



Engineered Sewage Treatment System in Selected Niger Delta Environment

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This work was carried out in collaboration with all authors. All authors read and approved the final manuscript.

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ABSTRACT

Water is life. Unfortunately, there has become a great scarcity of this precious liquid due to anthropogenic/human activities which have generated wastes, especially sewage that has not been adequately treated in the country, more especially in the poverty-stricken Niger Delta area of Nigeria. The few freshwater bodies not only serve a means for domestic use, including drinking, but it is also used as a means of direct sewage disposal both by the locals and other related unabated activities, thereby increasing the prevalence of water-borne diseases.

A locally designed sewage plant "engineered sewage treatment system" (ESTS) was therefore designed and developed with local materials like palm kernel shell (PKS), periwinkle shell (PWS), charcoal, fine, and coarse sand to treat domestic wastewater and improve the quality of the available water source within the local communities. The ESTS was operated for three months, and weekly monitoring carried out. The analysis of the treated effluents showed a significant reduction in the levels of contaminants as most of the physicochemical and biological parameters were within acceptable limits by the World Health Organization/Federal Ministry of Environment (WHO/FMEnv). The quality of treated sewage water improved when subjected to treatment by ESTS and compared well to the borehole water, which served as control. The results of the

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treatment process showed a 93% to 100% treatment efficiency of ESTS in the removal of *F. coliform*, *E. coli*, *Streptococcus* and *Clostridium* from the sewage. This high-efficiency rate has provided a holistic and affordable (cost-effective) means to curb the proliferation of water-borne diseases and help improve water quality in riverine communities.

Keywords: *Locally designed sewage plant; engineered sewage treatment system; efficiency; physicochemical and biological parameters; water-borne diseases.*

1. INTRODUCTION

Most rural dwellers within the Niger Delta and even in Nigeria, do not understand what the safety and health implications of not having an adequate and effective sewage treatment facility [1]. Only a handful of people (mostly the educated ones) within our communities know that sewage can undergo treatment and the effluent from the sewage treatment plant recycled for household use and the sludge deployed for agricultural use as manure as practiced in developed countries. This ignorance has left the surface and groundwater contaminated from the current practice of indiscriminate dumping of sewage, especially to surface water as practiced in the selected Niger Delta community (Igbu-Ehuda) (Fig. 1a and 1b) and other areas in the Niger Delta [1]. In addition to direct dumping to surface water, there exists poorly designed and built underground septic systems in the Niger Delta and other parts of Nigeria.

No matter how long the sewage treatment facilities are ignored, the truth is that an effective engineered sewage treatment system is the foundation of community health and well-being. Hence the urgent need to have a reliable and effective disposal method in place.

It is common knowledge that untreated discharges/washouts from kitchens, bathrooms, and toilets end up in the environment. In some areas in the Niger Delta, buried PVC and asbestos pipes connect the discharge drains to the septic tank system, which in most cases are poorly designed and constructed, or the drain pipes are left to discharge to the nearby environment especially effluents from bathrooms and kitchens. On the other hand, direct discharge to surface water bodies (such as rivers, creeks, lakes, and streams) is practiced in the study area. In all the above cases, the effluent that percolates to the aquifer is untreated, hence making the source of household and available

community borehole water not conforming with the World Health Organization and Federal Ministry of Environment regulatory limits.

In Nigeria, there is no existence of central Sewage Treatment Plants (STP) operated and maintained by the government. However, there exist pockets of STPs in private sectors or establishments.

According to Ward [2], one can argue the relative merits of modern septic systems, but the truth is that a septic tank (or a sewage treatment plant) is only as safe as the maintenance process. A poorly designed, installed, or maintained septic system will subsequently fail. Every system has a designed lifespan and must eventually be replaced on expiration.

Recognizing the above fact as tenable for a Septic system to be safe, it is clear that the case within our environment is different because existing septic systems are not inspected for leaks and integrity failures. The only evacuation of sludge is practiced and handled by refuse disposal agents who dump the sewage at their selected sites, thereby increasing the environmental impacts and associated health hazards.

A failed septic system in a community with a high water table is high risk and more devastating, where no sewage handling facility exists. Hence, the need for proper stakeholders' awareness and support with the provision of an effective sewage treatment facility.

In the Niger Delta, therefore, because of the peculiar hydrogeology of many areas having a high water table and level of poverty is high, direct wastewater discharge into nearby water bodies, which is the current practice and contributing to the pollution of water bodies (Fig. 1a & 1b). Clearly, both surface and groundwater are polluted, making access to potable and household water not readily available.



Fig. 1a. Floor wooden platform of the community toilet in the Sombrero river showing openings for faeces droppings into the river beneath



Fig. 1b. Walkway to the community toilet inside the river

This research work, therefore, highlights the following:

- The impacts of long-practiced untreated wastewater discharge into nearby water bodies, as it affects both human and aquatic health.
- Design a cost-effective, innovative, efficient, and SMART Engineered Sewage Treatment System (ESTS) that can be easily replicated across the Niger Delta and possibly other parts of Nigeria.
- Construction and deployment of a prototype ESTS using local materials readily available within the project area with the objective of having the treated effluent physicochemical and biological parameters conforming to the stipulated regulatory WHO and FMENV [3] limits before discharge.
- The generated sludge which is of economic importance will be used as manure for agricultural purposes.
- The possibility of harnessing the methane produced from the designed sewage

treatment process for generating electricity (renewable energy through a bio-gas engine installation - waste to wire). Adopting bio-methanation, the waste can be effectively treated, and the biogas produced can also be used as cooking gas. This, therefore, is outside the scope of this project.

Recently, at a workshop in Abuja, Nigeria, on the 18th November 2019, the Minister of Water Resources, Mallam Suleiman Adam, announced that President Muhammadu Buhari would sign an executive order to back the law banning open defecation in the country. This concern, therefore, heightens the need to provide an environmentally friendly and affordable mean of sewage disposal and treatment within our rural and suburban communities.

2. MATERIALS AND METHODS

This explains the following; Engineered Sewage Treatment System (ESTS) Design, Construction of the Engineered Sewage Treatment System,

Treatment Materials and Engineered Sewage Treatment System Cost [4].

2.1 Engineered Sewage Treatment System (ESTS) Design

The Engineered Sewage Treatment System consists of the following:

- (1) Sewage receptor/ Separation Chamber
- (2) Periwinkle shell unit (first chamber); Flocculation/Coagulation
- (3) Palm kernel shell unit (second chamber); Flocculation/ Coagulation
- (4) Sharp sand unit (third chamber); Filtration
- (5) Charcoal unit (Forth chamber); Filtration/ detoxification
- (6) Coarse sand unit (fifth chamber); Filtration
- (7) Fine sand unit (Sixth chamber) Filtration

The design flow rate of 0.6 m³/d was considered for the prototype model. The ESTS facility consists of a toilet connected to seven treatment chambers covering a total area of 9.0 m² (Fig. 2).

The Engineered Sewage Treatment System (ESTS) is deepest at the influent point (Sewage receptor/ Separation Chamber) with a depth of 1.0 m decreasing/sloping gradually to a depth of 0.3 m at the effluent discharge point. Details are provided in Fig. 3.

The units (Cells) are connected in series with the first six units measuring 0.8 m x 0.8 m x 1.0 m each and covering an area of 3.84 m², with the fine sand unit measuring 0.8 m x 2.70 m x 1.0 m cell and covering an area of 2.16 m².

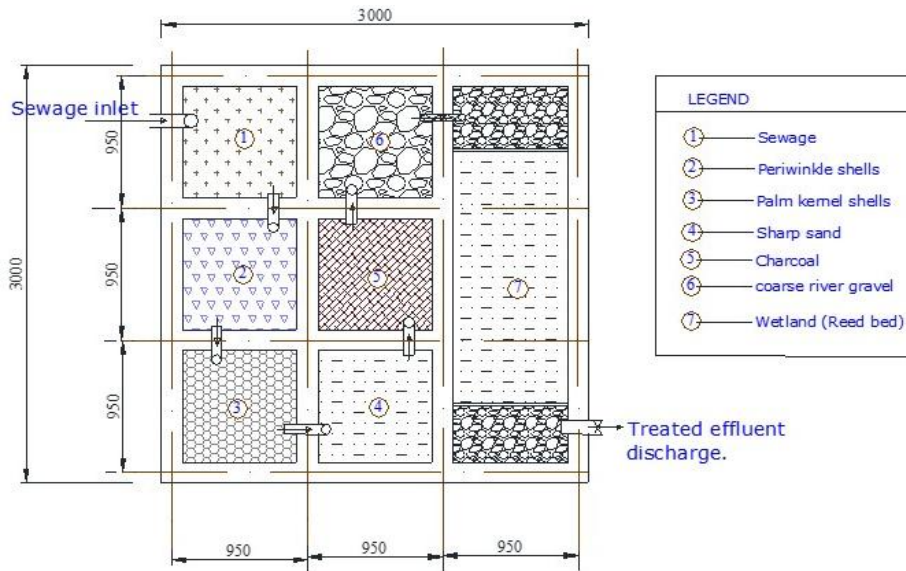


Fig. 2. Schematic diagram of the engineered sewage treatment system design layout (Plan elevation)

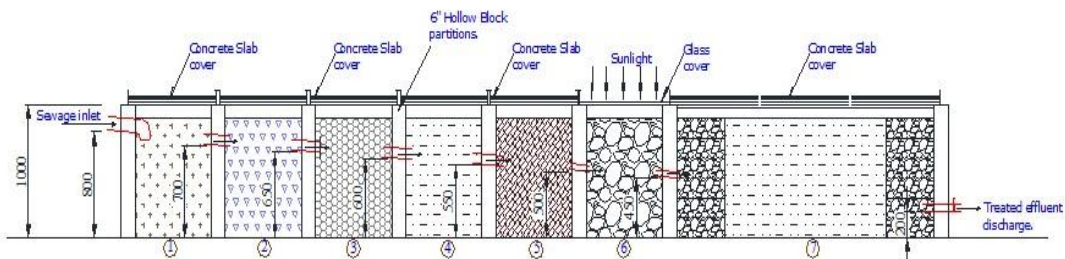


Fig. 3. Schematic diagram of the engineered sewage treatment system process flow



Fig. 4. Inside and outside view of toilet



Fig. 5. Aerial view of empty treatment chambers of ESTS

Table 1. Design parameters of a domestic wastewater treatment system

Design parameters	Values
Population (person)	10
Minimum daily flow (m ³ /d)	0.2
Maximum hourly flow (peak coefficient = 3.38) (m ³ /hour)	0.0282
Maximum daily flow = 3 × (minimum hourly flow) (m ³ /d)	0.6
Daily flow per person (L/person d)	20
Daily organic load per capita (grBOD ₅ /capita-d)	0.1665
Size of Sewage Cell (Unit) (m ³)	0.64

2.2 Construction of the Engineered Sewage Treatment System

The walls of ESTS chambers (cells) were built with 150 mm hollow sand-crete blocks with the

pockets filled with a weak concrete mix (1:4:8) and walls/floor rendered in mortar (1:3) to make the walls and floor liquid impermeable. The tops of cells one to five were covered with concrete slabs after treatment materials were introduced

into the respective cells to prevent external factors (such as rain and human) from affecting the treatment process, thereby creating an enabling environment for in-situ filtration processes (Figs. 4 to 6). The top of the sixth cell was covered with a 6 mm thick glass sheet that allowed the absorption of UV rays from the sun for effective inactivation of microbial load through a physical process [5]. This process is simple, safe and environmentally friendly; hence no potential negative effect on aquatic life. Whilst the last cell, which is the fine sand unit, was covered to prevent external microbial action before effluent discharge. The design parameters considered are as shown in Table 1.

2.3 Treatment Materials

There are different materials deployed in the seven chambers of the ESTS that perform the processes of filtration, purification and disinfection of the wastewater (Fig. 2). This system has shallow treatment beds and uses inert materials (such as periwinkle shells (PWS), palm kernel shells (PKS), sharp sand (Fine), and coarse sand) for treatment.

2.3.1 Palm Kernel Shell (PKS)

The Palm Kernel Shell is a waste material obtained during the crushing of palm nuts in the palm oil mills from palm oil extraction. In the Niger Delta, it is one of the most common waste materials generated. Nigeria produces approximately 0.4 million tons of PKS annually [6,7,8]. Alemu Farms, a subsidiary of Nakspec West Africa Ltd, is a 350 hectares of oil palm plantation situated in Ahoada West Local

Government Area of Rivers State with palm kernel oil production estimated at 200,000 tonnes per annum [9]. This is in addition to the palm kernels produced by medium scale palm oil factories and locals. Hence, utilizing PKS would be a huge cost-saving and environmental stride, as heaps of palm kernel shells are dumped at various locations constitute environmental menace.

In this work, PKS is used in the improvement of wastewater filtration activities in terms of water absorption, and coagulation of contaminant/particulates. The PKS used in this research work (Fig. 7) was collected from a local palm oil factory in Igbu-Ehuda, Ahaoda East LGA, Rivers State. The PKS was air-dried and then soaked for a few days under ambient temperature to obtain Saturated Surface Dried (SSD) aggregates. The PKS grading size used was between 10.0 to 12.5 mm (Table 2).

2.3.2 Periwinkle Shells (PWS)

Periwinkles (*Tympanotonus fuscatus*) are small greenish-blue marine snails with spiral conical shell and round aperture. The average winkle lives for three years and grows to a shell height of 20 mm, but the largest recorded winkle grew to 52 mm [10]. They are common in the riverine areas and coastal regions (Niger Delta) of Nigeria, where they are used for native dishes. The periwinkle shells are generated as waste and also dumped at different locations in the community. Previous studies revealed PWS as coarse aggregates in full or partial replacement for expensive, unaffordable or unavailable crushed stones or local washed gravels [10].



Fig. 6. 3D view of the completed ESTS

Table 2. Physical properties (Aggregates) of the treatment materials

Properties	PKS aggregate	PWS aggregate	Fine aggregate	Coarse aggregate	Charcoal aggregate
Specific gravity	1.21	1.48	2.6	2.72	0.4
Water absorption (%)	25.64	14.4	1.1	0.7	18 – 40
Bulk density (kg/m ³)	572	577	1120	880	220
Maximum size (mm)	10.0 – 12.5	20.0 – 35.0	0.3 – 5.0	5.0 – 20.0	2.0 – 3.0

Source: Journal of Housing Science, 1995



Fig. 7. Palm kernel shells in the treatment chamber



Fig. 8. Periwinkle shells in the treatment chamber

This research focuses on the contribution of PWS in the improvement of wastewater filtration performance in terms of water absorption and coagulation of contaminants/particulates. The PWS used in this research work (Fig. 8) was collected from the local market at Igbu-Ehuda, Ahaoda East LGA, Rivers State. The PWS was air-dried and then soaked for a few days under ambient temperature to obtain Saturated Surface Dried (SSD) aggregates. The PWS grading size used was between 20.0 to 35.0 mm (Table 2).

2.3.3 Fine and coarse sand

Sand is capable of treating organic materials, inorganic substances, and pathogens in wastewater by acting as a filter, cation exchanger, absorber, and a surface on which many chemical and biochemical processes may occur. The combination of these processes acting on the wastewater as it passes through the sand produces water of acceptable quality for discharge into the groundwater/surface water.

Physical entrapment of particulate matter in the wastewater may be responsible for much of the treatment provided by sand. Optimal performance is achieved when the sand is unsaturated. The sand system is able to sorb bacteria, viruses, ammonium, nitrogen and phosphorus, the principal wastewater constituents of concern. The retention of bacteria and viruses allows time for their die-off or destruction by other processes, such as predation by other soil microorganisms [11]. The fine and coarse sand used in this research work (Figs. 9 and 10) were collected from the sand winning dumpsite at Igbu-Ehuda Community. The grading sizes for the fine and coarse sand were 0.3 to 5 mm and 5 to 20 mm, respectively (Table 2).

2.3.4 Charcoal

Charcoal is a slow but effective water filter. The most common purpose for using a charcoal-based filter would be to eliminate impurities. Charcoal filters out particles down to 1 micron, including nitrogen oxide, lead, and sulfur oxide.

Humans have been using charcoal to purify water for years. Charcoal is the remnants of incomplete combustion of pieces of wood or other materials like coconut shells etc. Only the readily combustible material in the wood has burned away, either because of insufficient heat or poor supply of oxygen. The black char that remains is mostly carbon [12].

The charcoal used in this research work was activated by steaming it in hot water, which creates a lattice of tiny pores in the carbon, vastly increasing its surface area. This creates many more places for molecules to become trapped and makes the carbon far more effective as a filter medium. The charcoal used (Fig. 11) were locally purchased from Igbu-Ehuda Market.

2.3.5 Sample collection

Water samples were collected weekly from the sedimentation (Sludge) tank (sewage), gravel (UV) tank (Treatment), wet bed (final Treatment), and borehole (water source), and they were analyzed for specific water quality parameter in relation with domestic wastewater components.



Fig. 9. Sharp sand in the treatment chamber



Fig. 10. River gravel (Coarse sand) in the treatment chamber



Fig. 11. Charcoal in the treatment chamber

3. RESULTS AND DISCUSSION

The effectiveness of the engineered sewage treatment system is measured by comparing the quality of the untreated influent with the treated effluent, as shown in Table 3.

Wastewater measurements were carried out at the injection point (influent) – sewage receptor/separation chamber (cell 1), UV chamber (cell 6) (Treatment), and effluent discharge point (Final Treatment) (cell 7) weekly for 4 weeks. The results, when compared with the WHO and FMENV [3], were within acceptable limits, which suggests that the innovative ESTS is adequate for the treatment of sewage in the selected Niger Delta community. Total Suspended Solids (TSS) mean values for the influent sampled point was 70.48 ± 67.11 and effluent sampled point was 1 ± 0 mg/L (Table 4). The mean TSS for Site borehole (control) of 1 ± 0 mg/L was comparable to the effluent with 100% TSS removal at the effluent sampled point (Table 4). The mean value of BOD_5 for Site borehole (control) of 2.35mg/L was also comparable to the mean BOD_5 of the effluent of 2.2mg/L but was lower than the mean BOD_5 of the influent of 1.325mg/L (Table 3). At the effluent point, BOD_5 removal efficiency was 66.00%, and this result is similar to the study by Rono [13]. Mean values for Phosphate, Nitrate, *Escherichia coli*, *Streptococcus spp.*, *Clostridium spp.*, Total coliform, and Fecal coliform were well within the

FMEnv statutory limits and with removal efficiencies ranging from 89 to 100% (Table 4).

There was no Significant Difference between the Site Borehole (Control) to the Samples from the effluent for most of the parameters analyzed.

The treatment plant demonstrated substantial efficiency (Table 4) in enhancing the metabolic activities of indicator organisms, as evidenced in the population densities of *Escherichia coli*, *Streptococcus spp.*, *Clostridium spp.*, Total coliform, and Fecal coliform (in Most Probable Numbers per 100 Milliliters). On the strength of its overall efficiency and environmental friendliness, the locally designed plant can be deployed in-situ for the treatment of sewage.

3.1 Efficiency of Engineered Sewage Treatment System

The percentage effectiveness of the Engineered Sewage Treatment system was calculated for the sewage samples passed through the system. The treatment efficiency in the removal of *F. coliform*, *E. coli*, *Streptococcus*, and *Clostridium* was between 93% and 100%. Turbidity and TSS had a 100% Treatment efficiency. The Increase in pH although showed negative, as shown in Fig. 12 is a positive phenomenon as the pH moves from being slightly acidic to neutral. The removal of nutrients in sewage effluents is necessary to reduce the effects on the receiving water bodies [14]. This study findings

Table 3. Engineered Sewage Treatment System (ESTS) Physico-chemical parameters

Parameters Units	pH	Temp °C	EC □s/cm	TDS mg/l	Turbidity NTU	TSS mg/l	Do mg/l	BOD ₅ mg/l	COD mg/l	NO ₃ mg/l	PO ₄ mg/l	<i>E. Coli</i> MPN/ 100ml	<i>Strept.</i> MPN/ 100ml	<i>Clostri.</i> MPN/ 100ml	<i>T. Col</i> MPN/ 100ml	<i>F. Col</i> MPN/ 100ml
Sewage																
Week. 1	5.1	25.7	461	231	196	219	3.1	1.3	17	112	55	17	23	18	470	380
Week. 2	5.6	27.2	340	170	73	163	3.3	1.2	14.2	120	58	19	21	15	440	350
Week. 3	5.6	29.3	404	203	45	64	3.6	1.4	16.1	2.4	180	17	16	12	410	300
Week. 4	5.7	30	390	195	36	52	3.8	1.4	20.4	2.9	234.7	20	15	12	450	380
Avg.	5.5	28.05	398.75	199.75	87.5	124.5	3.45	1.325	16.925	59.325	131.93	18.25	18.75	14.25	442.5	352.5
Treatment																
Week. 1	6.1	25.5	243	122	6	8	4.1	1.9	13	5.1	30.44	8	5	2	45	20
Week. 2	6.4	25.7	197	99	<1	<1	4.3	1.7	9.4	4.8	20.3	5	3	3	32	17
Week. 3	6.2	27.9	275	139	12	16	4.1	1.6	8.7	2.5	95.25	3	2	4	29	15
Week. 4	6.6	29.2	274	138	4	7	4.2	1.3	11.89	2.4	85.2	4	2	2	29	10
Avg.	6.325	27.08	247.25	124.5	7.3333	10.333	4.175	1.625	10.748	3.7	57.798	5	3	2.75	33.75	15.5
Final Treatment																
Week. 1	6.7	25.5	26	13	<1	<1	4.9	2.1	4	4.2	3.44	2	1	1	8	1
Week. 2	6.4	26.2	102	52	<1	<1	4.8	2.3	2.1	3.9	3.2	1	1	1	6	1
Week. 3	6.6	27.7	180	90	<1	<1	4.6	2.5	1.9	12.1	0.69	1	0	1	9	1
Week. 4	7.1	28.5	218	109	<1	<1	5	1.9	2.1	6.5	0.24	0	1	1	9	1
Avg.	6.7	27	131.5	66	0	0	4.825	2.2	2.525	6.675	1.8925	1	0.75	1	8	1
Bore Hole																
Week. 1	6.2	25	33	16	<1	<1	5.1	2.4	2	1.8	0.88	0	0	0	5	0
Week. 2	6.3	26.5	22	11	<1	<1	5.3	2.6	1.55	1.2	0.73	0	0	0	4	0
Week. 3	6.9	27.2	22	12	<1	<1	5.1	2.4	1.31	<1	1.23	0	0	0	7	0
Week. 4	6.3	28.7	17	9	<1	<1	5.2	2	1.14	1.4	0.71	0	0	0	8	0
Avg.	6.43	26.85	23.5	12	0	0	5.175	2.35	1.5	1.467	0.888	0	0	0	6	0

Table 4. Treatment performance of the engineered sewage treatment system (Mean ± SD) (ESTS)

Parameters	Concentration (mg/l)		Removal efficiency (%)	FMENV
	Influent (Sewage)	Final Treatment		
pH	5.5±0.27	6.7±0.29	96%	6.5 - 8.5
Temperature	28.05±1.97	26.98±1.37		-
Electrical conductivity (EC)	398.75±49.77	131.5±85.31	67%	10
Total Dissolved Solid (TDS)	199.75±25.13	66±42.54	67%	500
Turbidity (NTU)	87.5±74.03	1±0	100%	10
Total Suspended Solid (TSS) (mg/l)	124.5±80.27	1±0	100%	4
Dissolved Oxygen (DO) (mg/l)	3.45±0.31	4.83±0.17	40%	10
Biological Oxygen Demand (BOD ₅) (mg/l)	1.33±0.1	2.2±0.26	66%	5
Chemical Oxygen Demand (COD) (mg/l)	16.93±2.59	2.53±0.99	85%	25
Nitrate (NO ₃) (mg/l)	59.33±65.52	6.68±3.8	89%	45
Phosphate (PO ₄) (mg/l)	131.93±89.92	1.89±1.66	99%	100
E. Coli (MPN/100ml)	18.25±1.5	1±0.82	95%	0
Streptococcus (MPN/100ml)	18.75±3.86	0.75±0.5	96%	0
Clostridium (MPN/100ml)	14.25±2.87	1±0	93%	0
Total Coliform (MPN/100ml)	442.5±25	8±1.41	98%	<10
Fecal Coliform (MPN/100ml)	352.5±37.75	1±0	100%	0

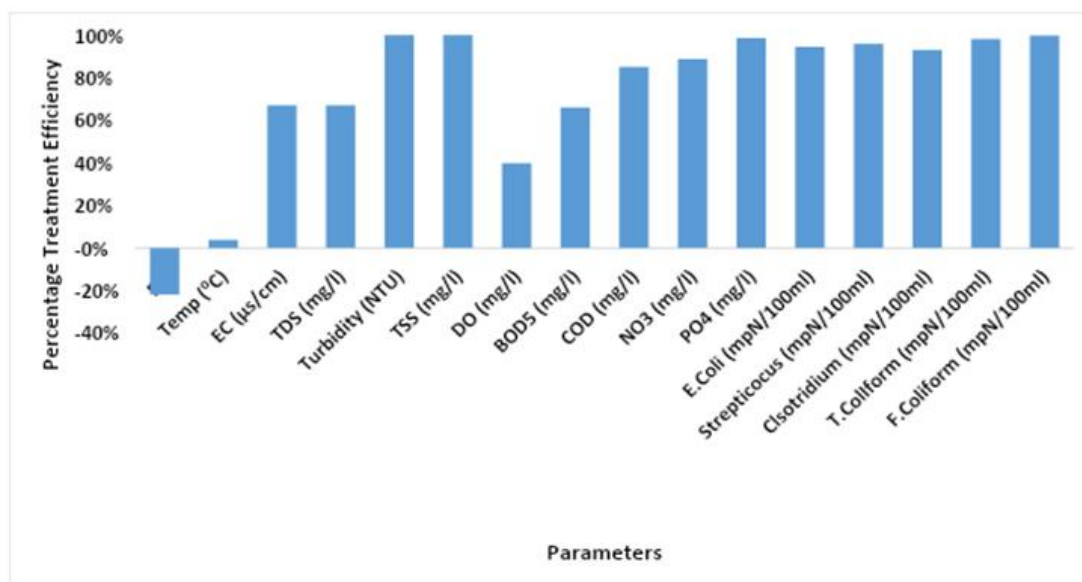


Fig. 12. Percentage treatment efficiency of ESTS on sewage samples

revealed reduced mean values of Phosphate (131.93 mg/L) at the Influent point to (1.8925 mg/L) at the effluent point with 99% removal. The removal efficiency of 99% of Phosphate at effluent point implies that no eutrophication could occur in the water body where the effluent could be discharged that would significantly deteriorate water quality and hinder aquatic life metabolic and physiological processes [13].

4. CONCLUSION

This novel and prototype “Engineered Sewage Treatment System” has revealed from this research work to be an effective and SMART method for handling sewage in the selected Niger Delta community and could be deployed within the Niger Delta for communities with similar sewage disposal challenges.

The treated water is therefore suitable for household use in washing, bathing, toileting and agricultural purposes, amongst others, including industrial purposes as well. In order to make the treated water drinkable, it is recommended the further treatment like distillation should be carried out to make the water safer.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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