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BIOPHYSICOCHEMICAL EFFICIENCY OF A LOCALLY DESIGNED SEWAGE SYSTEM FOR TREATMENT OF IMPACTED WATERS OF SOMBRIERO RIVER IN NIGER DELTA, NIGERIA

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ABSTRACT

The efficiency of a locally designed sewage treatment plant was tested, using untreated sewage water samples from Sombriero River in the Niger Delta region of Nigeria. A two-week field reconnaissance campaign was carried out in order to identify areas to be sampled, and delimit hot spots of open river defecation. Composite samples were thereafter collected within an interval of four weeks (on weekly basis). All biological and physicochemical parameters were determined according to standard analytical methods for examination of water and wastewater. The efficiency in the removal of the sewage load was found to be significantly high ($P \leq 0.05$) as corroborated by the evaluated indicator parameters, which showed an average removal efficiency of >70%; PO4-P (phosphorus as phosphate) removal recorded the highest efficiency of 98.6%. Dissolved Oxygen (DO) for the untreated sewage water ranged from 3.1 - 3.8mg/l (with an average DO of 3.45mg/l±0.31); while Biochemical Oxygen Demand within 5 days (BOD5) was in the range of 1.2 - 1.4mg/l, with an average of 1.33±0.1mg/l in the untreated sample. The treated sample gave an average DO and BOD5 values of 4.83±0.17mg/l and 2.20±0.26mg/l respectively. An acidic pH range of 5.1 – 5.7 measured in the untreated sewage water similarly transformed to a near to neutral pH range of 6.4 - 7.1, after treatment. The treatment plant also demonstrated substantial efficiency in enhancing the metabolic activities of indicator organisms, as evidenced in the population densities of Escherica coli, Streptococcus spp., Clostridium spp., Total coliform, and Fecal coliform (in Most Probable Numbers per 100 Millilitres). On the strength of its overall efficiency and environmental friendliness, the locally designed plant can be deployed in-situ for the treatment of the impacted hot spots of the Sombriero River. Also, due to the high human fecal contamination detected in this work, there is an urgent need for government and development stake holders in the oil rich Niger Delta to adopt sanitation security models that would guarantee critical infrastructures which discourage open sea defecation and promote healthy living conditions in the rural riverine communities. Such critical interventions by government and stakeholders in the Niger Delta should include, inter alia, the provision of toilet amenities and the immediate development and deployment of this locally designed treatment plant.

Keywords: Locally designed Sewage plant, engineered sewage treatment system, efficiency, physicochemiocal parameters, indicator organisms

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Introduction

The Niger Delta is the largest wetland in Africa, and most of its watercourses are situated within its communities [1]. These watercourses have lost their natural aesthetics and domestic usages due to pollution.

Most of the rivers in the region serve as waste bins and sewage troughs for defecation and environmental despoliation. Whereas the people are naturally deemed rich on account of oil and gas exploration, being a petroliferous region, the reality on ground is that of abject poverty as a result of either complete deprivation or the near absence of basic socio-economic amenities. The absence of such legitimate uses of the environment may not only lead to community pressure and restiveness, but may also encourage uncouth behavioural attitudes such as the unethical practices of open defecation along the waterways.

In the absence of sanitation infrastructures, such as toilets, people use forests, open fields, open water bodies or other open places for defecation. About 892 million people or 12 percent of the global population practice this [2], and in the riverine areas, open bodies of waters are known to be the most patronized. The Sombriero River is one of such open water bodies in the riverine area of Niger Delta degraded by open defecation. World Bank statistics suggest that regions with high rates of open defecation experience tremendous problems in terms of sanitation and proper waste management [3]. It goes without saying therefore that these unwholesome practices have their thrusts on environmental health and hygiene.

Justifying the use of any engineered treatment system for such sewage sinks or despoiled water resources such as the Sombriero waters, requires a clear distinction of its definitive advantages, bearing in mind that the purpose of such treatments in any municipality or region is to attain certain objectives which depend on local requirements. These advantages may include economic advantages, positive functioning of treatment processes, and higher efficiency of treatment for more satisfactory results. It is for this reason that the impacted waters of Sombriero was used to test run the biophysicochemical efficiency of our locally designed sewage treatment system.

It is known that an efficient treatment method is based on the physical, chemical and biological characterization of the water [3-7]. Therefore it is necessary and expedient to evaluate the efficiency of our treatment technology based on its ability to stabilize sewage induced physicochemical and biological alterations, as the case may be.

The open defecation hotspots as identified and delimited upon reconnaissance surveys of the Sombriero River have thus provided a good platform for evaluating the efficiency of our design. If found efficient, it is hoped that this locally designed facility can be fully deployed to the treatment of the impacted hotspots of the Sombriero River and other areas with similar indices, as the ones tested in this work.

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Results and Discussion

The results of the biological and physico-chemical properties are as collected in Figures 3 – 6 and Table 1 respectively. Generally, the entire determination of the efficiency of the treatment system depends on the performance of the treatment plant in terms of the average removal of the indicator parameters, including TDS, COD, BOD_5 and the other biological and physicochemical indices evaluated in the work.

Biological Properties

Validation campaign of the efficiency of any treatment plant is governed by the biological regime of the entire treatment process of the test plant. The preponderance of the identified organisms in Figs 3-6, *viz Escherica coli, Streptococcus spp., Clostridium spp., Total coliform, Faecal coliform*, indicates the level of biological activity in the water, and therefore the dynamics of its *phys-chem*. There is a marked decrease in the biological activity as the water samples get treated (*cf*: Figs 3-6). This presupposes a higher presence of the organisms in the untreated sewage water sample than in the treated and borehole samples, as corroborated by their population densities. The treated samples had an average population density of 1.0 Most Probable Number per one hundred millilitres (MPN/100ml) for *E. coli*, 0.75MPN/100ml for *Strept*., 8.0MPN/100ml for *T. coli* and 1.0MPN/100ml for *F. coli* as against 18. 25MPN/100ml (*E. coli*), 18.75MPN/100ml (*Strept*), 14.25MPN/100ml (*Clostri.*), 442.5MPN/100ml (*T. coli*) and 352.5MPN/100ml (*F. coli*) respectively in the sewage sample. There was a significant reduction ($P \leq 0.05$) in the population densities of *T. col* and *F. col*. These marked differences in the population densities of the microflora are known to play a critical role in the biogeochemical cycle of the entire ecosystem owing to the dynamic influence of the metabolic activities of the organisms [6]. The significantly high average bacterial load of the fecal coliforms of the sewage water sample also provides substantial evidence of the human fecal contamination of the Sombriero River.

Physico-chemical indices

1. pH

pH, a measure of the acidity or alkalinity of the water, is one of the secondary indicator parameters used for the assessment of the treatment process. Generally, a pH range of 5.1- 5.7 (with an average of 5.5) is acidic, and less tolerable compared to the final treated sample with a near to neutral pH of range of 6.4-7.1 (*cf*: Fig. 2).

pH affects many chemical and biological process in water. Though different organisms flourish within different pH ranges, primary fish-production processes are affected when the pH is either very low or higher than 8.5. A low-pH (acidic) medium can allow toxic elements and compounds to become mobile and 'available' for uptake by aquatic plants and animals [6-10].

The acidic pH regime of the sewage water sample portends danger to the acquatic organisms in the monitored sites of Sombriero river. However, the neutral pH of the treated water affirms the deacidification and neutralization of the treatment process. A plausible explanation to the low pH regime might be the influx of the metabolic by process of the organic load from the sewage as indicated by the high population density of the microrgsnisms. This by product, possibly a carboxylic acid, may have increased the acidity of the system, as indicated by the low average pH of 5.5 measured.

2. Dissolved Oxygen and Biochemical Oxygen Demand (DO and BOD_5)

The Dissolved Oxygen (DO) range for the untreated sewage water sample is 3.1-3.8mg/l (with an average DO value of 3.45mg/l); while the Biochemical Oxygen Demand within 5 days (BOD_5) is 1.2-1.4mg/, with an average of 1.325 in the untreated sample. The treated sample gave an average DO and BOD_5 values of 4.825mg/l and 2.30mg/l respectively (cf: Table 1).

Generally, oxygen levels in water depend on the balance between the inputs from the air and plants, and the consumption by all forms of life. Inputs from the air depends on the turbulence of the air-water interface, and the oxygen deficiency of the water. While inputs from plants depend on photosynthetic activity, which increases with temperature and sunlight. Decomposition processes utilize oxygen; the more the organic matter in the water, the greater the amount of DO required. The amount of DO is therefore a representative of the chemical and biological compounds that can be oxidized and have pollution potential [6].

The DO can affect processes that include re-aeration, transport, photosynthesis, respiration, and nitrification. Low DO concentration of the range observed in the untreated sewage water can lead to impaired fish development and maturation, increased fish mortality and underwater habitat degradation [6] [11] [12] [13]. Fish and shellfish are very sensitive to depletion in oxygen level in water and die very quickly in a matter of minutes with reduced oxygen concentration. Prolonged oxygen deficiency causes asphyxiation, a condition of suffocation to the aquatic fauna trapped below. Fish will die of asphyxiation depending on the oxygen requirements of the species and to a lesser extent, the fish adaptation. Indeed, an extremely low DO of less than 2.0mg/l usually indicates a completely degraded aquatic system. Osuji and Uwakwe [6] observed that besides such factors as high temperature and high salinity levels, DO levels are mainly reduced by oxygen depleting wastes.

Biochemical oxygen demand (BOD), usually measured after five days as BOD_5, is the amount of oxygen needed to completely decompose the organic matter in the water to simplest molecules, i.e., CO_2 and H_2O. When the organic loading of the aquatic environment becomes abnormally high, the BOD far exceeds the available oxygen. When this happens, microorganisms still degrade the organic matter, but this is done only by those microorganisms that can do so in the absence of oxygen. In anaerobic decomposition, the organic matter is not completely degraded; the end products of the metabolic pathways include alcohol, methane and the foul smelling H_2S. In these conditions, while the microorganisms thrive in oxygen deficiency, aerobic aquatic fauna die [6-10]. Therefore, the fact that the DO in the system exceeds the BOD_5 values obtained (Table 1) means that the organic loading is not abnormally high, which presupposes that the degradation pathway is aerobic. This provides the most plausible explanation to the decreased average BOD_5 value of 1.325mg/l for the untreated sewage as against 4.825 and 5.175mg/l for the treated and borehole samples respectively. The paucity of data is probably as a result of the increased DO in the treated samples which might have informed increased aerobic decompositions in the system. Oxygen consumption depends on the respiration of aquatic organisms, including plants, and aerobic decomposition of organic material by bacteria. An understanding of this balance provides a clearer explanation on the paucity of the BOD_5 values observed in the treated water samples of Sombriero River.

3. Chemical Oxygen Demand (COD)

The chemical oxygen demand (COD) is the amount of oxygen needed to chemically oxidize organic water contaminants to inorganic end products. An average COD of 16.9mg/l in the untreated sewage water sample was significantly reduced to 2.53mg/l. Although the COD values of untreated, treated and borehole water samples are all below the maximum acceptable limit of 125mg/l, the lower COD value in the treated sample indicates that the treatment plant a significant oxidative efficiency. COD values reflect the organic and inorganic compounds oxidized with dichromate, with the exceptions of some heterocyclic compounds (e.g. pyridine), quaternary nitrogen compounds and readily volatile hydrocarbons. The relatively higher COD value in the untreated sewage sample suggests that there are more oxidizable organic and inorganic compounds in the sewage water sample since COD represents not only the oxidation of organic compounds, but also the oxidation of reductive inorganic compounds.

4. Turbidity, TSS and TDS, Temperature

The significantly higher than normal ($p< 0.05$) average turbidity of 87.5 NTU for the untreated sewage water sample compared to <1 NTU in the treated and borehole samples implies that a reduced amount of light passed through the aqueous medium. Expectedly, there would be more cloudiness as a result of the dissolved and suspended solids in the contaminated sewage water. The turbidity result therefore corroborates the significantly high TDS and TSS values of 199.8mg/l and 70.5mg/l obtained for the untreated water (*cf*: Table 1). High turbidity is expected to reduce dispersion and increase temperature because of increased heat absorbance. This in turn, should reduce the concentration of the DO, since the distribution of oxygen in freshwater is governed by the balance between inputs from the atmosphere and photosynthesis, and losses due to chemical and biological oxidation [5-8].

The slightly higher average temperature (of 28.05^{o}C) of the untreated .sewage sample may not only be due to the increased heat absorbance, but also due to the increased biological activity. The results showed the highest range of temperatures 25.7 – 30.0 ^{o}C in the untreated sewage water sample shows that the temperature increased with increasing age of sample (from week 1 to week 4). These results corroborate the increasing biological activity in the samples as indicated by the oxygen regime.

5. Electrical conductivity (EC)

The result showed a significant reduction in EC, from the 398.8µs/cm in the untreated sewage sample to 131.5 µs/cm in the treated water sample. This indictor parameter also provides substantial evidence on the efficiency of the treatment plant. This implies that the treatment has a overall percentage removal efficiency of 67.02% in terms of EC.

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Conductivity in water is affected by the presence of inorganic anions and cations such as Cl, HCO_3^-, CO_3^{2-}, NO_3^{2-}, SO_4^{2-}, PO_4^{2-}, Na^+, Mg^{2+}, Ca^{2+}, Fe^{3+}, and Al^{3+}. [8-11].This implies that the untreated sewage water had some dissolved salts which might be responsible for the high conductivity measured. On the other hand, the treatment process was highly efficient in the removal of dissolved salts. Like DO and turbidity, EC is also affected by temperature; the warmer the water, the higher the EC. For this reason, the acceptable EC range is usually reported at 25^{o}C, which is lower than the temperature range of the untreated sewage sample.

6. Nutrients (NO_3, P-PO_4) and Heavy Metals

Nitrate recorded a higher than normal average concentration of 59.3mg/l as against the 6.7mg/l in the treated water sample and 1.47mg/l in the borehole sample (Table 5). This result puts the average percentage removal efficiency of the treatment plant at 88.7%.

The result obtained in this work shows the vulnerability of the Sombriero River to the nitrate sources of faeces and decaying organic matter, among others. High quantities of nutrients which are impossible to be removed naturally can be found in rivers, and leads to eutrophication of natural waters. In view of this, an increase in the lifetime of pathogenic microorganisms is expected. Measurements of nutrient variations in domestic wastewater is strongly needed in order to maintain the water quality of receptors [6] [11-13].

PO_4-P (phosphorus as phosphate) variation of 139.9mg/l in the untreated sewage sample and 1.89mg/l in the treated sample is linked to the variation in soluble Fe^{2+}. Interestingly, the two elements exist together in most domestic systems because they are dominant in proteins, lipids, and degradation products. The results point to 98.6% removal efficiency of the locally designed treatment plant. In the case of the heavy metals, their concentrations in all the samples are within acceptable limits. The heavy metals therefore do not pose any potential toxicity to both the untreated and treated sample samples. The results are as collected in Table 1.

Conclusion and Recommendations

The results of the indicator biological and physicochemical parameters tested in this work have provided substantial evidence of the positive remedial action of our locally designed sewage treatment plant. The significantly high average bacterial load of the fecal coliforms of the sewage water sample points to the human fecal contamination of the Sombriero River in the Niger Delta region of Nigeria. However, the efficiency in the removal of the sewage load of the river was found to be significantly high ($P \leq 0.05$), as corroborated by the tested parameters, which showed an average removal efficiency of over 70%. The system showed the highest efficiency of 98.6% in the removal of PO_4 – P (phosphorus as phosphate) from the untreated sewage water. Considering the overall efficiency of the engineered treatment system, it can be deployed *in-situ* for the treatment of the impacted hot spots of the Sombriero River. There is also need for government and development stakeholders in the oil rich Niger Delta to adopt sanitation security models that would guarantee critical infrastructures which discourage open sea defecation and promote healthy living conditions in the rural riverine communities. Such critical infrastructures should include the provision of toilet amenities, and the immediate development and deployment of this treatment plant, since the findings of this work point to the environmental friendliness of the treatment process.

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Experimental Part

1. Site Description

The study area "Sombrero River" is located in Ahoada East, Rivers State in the Niger Delta region of Nigeria within the Igbu Ehuda community as shown in Fig 1. It lies between latitude 5^0 03′ 30″ N and 5^0 05′ 45″ N, longitude 6^0 38′ 45″ E and 6^0 39′ 45″ E. It is a tidal dominated river, with possible freshwater input. The study area is accessed through the East-West road going from Port Harcourt to Warri [14] [15].

2. Reconnaissance Survey and Sample collection

A two week field reconnaissance campaign was carried out in order to identify hot spots of open river defecation and sample collection. After delimiting areas to be sampled, four composite samples were sampled on weekly basis for four weeks.

The respective water samples from the project area were collected with glass bottles pre-treated by washing with dilute HCl (0.05M) and later rinsed with distilled water. They were then air-dried. At the collection points, containers were rinsed with relevant samples twice, filled with the samples and then corked tightly and labelled. Four (4) glass bottles were used to collect water samples from the sampling points. Amber Bottles were used to collect samples for BOD_5 for the four stations [14]. The samples were sent to the laboratory for analysis of water quality parameters. The samples were preserved in a cooler with ice packs to keep the temperature at 4 degrees and they were received at the laboratory within two hours of samples collection. A Global Positioning Systems (GPS) unit, portable GARMIN Etrex 76, was used for recording coordinates and elevation readings.

3. Sample Collection

Water samples were collected from the four (4) locations of the sampling stations considered in the research work. One (1) liter of water was collected from each position. The three (3) Samples collected from the Sombrero River where collected from the river bed, while the sample collected from the community borehole prior to sample collection, the pump was allowed to run off for about three to five minutes. This was to ensure collection of representative samples. Samples were collected in three (3) labeled, tightly corked plastic containers. The first container was 250ml for microbial test. The second (1 litre container) was acidified with two (2) drops of concentrated Nitric acid (HNO_3) for cations determination. The acidification was to homogenize and prevent absorption/adsorption of metals to the wall of the plastic container. Acidification equally stops most bacterial growth, inhibits oxidation reactions and precipitation of cations. The third plastic container (1 litre) was used for anion determination. These samples were preserved in ice-packed coolers to keep the temperature below 20°C for eventual transfer to the laboratory for analyses within twenty-four (24) hours.

Sampling protocols and the use of appropriate sampling tools as recommended in the Federal Ministry of Environment (FMENV) guidelines and other international guidelines were rigidly followed.

Before sample collection, the containers were properly rinsed with the river water and borehole water to be sampled, filled to the brim, and tightly covered to avoid oxygen contamination. Oxygen contamination could trigger reactions and falsify results. The samples were properly labelled and transported to the laboratory for analyses. Sampling was done only in good weather conditions to avoid rainwater contamination, as this would affect the quality of the samples collected.

4. On Site Determinations

The Colour, pH, Conductivity and Temperature were measured and recorded *in-situ* using a portable Multiparameter analyzer

5. Laboratory Analyses

5.1. Bacteriological

Bacteriological analysis was carried out to determine the presence and population density of coliform in the water. The water samples were mixed thoroughly in Petri dishes using a sterile pipette. A Media Culture Agar (MCA, 5 x 10 ml) was aseptically inoculated with 10 mls of the water sample. The tubes were incubated at 37°C for 24 hours and all tubes that showed acid and gas were regarded as presumptive positive. The Most Probable Number (MPN) of coliform organisms present in 100ml of sample was ascertained using Mc Crady's statistical table [15]. The control experiment was distilled water with zero coliform count per 100ml [14].

5.2. Turbidity

Five millilitres of the sample was illuminated by a light source and a photoelectric detectors were used with a readout device to indicate the intensity of scattered light at right angle to the path of the incident. The turbidity was then determined using the Turbidity meter (HAH 2100AN)

5.3. Biochemical Oxygen Demand (BOD)

The 5-day BOD test method (APHA 5210B) was used for BOD_5 determination. Samples for the BOD_5 test were diluted appropriately, seeded and incubated in the dark for 5 days at 20˚C. The residual dissolved oxygen was determined electrometrically after the incubation period and the BOD_5 calculated afterwards.

5.4. Chemical Oxygen Demand (COD)

USEPA 5220 D/ HACH 8000 method was used for the analysis of Chemical Oxygen Demand (COD). In this procedure, the samples were heated in a COD Digester for 2hrs th a strong oxidizing agent, Potassium dichromate. Oxidizable organic compounds react, reducing the dichromate ion ($Cr_2O_7^{2-}$) to green chromic ion (Cr^{3+}).

The COD reagent also contains silver and mercury ions. Silver is a catalyst while mercury is used for complex chloride interferences.

5.5. Phosphate in water

Phosphate in the water sample was determined with APHA 4500-PC test method [16]; a colorimetric method based on the formation of a yellow complex under acidic condition in the presence of Vanadium. The intensity of the yellow colour is proportional to Phosphate concentration. The sample was analyzed at a wavelength of 470nm with UV-Spectrophotometer – DR2000.

5.6. Nitrate in water

Nitrate in the effluent samples was determined by Cadmium Reduction Method (APHA 4500-NO_3-E) using UV-Spectrophotometer – DR2000 at a wavelength of 543nm. To 50ml clear sample, one 1 ml HCl solution was added and mixed thoroughly. NO_3^- calibration standards were prepared in the range of 0 to 7mg NO_3^- by diluting to 50ml the following volumes of standards nitrate solution: 0, 1.00, 2.00, 4.00, 7.00, 35.00ml. NO_3^- standards were treated in same manner as sample. Absorbance or transmittance against redistilled water set at Zero abs or 100% transmittance was read. A wavelength of 220nm was used to obtain NO_3 reading, and a wavelength of 275nm was used to determine interference due to dissolved organic matter.

5.7. Sulphate in water

Sulphate was determined using APHA 4500.SO_4^{2-}.E test method [16] Sulphate precipitates by displacing chloride in the presence of $BaCl_2$ and precipitated turbid solution was measured calorimetrically for sulphate concentration.

The sample was filtered and temperature was adjusted to between 20°C. One hundred millilitres (100ml) of the clear sample was pipetted into a 250ml beaker. This was diluted to 100ml distilled water, and 5.0ml of conditioning reagent was added and mixed in the stirring apparatus. While the solution was being stirred, 0.3g $BaCl_2$ was added and stirred exactly for 1.0min at constant speed. Immediately after the stirring period elapsed, the solution was prepared into the cell. The turbidity at 30s interval was measured for 4 mins at 420nm wavelength. The maximum reading taken in the 4mins period was recorded

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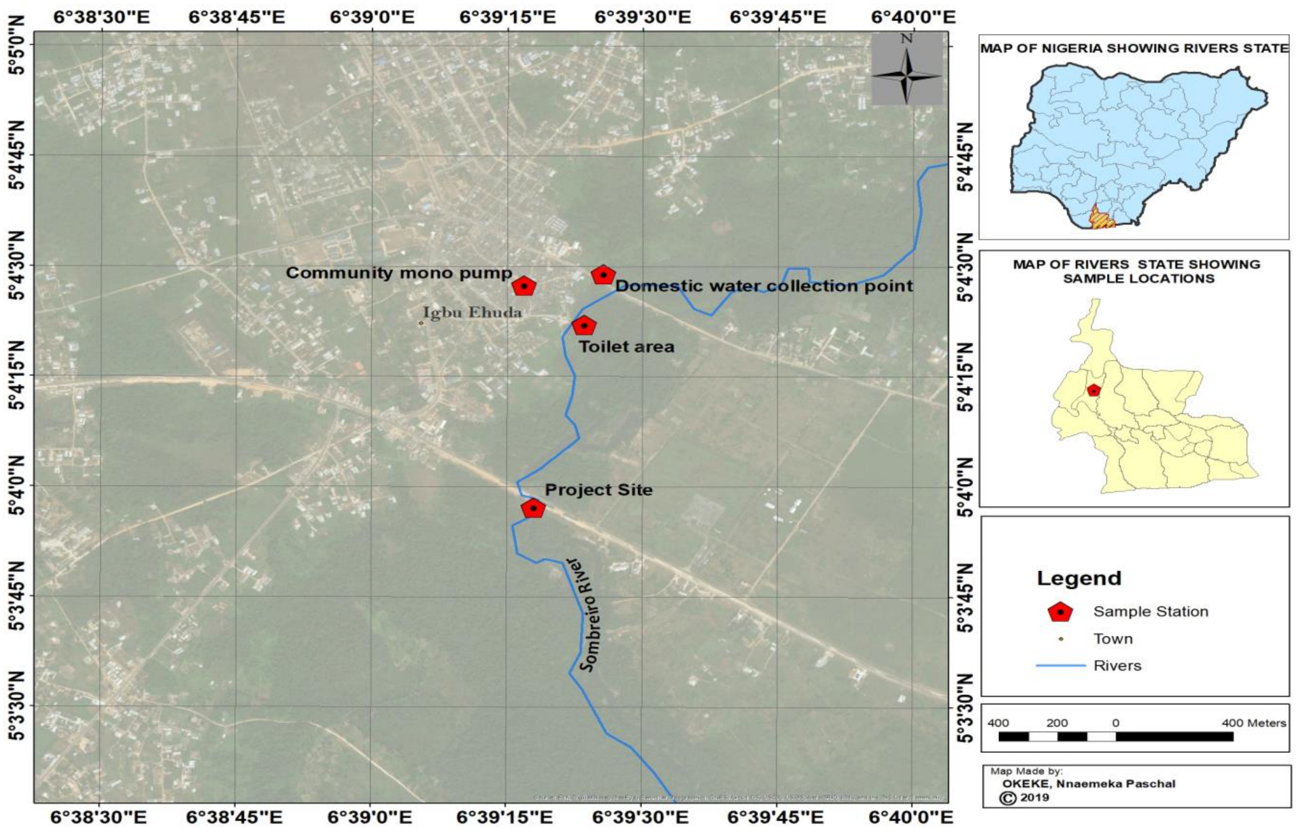

Fig 1: Map of the study area showing sampling locations

Table 1 Physicochemical properties of the untreated sewage and treated samples (Mean ± SD)

Parameters	Sample Sources			
	Factory borehole	**Sewage**	**Treatment**	**Final treatment**
pH	6.43±0.32	5.5±0.27	6.33±0.22	6.7±0.29
Temp (^{0}C)	26.85±1.54	28.05±1.97	27.08±1.79	26.98±1.37
EC (µs/cm)	23.5±6.76	398.75±49.77	247.25±36.65	131.5±85.31
TDS (mg/l)	12±2.94	199.75±25.13	124.5±18.7	66±42.54
Turbidity (NTU)	1±0	87.5±74.03	5.75±4.65	1±0
TSS (mg/l)	1±0	70.48±67.11	8±6.16	1±0
DO (mg/l)	5.18±0.1	3.45±0.31	4.18±0.1	4.83±0.17
BOD_5 (mg/l)	2.35±0.25	1.33±0.1	1.63±0.25	2.2±0.26
COD (mg/l)	1.5±0.37	16.93±2.59	10.75±2.03	2.53±0.99
NO_3 (mg/l)	1.35±0.34	59.33±65.52	3.7±1.45	6.68±3.8
PO_4 (mg/l)	0.89±0.24	131.93±89.92	57.8±37.89	1.89±1.66

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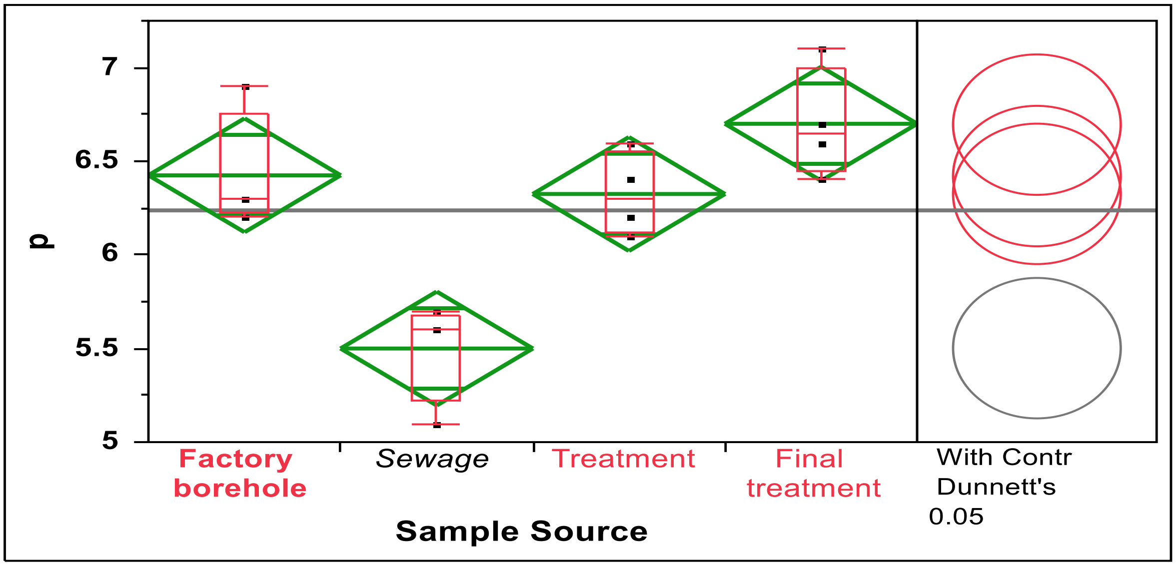

Fig 2. Plot showing variation of pH against sample sources

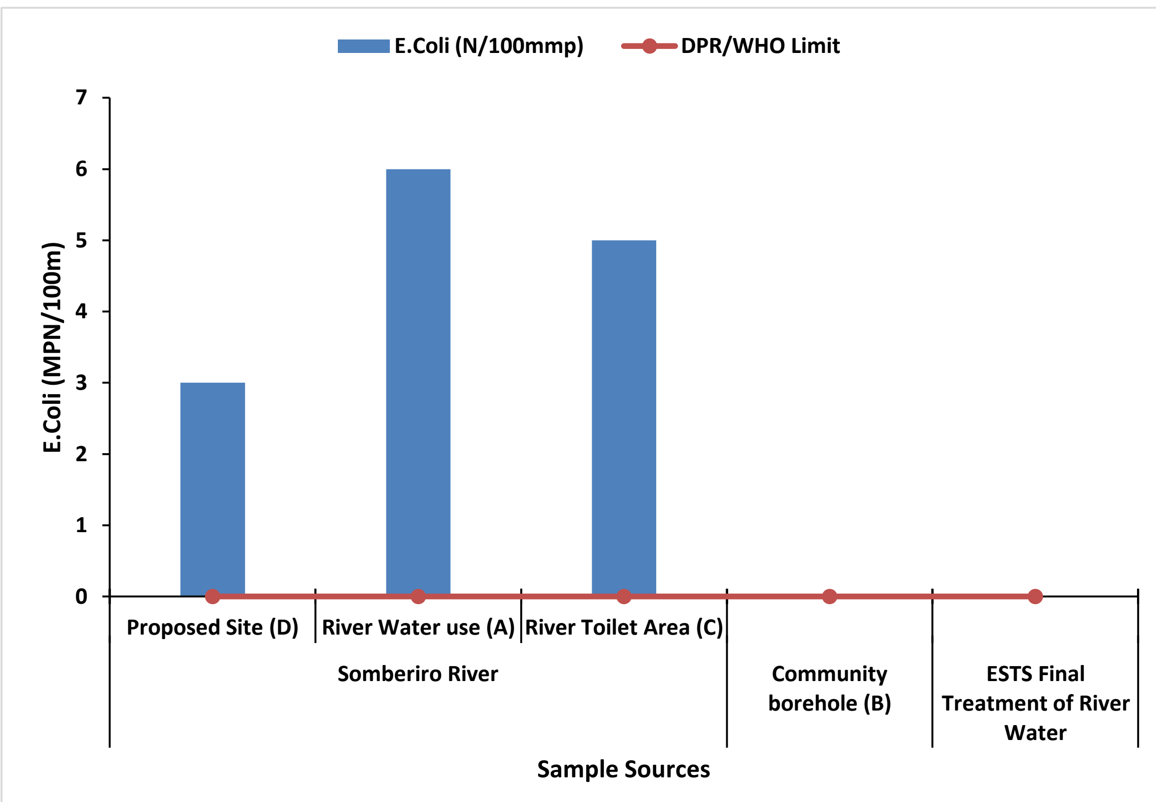

Fig. 3. Variation in the population density of E. coli in Water samples from Sombriero River

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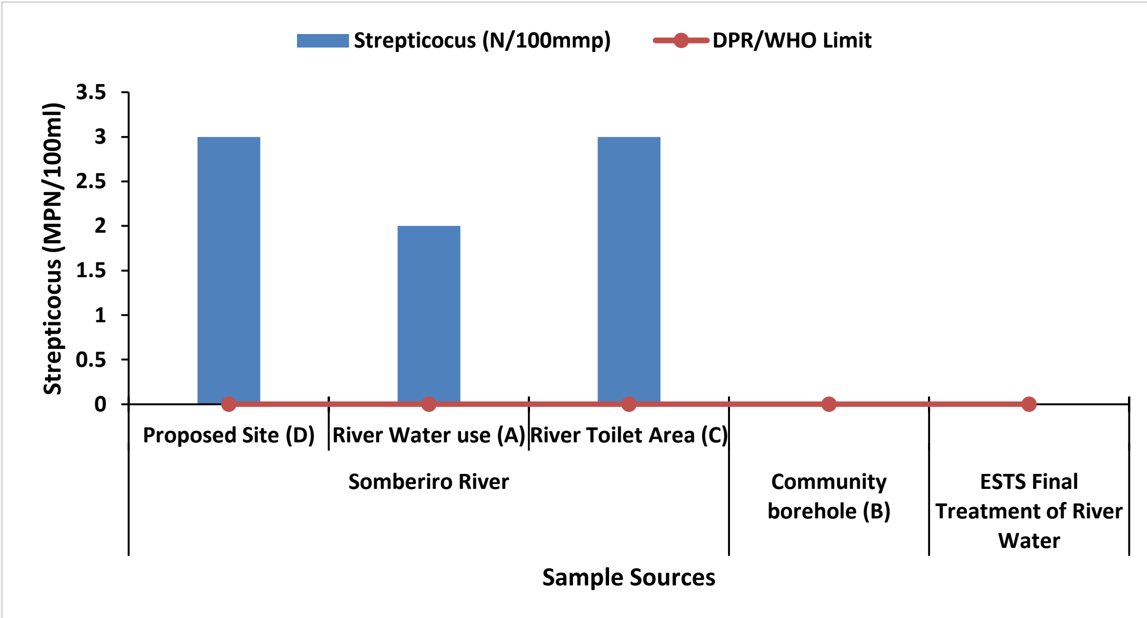

Fig. 4. Variation in the population density of Strepticoccus in water samples from Sombriero River

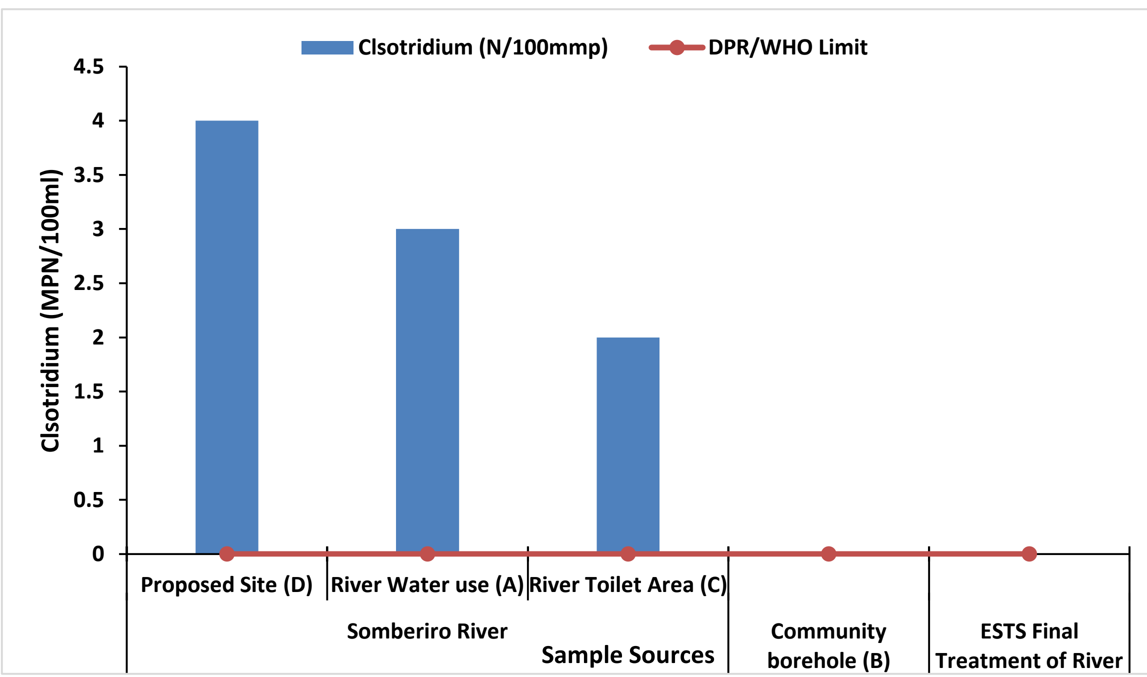

Fig. 5. Variation in the population density of clisotridium in water samples from Sombriero River

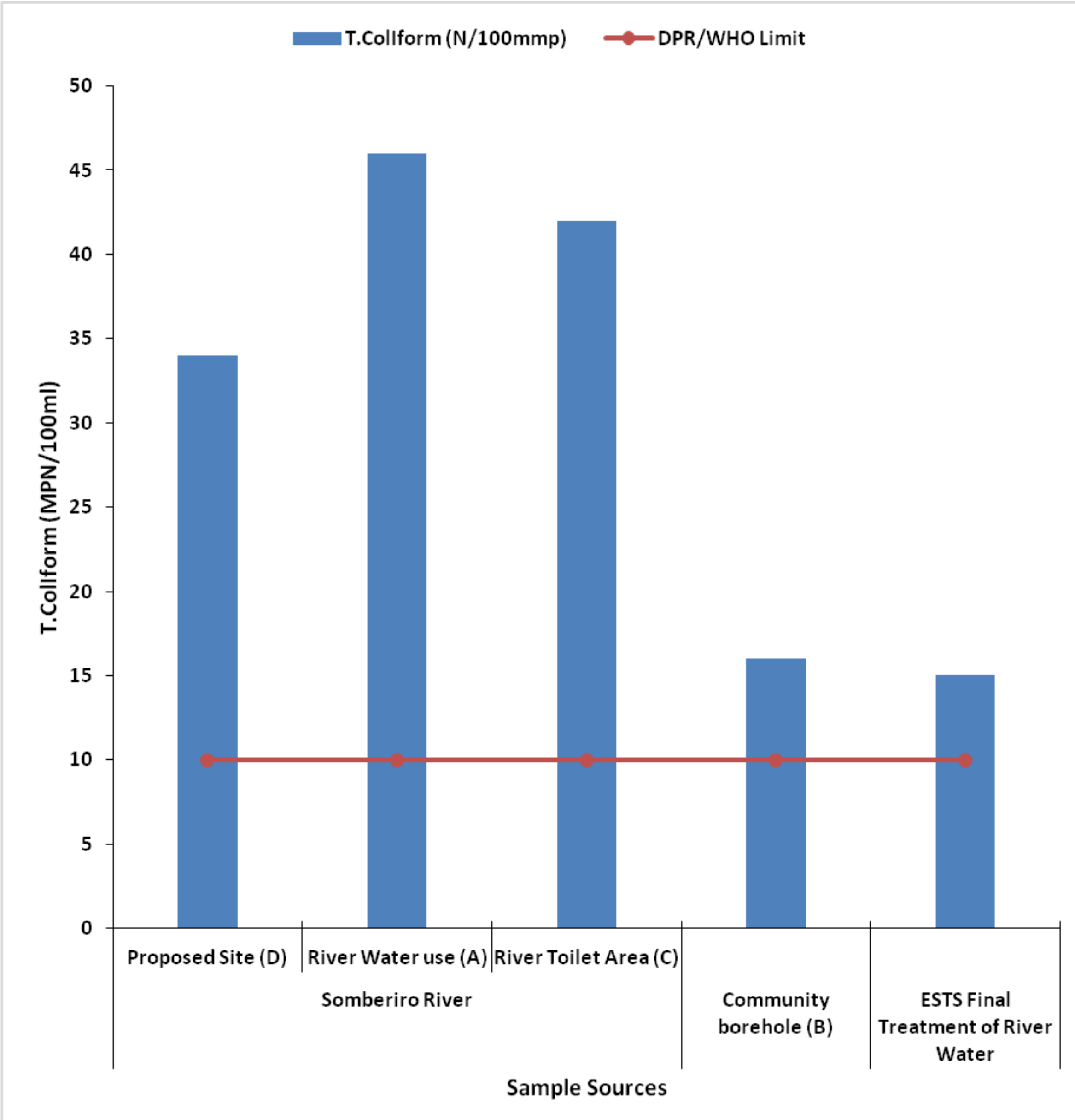

Fig. 6. Variation of the population density of T. coliform in water samples from Sombriero River