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Full Length Research Paper

Environmental compliance monitoring of treated sewage effluent from WWTPs in gulf of guinea nearshore and offshore facilities

[1]Sunday B. Akinde*, [2]Micheal I. Nwachukwu, [3]Young K. Umbu, [4]Catherine C. Iwuozor

[1]Department of Biological Sciences, College of Science, Engineering and Technology, Osun State University, P.M.B. 4494, Osogbo, Nigeria.
[2]Department of Microbiology, Imo State University, P.M.B. 2000, Owerri, Nigeria.
[3/4]Fugro Nigeria Limited, 91 Odani Road (Fugro Avenue), Elelenwo, P. M. B. 053, Port Harcourt, Nigeria.

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Sewage from nearshore and offshore oil production facilities in the Atlantic Ocean of the Gulf of Guinea are commonly treated in on-site WWTPs using aerobic biological and physical-chemical combined processes. This work evaluates the environmental compliance of treated sewage effluent from 3 nearshore houseboats and 3 offshore platforms WWTPs prior to discharge. ASTM, APHA and other international methods were adapted to determine pH, temperature, residual chlorine, BOD, TSS and DO while faecal coliform was enumerated using Most Probable Number (MPN) method. The evaluation made on weekly basis for 8 weeks revealed improved treated sewage effluent quality when compared with the raw sewage data and no significant variation ($P>0.05$) in the performance of all the WWTPs. The mean values of physico-chemical parameters of near-shore houseboats treated sewage effluent samples ranged between 0.12-0.60 mg l^{-1} for residual chlorine, 15.3-52.5 mg l^{-1} for BOD_5, 53.9-62.4 mg l^{-1} for TSS, and 3.63-6.18 mg l^{-1} for DO. The average values of physico-chemical parameters of offshore platforms treated sewage effluent samples ranged between 0.26-1.39 mg l^{-1} for residual chlorine, 27.6-118 mg l^{-1} for BOD_5, 77.1-243 mg l^{-1} for TSS and 4.82-5.55 mg l^{-1} for DO. Most of these magnitudes were higher than their respective specified DPR regulatory limits, which is an indication of probable cumulative anthropogenic contamination of the recipient Atlantic Ocean of the Gulf of Guinea. The mean faecal coliform range of 4.00-30.1 MPN/100 ml and 7.37-42.0 MPN/100 ml obtained for treated sewage effluent samples from nearshore houseboats and offshore platforms respectively were lower than 200 MPN/100 ml and 400 MPN/100 ml specified DPR limits for nearshore and offshore discharges. The faecal coliform results, therefore, gave an encouraging performance of the chlorination process in WWTPs with over 90% compliant to statutory DPR limits. Considering the growing volumes of sewage effluent that will be discharged into the Gulf of Guinea as a consequence of increased nearshore and offshore oil exploration and production activities, it is recommended that the WWTPs be optimally maintained and other disinfection processes such as UV radiation and nutrient removal be included. This will guarantee maximum reduction in waterborne pathogens that may pose direct hazard to public health and make the final effluent water re-usable.

Keywords: Sewage, effluent, WWTP, gulf of guinea, hydrogeochemistry, water pollution

INTRODUCTION

Sewage (black and grey water) in nearshore houseboats and offshore oil production platforms / rigs refers to wastewater and solids, which emanates from toilets, sinks, showers, laundries, galleys, sickbay and floor drains. The volume and concentration vary widely with time, facility occupancy as well as the storage situation

*Corresponding author Email: tundeakinde@yahoo.com
Tel: +234 8033798688

(Dorfman, 2004).

Sanitary waste can be difficult to resolve, especially in the African countries, where there are neither sewerage systems nor any well-engineered Wastewater Treatment Plants (WWTPs). It poses serious threats to the management of natural systems and security of public health due to the presence of enteric and opportunistic pathogens (Baross *et al*., 1975, Gareth, 1993, Erin *et al*., 2001).

The sewerage systems are crucial to the health and wellbeing of the personnel living aboard the houseboats and platforms in nearshore and offshore oil production facilities. For human sewage from oil production facilities continuously manned by 10 or more persons, the Department of Petroleum Resources (DPR) in Nigeria requires biological treatment, preferably by a standard Sewage WWTP (EGASPIN, 2002). The sewage treatment process is designed to remove the BOD and the solids, in order to reduce the bacterial load of the effluent/wastewater. In addition, in recent years, removal of new substances (such as phosphorous and nitrogen) too has become important (Sedlak, 1991, Grandy *et al*., 1999).

Treatment process is to be followed by mandatory monitoring of dissolved oxygen (DO), biochemical oxygen demand (BOD_5), total suspended solids (TSS), residual chlorine and faecal coliform in treated sewage effluent before discharge into the sea (EGASPIN, 2002). Because specific identification of pathogenic bacteria is extremely difficult, the coliform group of organisms is used as an indicator of pathogens in sewage effluents.

The area offshore of the Niger Delta, Nigeria exhibits a shallow sloping new coastal shelf area down to water depths of 20 m or more. This is followed seaward by a steeper slope, which flattens below 100 m to form a continental transition. The general area includes features of various depositional environments transitioning as distance from shore increases from river mouth (typically within 20 km from shore), to delta front, to pro-delta slope and open shelf, typically outside of 50 km from shore (Allen, 1965, Maloney *et al*., 2010).

The oil producing companies with facilities situated nearshore and offshore Nigeria utilize the Atlantic Ocean of the Gulf of Guinea as a convenient receiver of all effluent discharges including the sewage effluent. It is imperative to know the characteristics of sewage effluent discharge as well as the load level that will not compromise the sustainability of the recipient aquatic system. Growing volumes of this sewage effluent as a consequence of an increased offshore oil exploitation activities in the Atlantic Ocean of the Gulf of Guinea has also necessitates a closer look at its final quality before its discharge in order to ascertain the efficacy of the WWTPs.

This work, therefore, presents the physico-chemical and faecal coliform characteristics of the treated sewage effluent from nearshore houseboat and offshore platform WWTP facilities. The results obtained are compared with the Nigerian DPR limits and recommendations are put forward for improvement.

MATERIALS AND METHODS

Location of the Facilities

The study area is within approximately 27 km south of the Akwa Ibom State shoreline and located at X-Y coordinates 633,493m E and 31,826m N with respect to the Minna Datum and the Nigerian National Grid (approximately 4° 17.30' N and 8° 09.93' E) (Figure 1). Water depth at this location is less than 30m. Facilities currently existing within area include about 60 wellhead, 10 production, 5 gas compression, 7 houseboat platforms and a network of pipelines. The study covers three nearshore houseboat and three offshore oil production platform WWTPs.

Description of the WWTPs

The WWTPs sampled had similar system with capability to handle sufficient capacity for up to 200 persons onboard at operating temperature of 18 to 45°C. A complete system is made up of macerator, bar screen, as well as compartments for aeration, clarification and chlorination/disinfection. They operate on the principle of sewage collection by gravity feed and utilize naturally occurring aerobic bacteria that are present in sewage to biodegrade organic pollutants.

The Aeration compartment is fitted with two air blowers and sized for a retention time of 18 to 24 h for biological treatment. The clarification compartment is sized for an approximate retention time of 6 h, whereas that for the chlorination compartment is merely 30 minutes. Chlorination is achieved by injecting sodium hypochlorite mixture using electronic dosing pump. There is however no facility for nutrient removal in the WWTPs sampled.

Sampling and Analyses

Sampling was carried out on a weekly basis for a period of eight weeks at ambient temperature (25 ± 2 °C) from three nearshore houseboat and three offshore platform WWTPs. After homogenizing the liquid in the upper part of the storage tanks, the final treated sewage effluent sample was taken from the overflow pipe at the point of discharge in triplicates using sterile 1 l plastic bottles. Untreated sewage effluent was collected at the top of clarifier compartment. Samples were stored in ice packs (4 ± 2 °C) and transferred to the laboratory.

All analyses were carried out within 24 h. Analyses of the physico-chemical and faecal coliform characteristics

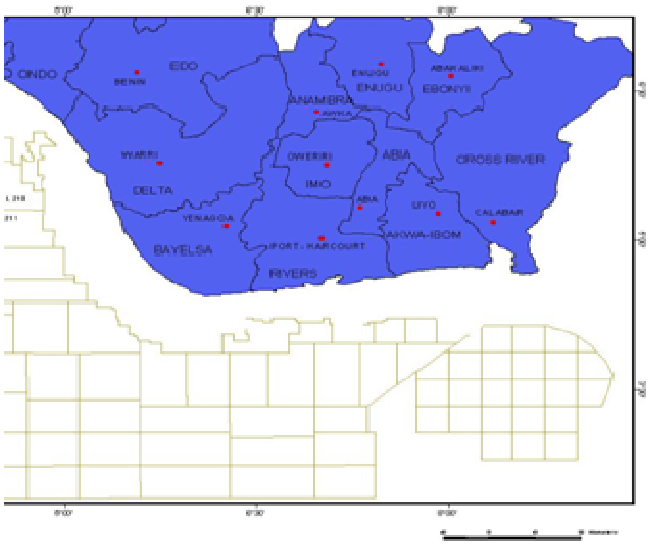


Figure 1: Map Showing Location of the Facilities

of the treated sewage effluent were carried out following the standard methods (APHA, 1998). pH, temperature and DO were determined *in situ* using Hanna multi-parameter logger (HI991300). The meter was calibrated according to manufacturer's specifications before use.

BOD_5 was determined using the (APHA5210B) method (APHA, 1998). The samples were diluted, appropriately seeded and incubated in the dark using WTW OxiTop IS 12 BOD track for 5 days at 20 ± 1 ^oC. The residual DO was determined after incubation period and the BOD_5 calculated.

The residual chlorine was estimated using a HACH test kit from which 25 ml of the sewage effluent sample was taken into a pre-calibrated cell bottle and one- content of one powder pillow was added to the cell bottle and swirled. The sewage effluent sample was poured into the cell bottle to the graduated mark. Another sample was poured without the powder pillow into another cell bottle as blank. Both cell bottles were put into the test kit with a graduated color comparator and were allowed to stand between 3-6 mins for residual chlorine before the mg l^{-1}concentration was read.

The TSS was determined with a membrane filter apparatus in accordance with the (APHA 2540D). About 100 ml of the water sample was filtered through dried pre-weighed 0.45µm filter paper and oven dried at 105 ± 5^oC for 1 h, after which the paper was cooled in a desiccator and weighed. In order to obtain realistic data devoid of salt interference from seawater, the filter apparatus after filtration of the seawater was thoroughly washed with distilled water. The determined residue was used to calculate the TSS.

Faecal coliform was estimated using multiple tube techniques in accordance with the ASTM D 5392–93, the (APHA 9221) and the (APHA 9222B). This was performed by preparing five tubes containing 10 ml of double strength presumptive broth (the MacConkey broth) each and ten tubes containing 9 ml of single strength of the same presumptive broth each. Durham's tubes were then inserted in each tube and all screw-capped tubes were sterilized at 121 ^oC at 15 psi for 15 minutes. With a sterile pipette, 10 ml of sample was added to each of five double strength tubes while 1 ml of sample was added to each of five single strength tubes. Serial dilution was made with Ringer's solution and 1 ml of 10^{-1} dilution was added to each of the remaining five single strength tubes. All tubes were shaken gently to distribute samples uniformly and then incubated at 44 ± 2^oC for 24 h. At the end of a 24 h incubation period, each tube was observed for the presence of gas in the Durham's tube. If none was visible, the tube was gently shaken for any effervescence (streams of tiny bubbles) and if present was considered positive. Number of positive tubes was recorded while negative tubes were re-incubated for another 24 h. Gas production at the end of either 24 or 48 h incubation could be due to the presence of coliform in the sample. The confirmatory test was carried out by transferring one or two loopful from each presumptive positive tube to a corresponding sterile confirmative 10ml tube containing sterile brilliant green bile broth and incubated at 44 ± 2 ^oC for 24 h after which tubes with the gas in the Durham's tubes were regarded and reported as positive. The number of positive findings of coliform group organisms resulting from multiple-portion decimal dilution was then recorded as the combination of positives and computed in terms of the Most Probable Number and reported as MPN/100ml of sample analyzed (ASTM, 1999).

RESULTS

Table 1 shows the average physico-chemical and total coliform characteristics of the untreated sewage effluent samples from nearshore houseboats and offshore platforms WWTPs.

Untreated sewage samples from nearshore houseboats and offshore platforms WWTPs with mean residual chlorine range of 0.02 – 0.28 mg l-1 were collected at temperatures ranging between 27.9 – 33.3 oC. The mean values of BOD5, TSS, DO and faecal coliform in untreated sewage from nearshore houseboat WWTPs were 145 mg l-1, 202 mg l-1, 7.10 mg l-1 and 1,467 MPN/100ml. On the other hand, the mean values of BOD5, TSS, DO and faecal coliform in untreated sewage from offshore platform WWTPs were 153 mg l-1, 202 mg l-1, 6.71 mg l-1 and 1,367 mg l-1.

The physico-chemical and faecal coliform characteristics of the treated sewage effluent from nearshore houseboat WWTP facilities are as presented in (Figure 2 and Table 2 below).

Test results indicated that the mean values for residual chlorine in nearshore houseboat effluent samples ranged from 0.12 mg l-1 to 0.60 mg l-1 (Figure 2A). Though the mean values for nearshore houseboats 1 to 3 were below the regulatory specified DPR limit of 0.8 mg l-1, results

The mean values of BOD5 for sewage effluent samples from the three offshore platforms in eight week study period ranged from 27.6 mg l-1 to 118 mg l-1 (Figure 3B). While the mean value for offshore platform 1 (27.6 mg l-1) was below the regulatory DPR limit of 45 mg l-1 for offshore discharge, the mean values of 50.1 mg l-1 recorded for offshore platform 1and 118 mg l-1 recorded for offshore platform 2 were far above the regulatory DPR limit. These high average values recorded for platforms 1 and 2 could be attributed to the excessive BOD5 concentrations of 240 mg l-1 (platform 1) and 760 mg l-1 (platform 2) in weeks 5 and 7 respectively.

The sewage effluent samples from the three offshore platforms had mean TSS values within 77.1 mg l-1 and 243 mg l-1 during the eight week study period (Figure 3C). Although offshore platform 2 recorded the highest

The DO values of the sewage effluent samples from the three nearshore houseboats as presented in Table 2 revealed a mean range of 3.63 mg l-1 and 6.18 mg l-1. Except for few discharge points, the DO values did not fall within the DPR permissible range of 4.0 mg l-1 and 5.0 mg l-1 for sewage effluent discharge into nearshore water body.

The average TSS values obtained for houseboat 1 (57.5 mg l-1), houseboat 2 (53.9 mg l-1) and houseboat 3 (62.4 mg l-1) were obviously above the required DPR permissible limit of 45 mg/l for discharge (Figure 2C).

Except for nearshore houseboat 3 in week 3 (Figure 2D), the most probable number of faecal coliform organism were below the specified DPR limit of 200 MPN/100ml for sewage effluent discharge into nearshore seawater body. period ranged between 15.3 mg l-1 and 52.5 mg l-1 (Figure 2B). The BOD5 values of the effluent samples tested were generally above the specified DPR limit of 30 mg l-1 in all the three nearshore houseboats within the period of investigation.

The BOD5 mean values for the three nearshore houseboat effluent samples tested within the eight week

The physico-chemical characteristics of sewage effluent from offshore platform WWTP facilities are as presented in (Figure 3 and Table 3 below).

from houseboat 1 in weeks 1 (0.94 mg l-1) and 7 (1.3 mg l-1) as well as houseboat 2 in week 2 (1.2 mg l-1) were above the specified DPR limit.

Except for platform 2 where the average residual chlorine concentrations of 1.76 mg l-1, 4.41 mg l-1 and 1.80 mg l-1 were recorded in weeks 3, 6 and 8 respectively, all other sewage samples tested had their chlorine concentrations below the regulatory DPR limit of 1.50 mg l-1 for offshore discharge within the period of study (Figure 3A).

average TSS value (243 mg l^{-1}), there is however no regulatory DPR limit for sewage effluent offshore discharge.

The DO values of sewage effluent samples from the three offshore platforms presented in Table 3 also revealed average range from 4.82_mg l^{-1} to 5.55_mg l^{-1}. Except for sewage effluent samples from offshore platform 1 week 2 with DO value of 4.46 mg l^{-1} and offshore platform 3 week 1 DO value of 4.20 mg l^{-1}, all sewage effluent samples from the three offshore platforms had DO concentrations outside the regulatory DPR range of 4.00 mg l^{-1} to 5.00 mg l^{-1}.

The average most probable number of faecal coliform (Figure 3D) in sewage effluent samples from the three offshore platforms analysed within the study period ranged between 4.00 mg l^{-1} to 30.1 mg l^{-1}. The values obtained for all the offshore platforms were below the 400MPN/100ml target specified by the DPR.

DISCUSSION

The physico-chemical and faecal coliform results of the treated sewage effluent samples from the nearshore houseboats and offshore platforms WWTPs when compared to the raw sewage samples revealed improved sewage quality within a 8 week study period. Sewage treatment using modern highly efficient compact systems comprising aerobic processes improves sewage quality and reduces its toxicity so that discharge or disposal to the environment does not pose any serious threat (Jowett, 1997, Iyo *et al.,* 1996a, 1996b).

However, when the values obtained from treated sewage analysis is compared with the DPR statutory limits the decision for further treatment becomes relevant putting into consideration the growing volumes of this sewage that will be discharged into the environment

Table 1: Characteristics of Untreated Sewage Effluent from Nearshore Houseboats and Offshore Platforms WWTPs

Samples	Characteristics					
	Temp., °C	Residual Chlorine, mg l^{-1}	BOD_5, mg l^{-1}	TSS, mg l^{-1}	DO, mg l^{-1}	Faecal Coliform, MPN/100 ml
Houseboat 1	30.4	0.02	175	240	6.28	1,600
Houseboat 2	27.9	0.09	120	200	7.82	1,200
Houseboat 3	31.1	0.03	140	166	7.20	1,600
Nearshore Mean	**29.8**	**0.05**	**145**	**202**	**7.10**	**1,467**
Platform 1	33.2	0.10	160	220	5.46	900
Platform 2	28.5	0.28	160	185	7.36	1,600
Platform 3	28.7	0.23	140	200	7.32	1,600
Offshore Mean	**30.1**	**0.20**	**153**	**202**	**6.71**	**1,367**

Table 2: Average DO Values (mg l^{-1}) of Sewage Effluent from Nearshore Houseboats

Location	Period (weeks)								Total	Mean	DPR Limit
	1	2	3	4	5	6	7	8			
Houseboat 1	5.60	5.20	7.65	7.79	3.51	6.26	7.55	5.89	49.45	6.18	
Houseboat 2	6.74	7.12	6.08	8.78	2.99	1.78	7.10	3.07	43.66	5.46	**4.00 - 5.00**
Houseboat 3	0.46	0.43	6.90	7.85	3.25	2.32	5.80	2.05	29.06	3.63	

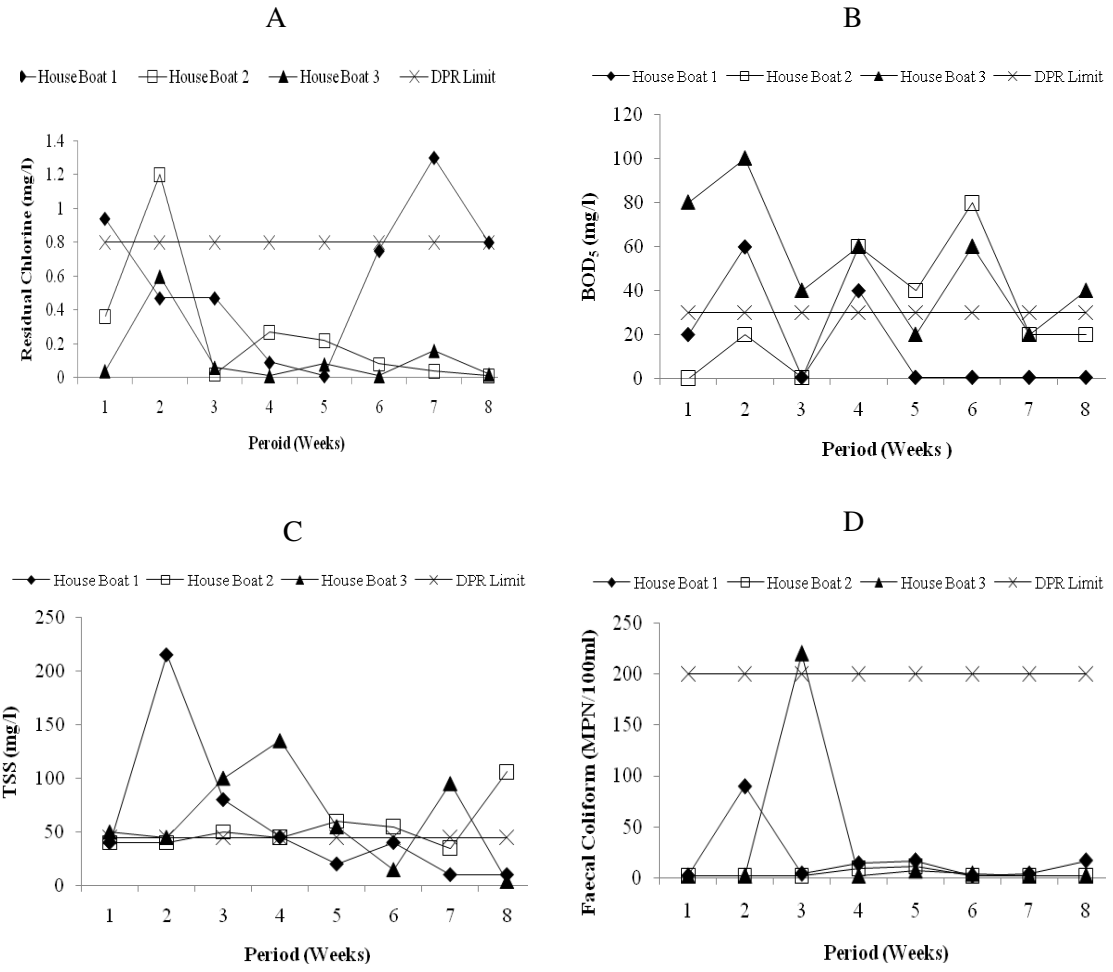
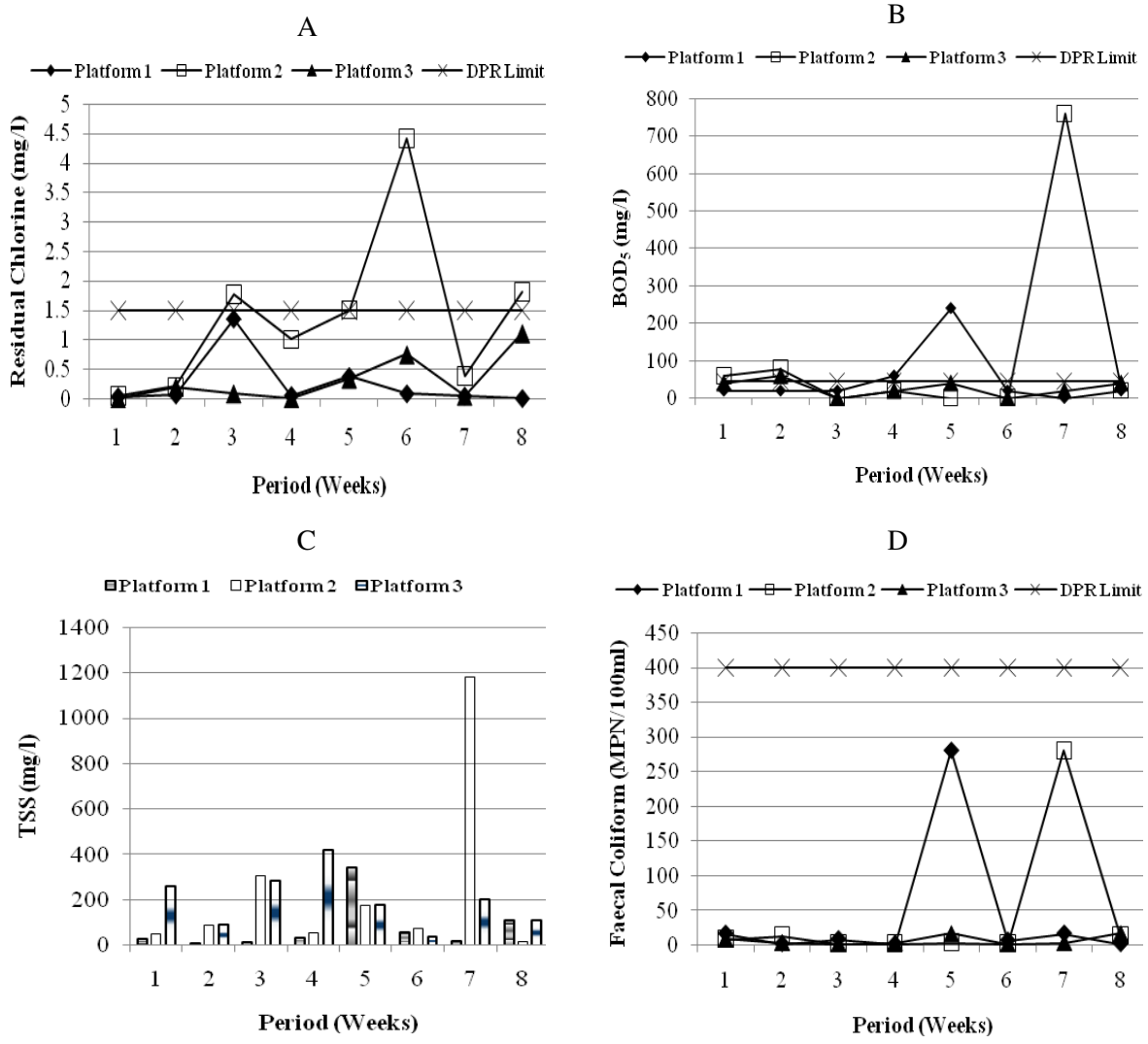


Figure 2: Physico-chemical and Faecal Coliform Parameters of Sewage Effluent from Nearshore Houseboats

Table 3: Average DO Values (mg l^{-1}) of Sewage Effluent from Offshore Platforms

Location	Period (weeks)								Total	Mean	DPR Limit
	1	2	3	4	5	6	7	8			
Platform 1	7.58	4.46	7.28	8.60	5.40	1.34	6.30	3.46	44.4	5.55	
Platform 2	5.48	5.26	7.60	6.97	3.27	6.65	3.22	5.95	44.4	5.55	**4.00 - 5.00**
Platform 3	4.20	6.88	6.47	7.98	0.73	6.26	5.35	0.65	38.5	4.82	



following increased nearshore and offshore oil exploration and production activities in the Atlantic Ocean of the Gulf of Guinea.

Chlorine is used in sewage effluent disinfection process before discharging into the sea. Residual chlorine reading in the treated sewage effluent shows evidence of completely destroying pathogenic bacteria. Residual chlorine values above the regulatory DPR limits of 0.8 mg l^{-1} and 1.5 mg l^{-1} observed in nearshore (houseboats 1 and 2) and offshore (platform 2) discharges respectively could be attributed to an excessive chlorine dosing or inadequate residence time of sewage effluent in the chlorination compartment.

BOD_5 is the measure of the quantity of oxygen used by bacteria consuming organic component of the sewage. It is corrected over a measured period of time at a fixed

temperature of 20°C in aerobic conditions. Higher the BOD_5 value, greater the pollution hazard (Beychok, 1971). Extremely high BOD_5 values of 240 mg/l for sewage from offshore platform 1 and 760 mg/l for sewage from offshore platform 2 are expected due to favourable conditions for increased microbial activities.

The TSS is the total amount of solid particles in suspension. Except for few discharge points, most of the points in nearshore houseboats indicated higher TSS values. Despite there is no regulatory DPR limit for TSS in sewage effluent offshore discharge, a TSS level of 80 mg l^{-1} appears to result in adverse effect on the macro invertebrate population (Garie and McIntosh, 1986). TSS levels in sewage effluent from offshore platforms were generally high (far above 80 mg l^{-1}). A high TSS provides high surface area for increased microbial activities (as evidenced in offshore platform 2 week 7) thereby leading to increased BOD_5 and rapid oxygen depletion. A high TSS in the sewage effluent discharged overboard could impair light penetration thereby reducing the ability of algae to photosynthesize (GEMS, 1992).

The DO is one of the most important parameters in aquatic life as it is an absolute requirement for the metabolism of organic materials by aerobic organisms and also influences inorganic chemical reactions. DO levels above the upper regulatory range in nearshore houseboats and offshore platforms are not considered to pose threat to the recipient aquatic environment .Waters with high concentrations of DO (specifically > 6.00 mg l^{-1}) have an additional advantage of serving as reserve or buffer to shock waste loads of high BOD / COD (KWW, 2001). Such waters are therefore considered healthy ecosystems and are capable of sustaining many species of aquatic organisms (Kiely, 1998; WSDE, 1991). However, DO levels in nearshore houseboats and offshore platforms below the regulatory DPR minimum value of 4.00 mg l^{-1} are indicative of DO deficient medium and unhealthy for the recipient marine environment.

Faecal coliform is non-pathogenic bacteria endemic in polluted water and its presence is utilised as guidance in the likelihood of occurrence of disease-causing bacteria in the water. From the microbiological analysis results, the percentage compliance of faecal coliform in treated sewage samples from nearshore houseboat WWTPs was 95.8% while that of offshore platform WWTPs was 100% within an eight week evaluation period. Therefore, a lower level of faecal coliform obtained in both nearshore houseboats and offshore platforms is an indication of reduced pathogenic bacteria. However, occasional increase in faecal coliform load in treated sewage discharged into the Atlantic Ocean of the Gulf of Guinea on regular basis has also been noted.

Further studies are required to discover faster and cost-effective methods of treating sanitary wastes which emanate from oil production facilities in order to achieve excellent removal of organic materials and microbial load. More work should also be done on possible reuse and recycling of treated water.

CONCLUSIONS AND RECOMMENDATIONS

WWTPs installed in three nearshore houseboats and three offshore platforms improved sewage quality discharged into the recipient Atlantic Ocean of the Gulf of Guinea within the study period.

However, some of the magnitudes obtained especially of residual chlorine, BOD_5 and TSS were higher than specified regulatory DPR limits. This indicates that the recipient environment may become polluted with time as the sewage effluents constantly discharge into the environment. We therefore recommend that the WWTPs should be optimized to enable the treated sewage effluent to meet the statutory DPR requirements for discharge into the environment**.**

The sewage slurry in the separation/aeration compartment can be seeded with aerobic heterotrophic microorganisms with high affinity for organic wastes to degrade faster. Together with an efficient filtration process, this procedure will drastically reduce the TSS level in the treated sewage.

Although removal of the faecal coliforms in the WWTPs through chlorination process gave encouraging results, it is also recommended that the sewage should pass through ultra violet (UV) radiation in order to achieve excellent removal of the microbial load. This will totally eliminate all potential opportunistic pathogenic organisms thereby making the treated sewage effluent water available for possible reuse and recycling such as flushing of toilets onboard.

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