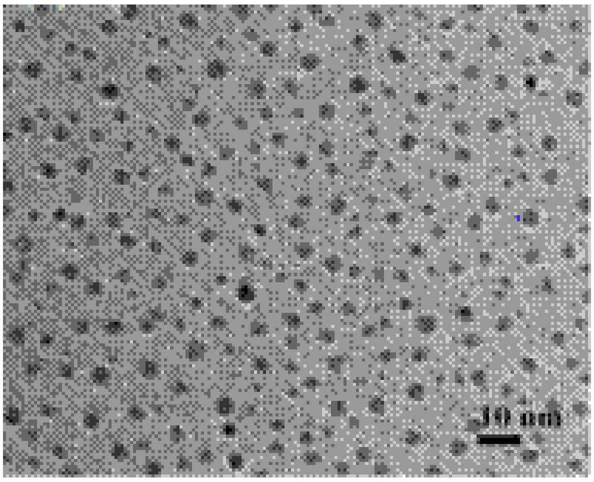

Figure 5: Transmission Electron Microscopy (TEM) image of C-dots

3.2. Physico-chemical, metals, and biological analysis

In all the groundwater samples except the table water, very low pH results were recorded. The pH values obtained in the samples ranged from 5.16 ± 0.03 to 6.81 ± 0.09 (Table 4). The filtration with the biosand filter effectively improved the taste, removed particles, and eliminated microbial contaminations; however, pH was still relatively low and in non-compliance with the WHO standard pH range of 6.5 to 8.5 recommended for potability (Annan *et al*., 2018).

The values of electrical conductance range from a minimum of 23 ± 1.4 μS/cm for the FUPRE Earth Science premises water to a maximum of 85.4 ± 8.4 μS/cm for the Eva table water. Total dissolved solids (TDS) concentration varied between 11.5 ± 0.05 mg/L and 42.7 ± 2.3 mg/L. The water was not turbid as revealed in the data obtained for turbidity, which varied from 0.14 ± 0.04 NTU to 0.57 ± 0.06 NTU (Table 4).

Salinity concentrations ranged from 2.59 ± 0.14 mg/L to 14.7 ± 0.82 mg/L (Table 5), an indication that the water from the sampling locations was considered ''fresh''. Freshwater has less than 500 parts per million (ppm or mg/L) or <0.50 ppt of dissolved salts.

Total iron concentrations were above the regulatory limits of 1.00 mg/L in some locations. In Aje and Edum Communities before and after biosand filtration, the concentrations recorded were between 0.758 ± 0.34 mg/L and 1.204 ± 0.74 mg/L, respectively. The Edum Community water had the highest iron concentration of 1.204 mg/L before filtration. However, the iron content was reduced after passing through the biosand filtration. A value of 0.758 mg/L was recorded for Edum Community after passing through the biosand filtration. The value for the non-conforming sample was above the WHO/DPR/FME/NT 09.14 upper limit of 1.00 mg/L by 0.204 mg/L. The other heavy metals (cadmium, lead, and copper) had concentrations below the detection limit of the measuring instrument (Table 5).

In the presumptive count, out of the 8 samples analyzed only one sample (Edum Community) was contaminated with fecal coliform bacteria. However, after filtration, the water was free of total coliforms (Table 5).

Table 4: Average results of in-situ analysis of the water samples from the study area.

Sample/Parameter	WHO'S Max Acceptable limit	WHO'S Max Allowable	DPR Standard	FME Standard	NT 09.14 Standard	Aje community Before BSF	Aje community After BSF	Edum community Before BSF	Edum Community After BSF	FUPRE hostel premises	FUPRE Earth Science premises	Eva water	VIO water
pH	6.5-8.5	6.5-8.5	6.5-8.5	6.5-8.5	6.5-8.5	5.19 ± 0.04	5.6 ± 0.07	5.53 ± 0.02	5.69 ± 0.05	5.16 ± 0.04	5.16 ± 0.03	6.81 ± 0.09	6.67 ± 0.07
Temperature (°C)	N/A	N/A	25	25	N/A	26.3 ± 0.02	24.4 ± 0.02	26.2 ± 0.04	26.3 ± 0.03	26.4 ± 0.06	27.7 ± 0.05	26.6 ± 0.04	27.9 ± 0.02
TDS	1500	1500	N/A	2000	1500	23.65 ± 1.40	22.75 ± 1.3	17.45 ± 0.90	30.05 ± 2.4	11.8 ± 0.07	11.5 ± 0.05	42.7 ± 2.3	28 ± 1.8
Conductivity	250	N/A	N/A	N/A	N/A	47.3 ± 2.3	45.5 ± 1.7	34.9 ± 1.4	60.1 ± 5.6	23.6 ± 1.6	23 ± 1.4	85.4 ± 8.4	56 ± 4.9
Turbidity NTU	5	5	N/A	10	5	0.56 ± 0.07	0.46 ± 0.04	0.3 ± 0.02	0.14 ± 0.04	0.31 ± 0.02	0.57 ± 0.06	0.15 ± 0.02	0.15 ± 0.03

BSF = biosand filter; TDS = Total dissolved solids (FEPA, 1991; DPR, 2002; WHO, 2011; INNORPI, 2018).

Table 5: Average results of physico-chemical, anions, cations, and biological parameters of the study area

Parameters	WHO'S Max Acceptable limit	WHO'S Max Allowable limit	DPR Standard	FME Standard	NT 09.14 Standard	Aje B (BSF)	Aje A (BSF)	Edum B (BSF)	Edum A (BSF)	FUPRE hostel premises	FUPRE Earth Science premises	Eva table water	VIO table water
Salinity mg/L	200	600	N/A	600	2500	10.38 ± 0.06	9.51 ± 0.04	7.78 ± 0.04	5.19 ± 0.03	3.46 ± 0.02	2.59 ± 0.14	14.7 ± 0.82	5.19 ± 0.04
Total Hardness mg $CaCO_3$/L	500	500	N/A	N/A	500	10.00 ± 0.10	6.00 ± 0.05	4.00 ± 0.02	8.00 ± 0.10	4.00 ± 0.02	4.00 ± 0.02	17.00 ± 0.50	4.00 ± 0.02
Metals													
Total calcium mg of $CaCO_3$/L	0.05	1.5	1.5	1.5	2	4.00 ± 0.02	2.4 ± 0.01	1.6 ± 0.01	3.2 ± 0.02	1.6 ± 0.01	1.6 ± 0.01	6.81 ± 0.06	1.6 ± 0.01
Total magnesium, mg of $CaCO_3$/L	0.05	1.5	1.5	1.5	1.5	0.97 ± 0.04	0.48 ± 0.02	0.48 ± 0.02	0.48 ± 0.02	0.48 ± 0.02	0.24 ± 0.01	1.69 ± 0.02	0.48 ± 0.02
Total Iron, mg/L	0.3	1.00	1.00	1.00	1.00	1.142 ± 0.64	1.034 ± 0.44	1.204 ± 0.74	0.758 ± 0.34	0.981 ± 0.48	0.963 ± 0.42	<0.001	<0.001
Cadmium, mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Lead, mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Copper, mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Microbiological													
Total Coli form MPN/100 mL	Nil	Nil	N/A	N/A	Nil	Nil	Nil	2 ± 1	Nil	Nil	Nil	Nil	Nil

A = untreated water (before filtration through BSF); B = treated water (after filtration through BSF); BSF = Biosand filtration

3.3. pH values for filtration of water using biosand filters fitted with granite

The pH results obtained for the water samples from two locations - Aje and Edum (before and after filtration) with the biosand filter showed that the biosand filter with sand and the two different diameters of granite made no significant influence on the pH since values were still below the lower regulatory norm of 6.5. pH values of 5.19 ± 0.04 (Aje Community before filtration) and 5.6 ± 0.07 (Aje Community after filtration) was recorded while 5.53 ± 0.02 and 5.69 ± 0.05 were reported for Edum Community before and after filtration respectively. These pH values indicated that the biosand filter using granite did not significantly impact the pH values, which was still a non-conformance (Figures 6 and 7).

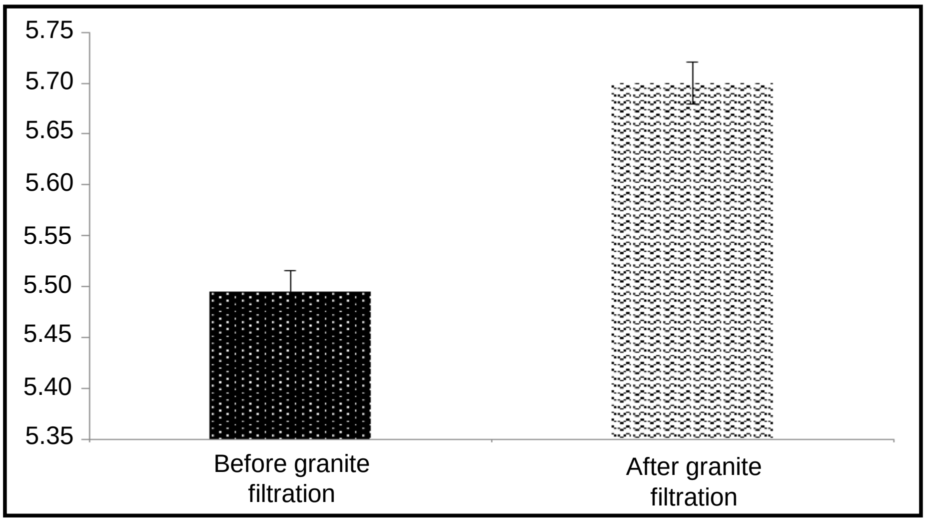

Figure 6: Comparison of pH for Aje Community water before and after filtration with biosand filter

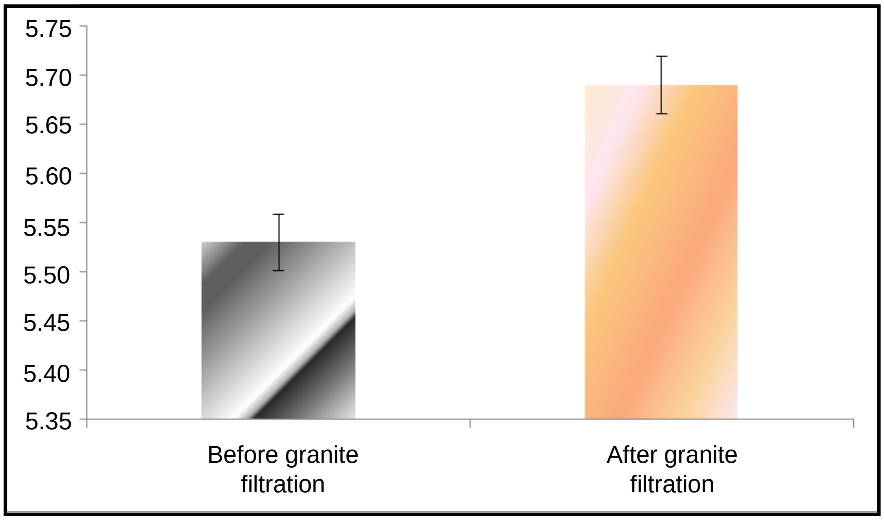

Figure 7: Comparison of pH for Edum Community water before and after filtration with biosand filter

3.4. pH values for filtration of water using carbon dots

Based on the results for pH reported in most of the water samples, which were below the standard of 6.5 to 8.5 stipulated by the regulatory authorities – [World Health Organization (WHO), Department of Petroleum Resources (DPR) - Nigeria, Federal Environmental Protection Agency (FEPA) - Nigeria, Institut National de la Normalisation et de la Propriété Industrielle (INNORPI) - Tunisia] (WHO, 2011; DPR, 2002; FEPA; 1991, INNORPI, 2018), we opted for two methods of filtration; one using carbon dots and the other using marble ($CaCO_3$). The filtration was carried out to reduce CO_2 in the water since the free CO_2 could likely be responsible for the acidity of the water and the relatively low pH.

It was noted that the experiment with marble showed no significant difference between the pH values before and after filtration, and as such the marble experiment was discontinued. However, the results for carbon dots indicated that there was pH enhancement (increased) when compared to the samples before filtration (Table 6). We opted for carbon dots because it was cheap and inert (non-reactive). Similarly, a fundamental quality was that it had the proficiency to increase the pH value and neutralize the water without the use of any form of chemicals. Carbon dots was able to reduce the acidity of the water, a major problem associated with the aquifers in Warri and similar areas in the Niger Delta (Figures 8 and 9).

Table 6: Results for filtration of water using carbon dots

	Aje community		FUPRE Hostel premises	
	Before filtration	After filtration	Before filtration	After filtration
pH	5.19 ± 0.04	6.97 ± 0.09	5.16 ± 0.04	6.89 ± 0.07
Temperature (°C)	26.3 ± 0.02	26.4 ± 0.10	26.4 ± 0.06	26.3 ± 0.06
TDS, mg/L	23.65 ± 0.44	120 ± 25	11.8 ± 0.07	68.45 ± 15
Conductivity (μS/cm)	47.3 ± 0.23	240 ± 34	23.6 ± 0.16	136.9 ± 20

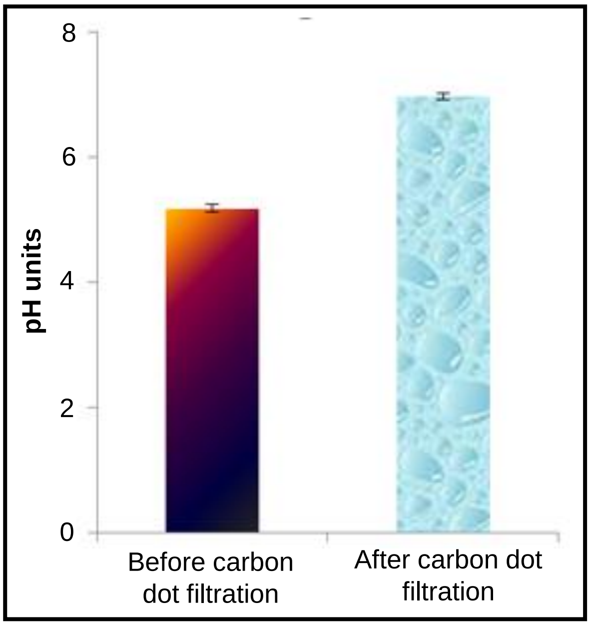

Figure 8: Influence of carbon dots on pH for Aje Community

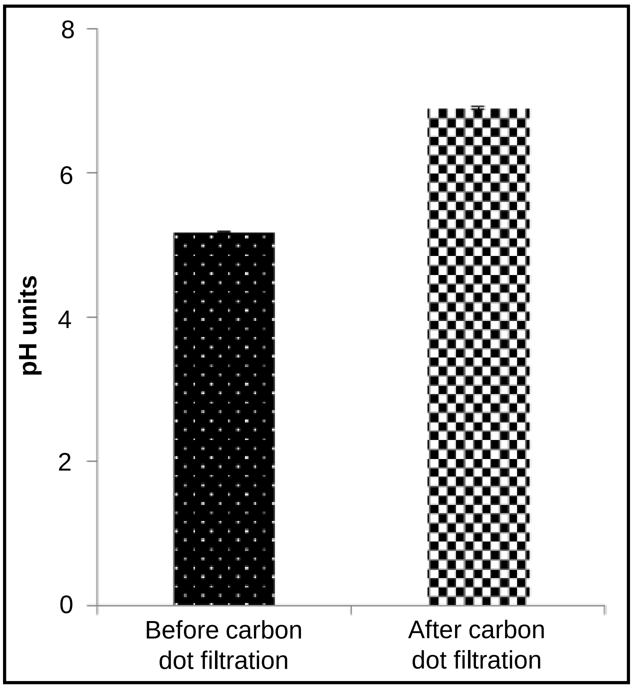

Figure 9: Influence of carbon dots on pH for FUPRE hostel premises

From the results obtained, the pH values for most of the water samples were acidic and in non-conformance with the WHO/DPR/FME/NT 09.14 standards of 6.5-8.5. In addition to the unpleasant foul/metallic taste impacted on water, low pH (acidic) water can corrode plumbing systems and release toxic metals such as iron, manganese, copper, lead, and zinc into water. Similarly, over-ingestion of highly acidic untreated water with a heavy metal load from corroded pipes can result in a myriad of health-related issues including gastrointestinal upset, severe stomach, and abdominal disorders, etc. not to mention nausea, diarrhea, and similar ailments in sensitive consumers. The World Health

Organization (WHO) / United Nations Children's Fund (UNICEF) and other authors have confirmed the health implication of drinking highly acidic water (WHO/UNICEF, 2017; Olobaniyi and Efe, 2007; USGS, 2018).

Chloride is present in a considerable concentration in all-natural water. The permissible limit of chloride according to WHO/DPR/FME/NT 09.14 is 600 mg/L with a WHO concentration of 200 mg/L. A high amount of chloride may impair taste, a salty or saline condition, and a likely indication that the water may likely be polluted with substances of organic origin. The value of chloride is an indication that the water from all the sampling locations was ‘‘fresh’’. Freshwater can be viewed as water with less than 500 parts per million (ppm or mg/L) or <0.50 ppt of dissolved salts. The results showed that all the values obtained for this study were within the WHO/DPR/FME/NT 09.14 recommended standard.

Turbidity has no health effects; it can interfere with disinfection and provide an environment and/or medium for microbial growth. Contaminated water with high turbidity values may imply an environment hosting disease-causing microorganisms such as bacteria, viruses, and parasites. Thus, consuming such water could likely result in a myriad of water-borne diseases namely dysentery, diarrhea, cholera, typhoid, and other health symptoms such as nausea, cramps, associated headaches, etc. (WHO, 2011). At high levels, turbidity can also lead to staining of materials, fittings, and laundry exposed during washing. In addition, most consumers equate turbidity with a measure of safety and consider turbid water as unsafe to drink (APHA, 2017; (Dietrich, 2006; WHO/UN, 2017).

Iron has little concern as a health hazard but can still be considered a nuisance in excessive quantities. Water with high iron concentration has an unwanted bitter, astringent, or metallic taste (UNICEF, 2008; WHO, 2011). The WHO has set the permissible limit of iron as 0.3 mg/L. The major concern is toxicity to humans since there could be a probability of threat to human health by consuming water with a relatively heavy metal load daily (UNICEF, 2008; Ogeleka and Rukeme, 2018).

Sustainable quality water and sanitation for all is goal #6 of the United Nations General Assembly adopted "universal, integrated and transformative" 2030 Agenda for Sustainable Development with a set of 17 Sustainable Development Goals (SDGs) that need to be achieved by the year 2030. Sustainable development is a development that meets the needs of the present without compromising the ability of future generations to meet their own needs (WHO, 2017). Using the biosand filter Appropriate Technology Enabled Development method for ensuring safe and quality water would assist in ensuring and accomplishing available and sustainable management of water and sanitation for all before the desired period. Generally, the presented results are in concordance with those obtained by previous studies (e.g., Sorlini et al., 2015; Enamul-Kabir et al., 2016; Ogeleka and Emegha, 2020).

4.0. Conclusions

The brackish water swamp and the Sombreiro-Warri deltaic plain deposits’ aquifers around Warri are relatively polluted and unsafe and unfit untreated for human consumption. The study shows that carbon dots are impregnated in biosand filter, an Appropriate Technology Enabled Development technique adopted by this study is a good method of treating contaminated groundwater to potable water in Warri and its environs. The filtration with biosand filter effectively improved the taste, remove particles, and eliminated microbial contaminations from the filtered water, however, pH was still relatively low which was further enhanced (increased) in the filtration with carbon dots. The carbon dot filtration can be viewed as a better alternative to granite and should be used to replace granites in the filter beds (layers) of the BSF unit that is currently in use in most residences since it was able to influence pH to conformance. Similarly, the biosand filter also effectively reduced the iron content in the water that is Fe^{3+} (soluble) reduced to Fe^{2+} (solid - precipitate).

Since it is unsafe to consume untreated water with low pH and high iron content, coupled with the associated risk, which may lead to a myriad of health challenges, it is, therefore, necessary to use biosand filter in residences as a simple non-expensive ATED to make water potable and save lives.

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