NIPES

Journal of Science and Technology Research

Journal homepage: www.nipesjournals.org.ng

Performance Evaluation of Oke-Afa Wastewater Treatment Plant in Isolo, Lagos State, Nigeria

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Article Info

Keywords:*Performance Evaluation, wastewater,wastewater characteristics, treatment plant, wastewater treatment, Oke-Afa.*

Received 21 September 2023
Revised 25 October 2023
Accepted 26 October 2023
Available online 22 Dec. 23

https://doi.org/10.5281/zenodo.10426207

ISSN-2682-5821/

Abstract

For three months, the Oke-Afa wastewater treatment plant (O-AWWTP) located in Oke-Afa was studied. Data was collected from both the raw influent, which enters the WWTP, and the treated wastewater (effluent) from the plant. The parameters indicators, including pH, dissolved oxygen (DO), biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), total suspended solids (TSS), Ammonia (NH_3), electrical conductivity (EC), fecal coliform (FC), and Phosphate concentration (PO4) were tested for both samples to evaluate the performance of O-AWWTP. The removal efficiency of the plant in treating these parameter indicators was estimated, and the treatment plant reliability factor (RF) of each parameter indicator was calculated based on the NESREA-approved acceptable limit for discharge. Based on the study conducted, the effluent's average concentration of parameter indicators was determined. BOD_5 had a concentration of 18.242mg/l, pH had a concentration of 7.186, DO had a concentration of 7.499mg/l, COD had a concentration of 44.458mg/l, TSS had a concentration of 10.586mg/l, NH_3 had a concentration of 4.392mg/l, EC had a concentration of 237.917µS/cm, FC had a concentration of 31.250 MPN/100ml, and PO_4 had a concentration of 1.903mg/l. The plant's removal efficiency for these pollutants: BOD_5, COD, TSS, NH_3, FC, and PO_4 was 85.5%, 78%, 93%, 67.5%, 97%, and 71.2%, respectively. However, the plant's performance was deemed unsatisfactory in terms of COD, TSS, and FC removal as their average pollutant concentration in the effluent still exceeded the maximum permissible discharge limit set by the NESREA. Specifically, the limits for COD, TSS, and FC are ≤20mg/l, ≤0.75mg/L, and ≤1.0MPN/100ml, respectively. Based on the indicators tested, most of the estimated RF values were less than 1.0. However, the RF values for COD, TSS, and FC were above 1.0, with values of 2.20, 14.11, and 31.25, respectively.

1. Introduction

Wastewater refers to water that is contaminated to a degree where it cannot be used without treatment for most purposes. Water that contains various impurities can lead to diseases that may cause a pandemic. Hence, it is essential to use available water in the cleanest form, and this is where the concept of a water treatment plant, WWTP, comes in. A WWTP is used to convert wastewater with various impurities, such as garbage, chemicals, and biological matter, into a form that is fit for discharge. Untreated or inadequately treated wastewater poses a direct threat to the environment. Discharging untreated sewage into the water body can lead to severe contamination, resulting in eutrophication and intoxication of aquatic organisms, as well as chemical and biochemical transformations of pollutants that release harmful gases and disrupt the functioning of ecosystems.

All these factors can cause changes in the biotic conditions and the physicochemical composition of wastewater receivers [1, 2, 3, 4]. Therefore, it is crucial to ensure the proper functioning of the WWTP to effectively protect water resources from pollution from sewers [3, 4,5, 6, 9].

In a typical wastewater treatment plant, water is drawn from the nearest source and undergoes several stages of treatment. The first stage is screening, which removes larger floating particles. This is followed by aeration, which further treats the water. Next, coagulation is done in a flash mixer, and the water enters a tube settling tank to remove suspended impurities. After settling, the water goes through a filtration unit to remove fine particles. Then, chlorination is done using liquid chlorine to kill pathogenic bacteria and other harmful microorganisms. Finally, the treated wastewater is discharged. However, over time, the performance of the wastewater treatment plant may decrease, resulting in lower discharge standards. Therefore, it is necessary to periodically assess the plant's performance to ensure it meets regulatory standards. A survey showed that some wastewater treatment plants are not producing water that is safe for discharge. The current situation may result in numerous hygiene issues related to water. Each unit in the water treatment facility plays a crucial role in purifying wastewater. Hence, it is vital to examine the functioning performance of each unit. Over time, treatment plants may be required to upgrade their wastewater treatment units using the latest technologies. Evaluating the performance of a WWTP is essential in monitoring and determining its efficiency, providing better insight into design and operational problems in water treatment facilities.

As modern societies continue to develop, their growing populations increase the demand for water supply and wastewater treatment. Unfortunately, there is concern in the water sector due to the inadequate treatment of sewage and the resulting lack of clean water. According to the World Health Organization (WHO), up to 80% of illnesses and infections worldwide are caused by poor sewage treatment. Additionally, more than 3.4 million people die each year due to pathogens in the aquatic environment. This is why the environment and public health have been affected by current trends and practices of wastewater disposal and treatment, which often result in poor effluent quality. The Oke-Afa plant was originally designed and constructed in 1982 to serve around 40,000 inhabitants of Jakande estate. However, it is now serving over 50,000 people, which exceeds its intended capacity. A study conducted by (Yahaya et al. 2016) found that the Oke-Afa canal, which is the discharge point for treated water from the plant, is heavily polluted when compared to the National Environmental Standard and Regulation Enforcement Agency (NESREA)[8] standards. This situation calls for an evaluation of the system's performance to ensure the protection of water resources and management. Although this approach to wastewater treatment plants is common in more developed areas, similar studies in Nigeria and the African context have not been widely reported. Therefore, an attempt has been made to evaluate the performance of the wastewater treatment plant (WWTP) at Oke-Afa in Jakande estate to determine its removal efficiency and treatment capacity.

2 Materials and Method

2.1 Study Area

The research was carried out in Jakande estate, located at Isolo in the Oshodi-Isolo Local Government Area of Lagos State where the Oke Afa wastewater treatment plant is constructed. Jakande Estate has 600 buildings with six flats in each building. The estate was housing about 18,000 inhabitants at the time the treatment plant was built. Over time, the population figures for the estate increased as the estate is observed to be housing other public users who now rent apartments in the estate. The estate is purely residential with different commercial and other economic activities taking place. The estate has primary and secondary schools, churches, mosques, and markets in different locations within the estate. These led to the population growth to over 50,000 in the estate according to National Population Commission. The Oke-Afa Wastewater

Treatment Plant, (O-AWWTP) lies within longitude 6.532°E of the Greenwich meridian and latitude 3.304°N of the equator. It was built to serve about 40,000 people through the activated sludge process, with the capacity of doing primary and secondary treatment. The Oke-Afa plant treats domestic wastewater within the estate. Treated water from the plant is discharged into the Oke-Afa canal. It was observed that each of the residents uses about 135 litres of water daily, about six million litres of water is generated daily of which 80 percent or over four million litres become wastewater. The processes involved in the wastewater treatment at the Oke-Afa plant consist of Primary and secondary treatment with activated sludge process, and Tertiary treatment processes. Figure 1 shows the Google Earth imagery of the plant.

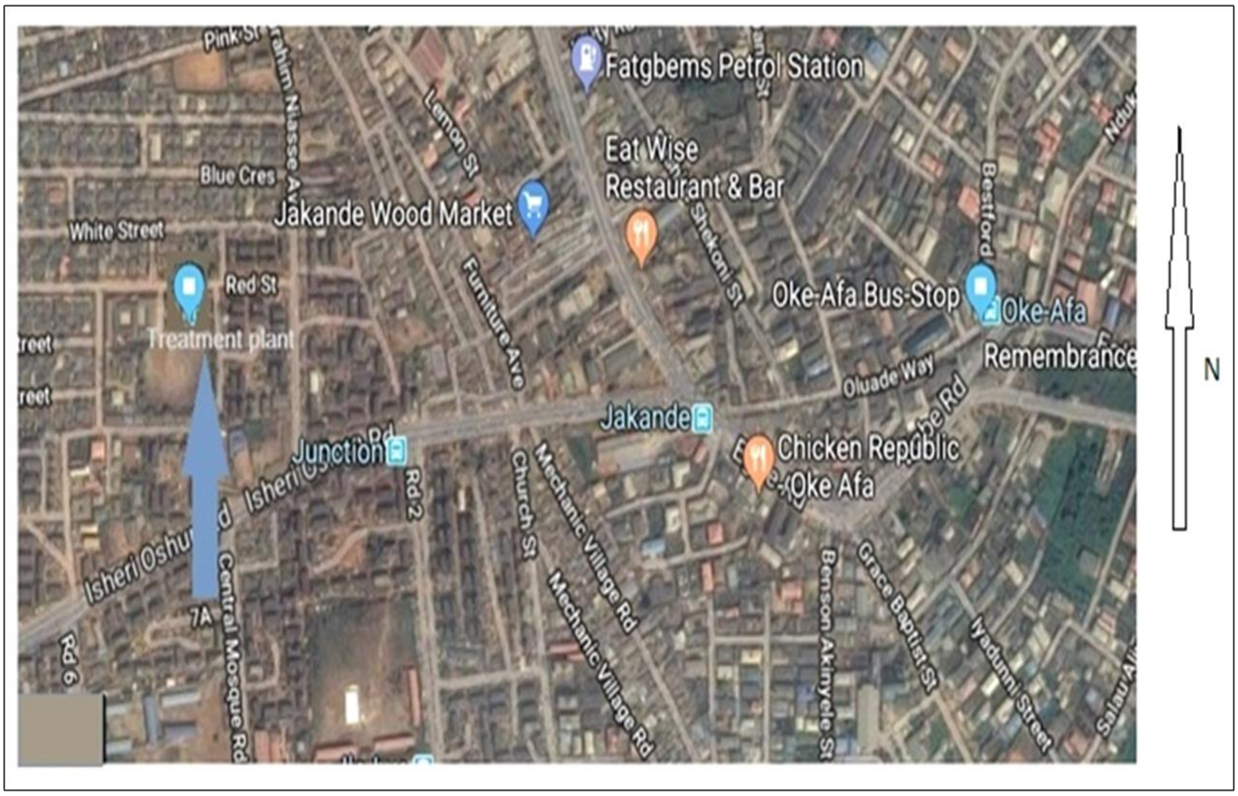


Figure 1: Map of the study area (Source: Google Earth Maps, 2019)

2.2 Sample Collection

For the study, wastewater samples were collected weekly for three (3) months, from July to September 2021 from the Oke-Afa Wastewater Treatment Plant (O-AWWTP). A total of twelve (12) samples of untreated wastewater (influents) and twelve (12) samples of treated wastewater (effluents) were collected for characterization and evaluation. Two sampling points were identified which include the wastewater treatment plant influent and the wastewater treatment plant effluent. The samples were collected with great care to avoid any disturbance or exposure to air. The collection time was chosen to be between 10:00 am and 3:30 pm, which is the period when most residents of the estate would have left their homes for their daily activities. This was to ensure that the sample was not fresh. To maintain hygiene, one-litre plastic containers that were previously cleaned were rinsed three times with the wastewater and labelled appropriately. The samples were then transported to the laboratory for analysis. Before analysis, the samples were preserved in a refrigerator and stored according to the recommended procedures in the standard methods, as stated in [7].

Pollutant parameters tested for these samples were the biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), total suspended solids (TSS), Ammonia (NH_3), fecal coliform

(FC), and Phosphate concentration (PO_4). Other parameters include pH, dissolved oxygen (DO), and electrical conductivity (EC). The values of the tested parameters were analyzed by using Excel 2010 software. Concentrations of effluent pollutants indicators after treatment were examined and compared with the permissible discharge limits of the Nigeria Environmental Standard Regulatory and Enforcement Agency (NESREA)[8]. The removal efficiency of the wastewater treatment plant was assessed on a pollutant-by-pollutant basis using equation 1 as follows:

$$\text{Removal Efficiency} = \frac{100\left(Influent - Effluent\right)}{Influent} \qquad (1)$$

Where;

Influent is the concentration of untreated wastewater pollutant indicator and *Effluent* is the concentration of treated wastewater pollutant indicator.

In addition, the value of the wastewater treatment plant reliability factor (*RF*) was estimated by the ratio of the averaged concentration of an evaluated pollutant indicator in the effluent wastewater and its permissible value in the wastewater discarded to the receiving river, as provided in the work of [4]

$$RF = \frac{X}{X_{Per}} \qquad (2)$$

Where;

X is the average concentration of a pollutant indicator in the effluent sewage (mg/L) and

$Xper$ is the permissible concentration of a pollutant indicator in the treated sewage (mg/L)

When the value of RF is greater than 1.0, it indicates efficiency of the wastewater treatment plant is low. Also, when the reliability factor (RF) is less than 1.0, it means the wastewater treatment plant is functioning optimally [9].

3. Results and Discussion

3.1 Wastewater Sample Assessment

The pollutant parameter indicators for wastewater samples were analyzed and the results were compared with the NESREA permissible discharge limits. The results of the analysis are presented in Tables 1, 2, and 3.

3.1.1 Total Suspended Solid (TSS): According to Table 1, the influent TSS concentrations varied between 102.300- 227.300mg/L, with a weekly average concentration of 155.183mg/L. Table 2 shows that the corresponding effluent ranged from 6.800-17.500mg/L, with an average weekly concentration of 10.586. The plant's TSS removal efficiency during the study period ranged was 93.0455%. However, the plant's performance was poor for TSS, as the effluent concentration exceeded the permissible discharge limit (<0.75 mg/L) set by NESREA [8], and the RF value was greater than 1.0, as shown in Table 3.

Table 1: Descriptive statistics of influent wastewater

Wastewater Parameter Indicator	Statistics			
	Range	Median	Mean	Standard dev.
BOD (mg/L)	97.900-169.20	124.000	127.508	22.155
COD (mg/L)	154.00-253.00	202.000	206.250	32.550
DO (mg/L)	2.760-4.230	3.760	3.662	0.501
EC (µS/cm)	217.300-321.000	263.000	267.500	31.567
TSS (mg/L)	102.300-227.300	152.850	155.183	40.276
pH (Nil)	7.120-7.760	7.410	7.406	0.197
PO_4 (mg/L)	5.430-7.440	6.985	6.648	0.729
NH_3 (mg/L)	10.800-17.300	14.100	13.917	1.700
FC (MPN/100ml)	840.000-1440.000	1125.000	1133.583	230.780

Table 2: Descriptive statistics of effluent wastewater, Removal Efficiency, and Standard Limit.

Wastewater Parameter Indicator	Statistics				Removal Efficiency (%)	Standard Limit (NESREA,2011)
	Range	Median	Mean	Standard dev.		
BOD (mg/L)	11.400-27.800	18.450	18.242	5.115	85.49719	30.000
COD (mg/L)	27.600-62.100	43.850	44.458	9.578	78.08495	20.000
DO (mg/L)	6.980-8.230	7.460	7.499	0.357		-
EC (µS/cm)	200.000-301.000	227.000	237.917	32.397	11.07719%	400.000
TSS (mg/L)	6.800-17.400	9.800	10.586	3.284	93.0455	0.750
pH (Nil)	7.020-7.520	7.135	7.186	0.162		-
PO_4 (mg/L)	1.030-3.220	1.825	1.903	0.648	71.21919	3.50
NH_3 (mg/L)	2.660-6.880	4.265	4.392	1.237	67.46351	10.00
FC (MPN/100ml)	10.000-80.000	20.000	31.250	26.894	97.00082	1.000

Table 3: Treatment plant reliability factor (RF) for the evaluated wastewater indicators

Wastewater Parameter Indicator	Average Effluent Concentration	Maximum Allowable Concentration	Estimated Plant Reliability Factor (RF)
BOD	18.242 mg/L	30.000 mg/L	0.608
COD	44.458 mg/L	20.000 mg/L	2.223
EC	237.917µS/cm	400.000 µS/cm	0.595
TSS	10.586 mg/L	0.750 mg/L	14.11
PO_4	1.903 mg/L	3.500 mg/L	0.544
NH_3	4.392 mg/L	10.000 mg/L	0.439
FC	31.25 MPN/100ml	1.0 MPN/100ml	31.25

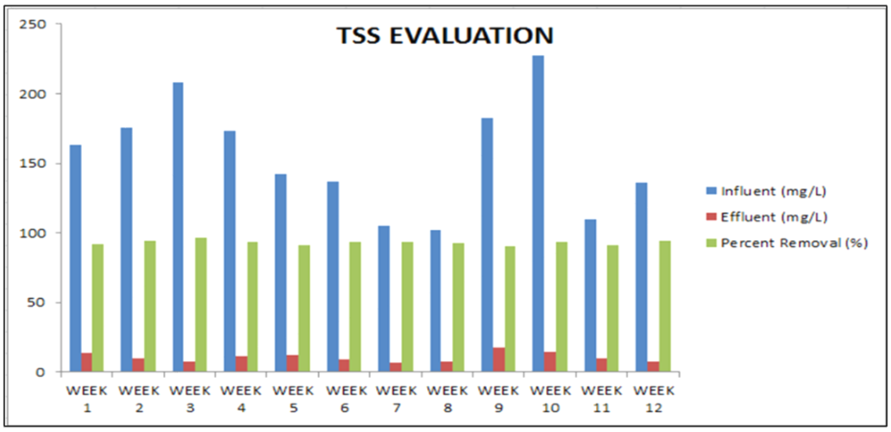


Figure 1: Weekly variation of TSS in the influent and effluent wastewater

Figure 1 presents graphical representations of the weekly variation in TSS concentrations. The highest percentage of TSS removal occurred in week 10 and week 12, while the lowest effluent TSS concentrations were recorded in week 7, week 8, and week 12. Effluent concentrations demonstrated low variability in comparison to influent concentrations. Overall, the treatment plant displayed a good capacity to deal with the presence of TSS in the influent wastewater, but the effluent concentration was higher than the discharge limits.

3.1.2 Electrical Conductivity (EC): This measures the wastewater's ability to conduct an electrical current. The electrical conductivity levels of the influent wastewater, as shown in Table 1, ranged from 217.0-321.0 µS/cm with an average weekly value of 267.50 µS/cm. The corresponding effluent value ranged from 200.0-301.0 µS/cm with an average value of 237.92 µS/cm, as presented in Table 2. The average enhancement efficiency of the plant for EC, as shown in Table 3, was 11.07719%. Although the plant's performance in handling this pollutant was poor, the observed (EC) values of both influent and effluent concentrations were below the permissible limit (<400 µS/cm) set by NESREA [19]. Additionally, the RF value remained below 1.0 during the study period.

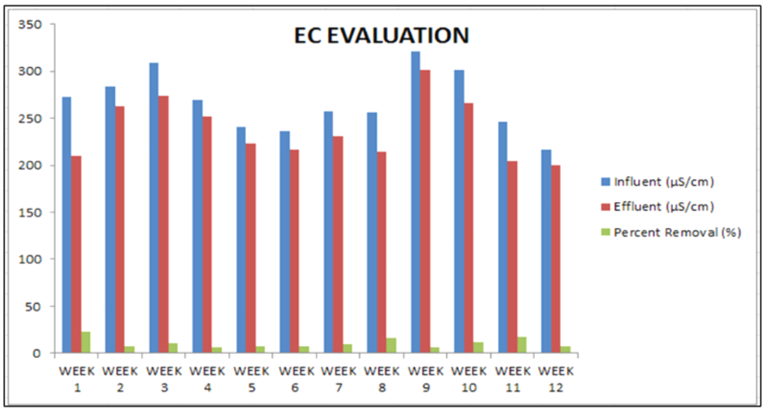
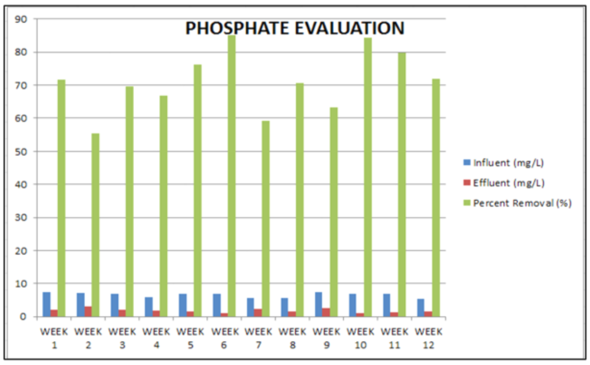


Figure 2: Weekly variation of EC in the influent and effluent wastewater

Figure 2 shows that the greatest reduction of EC was observed during the first and eleventh weeks, whereas the lowest concentration of effluent EC was recorded during the first, eleventh, and twelfth weeks as presented in Figure 2. Overall, the treatment plant exhibited a limited ability to handle the presence of EC in the influent wastewater, with minimal variation between the influent and effluent concentrations.

3.1.3 Phosphate (PO_4) and Ammonia (NH_3): The levels of phosphate and ammonia in wastewater are important indicators of water quality and pollution. High levels of these substances can lead to nutrient pollution, which can harm aquatic ecosystems and human health. During the study period, the minimum and maximum weekly influent concentrations of phosphate were 5.430mg/L and 7.44mg/L, respectively, with an average weekly concentration of 6.648mg/L. The minimum and maximum weekly concentrations of ammonia were 10.80mg/L and 17.30mg/L, respectively, with an average concentration of 13.92mg/L as presented in Table 1.
The effluent concentration of phosphate ranged from 1.03-3.20mg/L, with an average concentration of 1.90mg/L. The effluent concentration of ammonia ranged from 2.66-6.88mg/L, with an average concentration of 4.39mg/L. These concentrations are below the standard limit as reported in [8].
The removal efficiency of phosphate was 71.21919%, while the removal efficiency for ammonia was 67.46351%. These efficiencies are moderate in value and may be related to the variability of the effluent wastewater in terms of its source and composition. Nevertheless, the treatment plant showed good capacity to treat these parameters since their RF is less than 1.0, which indicates optimal plant performance [9]. The weekly variations of PO_4 and NH_3 in the influent and effluent of the treatment plant are presented in Figures 3 and 4 respectively.



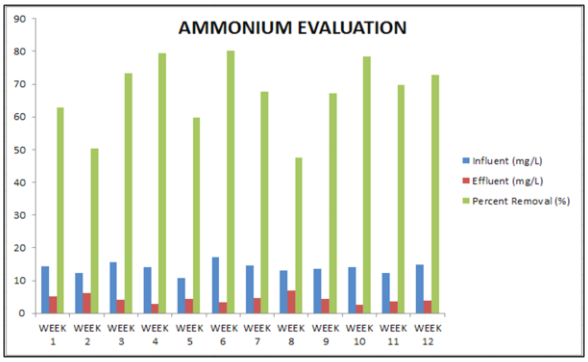
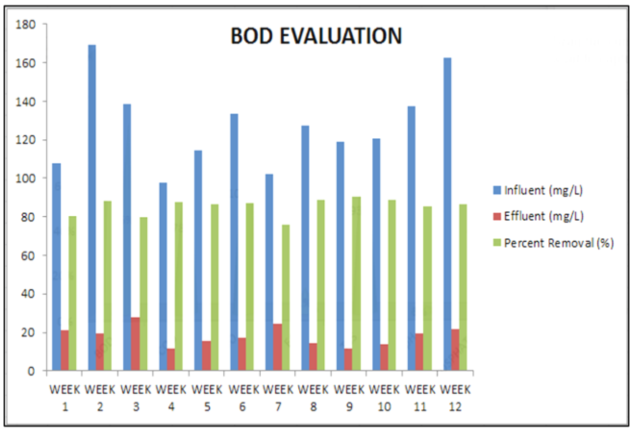


Figure 3: Weekly variation of PO_4 **in the influent and effluent wastewater**

Figure 4: Weekly variation of NH_3 **in the influent and effluent wastewater**

Based on the findings in Figure 3, the greatest reduction in PO_4 was observed in weeks 6 and 10, with the lowest concentration of PO_4 found in the effluent during the same period. Similarly, Figure 4 shows that the highest percentage decrease in NH_3 occurred in weeks 6 and 10, with the lowest NH_3 concentration in the effluent recorded during weeks 4 and 10.

3.1.4 Assessment of Oxygen Demand (BOD, COD, DO): The amount of dissolved oxygen (DO) consumed by biological organisms when they decompose organic matter in water is known as the biochemical oxygen demand (BOD). On the other hand, the chemical oxygen demand (COD) is the amount of oxygen consumed when the wastewater sample is chemically oxidized. Both BOD and COD can have negative effects on the oxygen levels of lakes and rivers, causing eutrophication and harm to aquatic life. In Tables 1, 2, and 3, the oxygen demand of pollutant indicators during the investigation period was presented. The plant demonstrated optimal performance for BOD, with an effluent concentration that was less than the permissible discharge limit (≤ 30mg/L) set by NESREA, an average weekly removal efficiency of 85.5%, and an estimated RF of 0.608. However, the average weekly effluent concentration for COD (44.46mg/L) was still higher than the recommended permissible limit of 20mg/L [8]. This may be due to the presence of non-biodegradable organic matter in the wastewater or the plant operating below full capacity. The RF for COD was estimated to be 2.223. Nevertheless, the effluent DO concentration during the study period was observed to be higher than the NESREA standard, indicating that the receiving water body is safe for aquatic life as there is enough oxygen in the effluent of the wastewater. The weekly variations of BOD and COD in the influent and effluent of the treatment plant are presented in Figures 5 and 6 respectively.



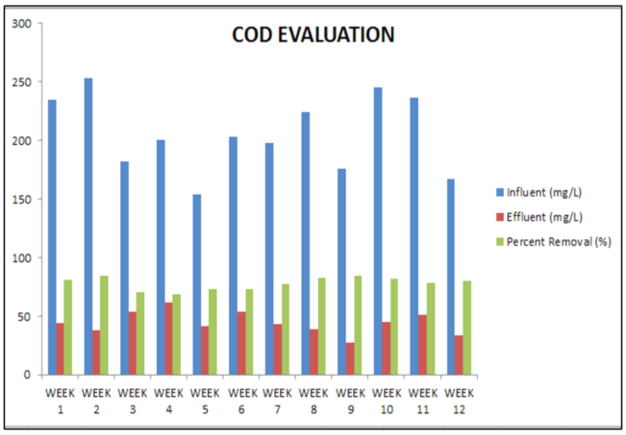


Figure 5: Weekly variation of BOD_5 **in the the influent and effluent wastewater**

Figure 6: Weekly variation of COD **in influent and effluent wastewater**

According to the findings in Figure 5, the greatest reduction in BOD levels occurred during the ninth week, while the lowest effluent BOD concentration was measured during the fourth and ninth weeks. The wastewater treatment plant demonstrated effective management of BOD in the influent wastewater. In Figure 6, the highest percentage removal of COD was reported during the second and tenth weeks, with the lowest effluent COD concentration being recorded during the ninth and twelfth weeks. The treatment plant demonstrated moderate effectiveness in the COD management of influent wastewater. The effluent concentration of both BOD and COD showed minimal variation compared to their influent concentration. The weekly variations of DO in the influent and effluent of the treatment plant are presented in Figure 7.

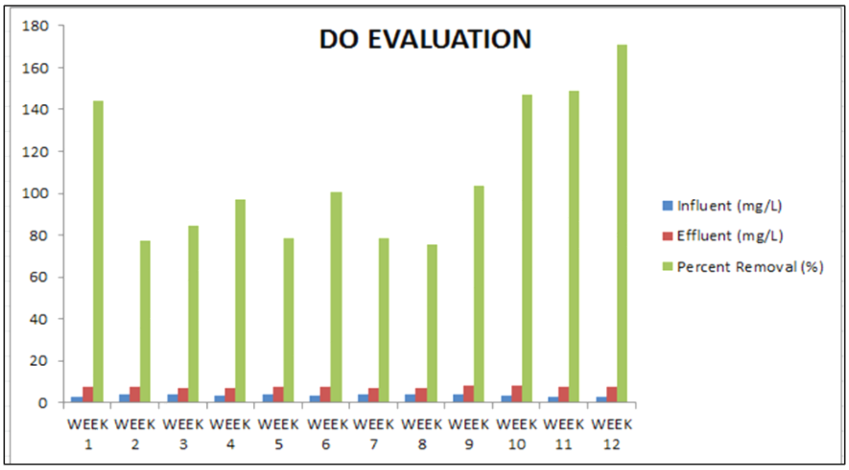


Figure 7: Weekly variation of DO in the influent and effluent wastewater

Based on the findings presented in Figure 7, the highest percentage increase in dissolved oxygen (DO) was observed during week 1, week 10, week 11, and week 12. Conversely, the concentration of effluent DO remains consistent throughout the entire sampling period. Generally, the treatment plant exhibited effective capabilities in managing low DO levels in the influent wastewater, with only low fluctuations observed in the effluent and influent concentrations.

3.1.5 Fecal Coliform (FC): Fecal pollution refers to the presence of disease-causing microorganisms in bodies of water, which typically results from human sewage or excreta from warm-blooded animals. Some coliform bacteria can make people ill, leading to symptoms such as vomiting, fever, diarrhea, or an upset stomach. In the treatment plant under investigation, both the influent and effluent concentrations exceeded the allowable discharge limit of 1.0MPN/100ml per week, as shown in Tables 1 and 2. Despite achieving a removal efficiency of over 97%, the average weekly concentration (31.250MPN/100ml) still exceeded the permissible discharge limit and had an RF value greater than 1.0, as indicated in Table 3. The treatment plant currently cannot effectively handle the presence of fecal coliform in the influent wastewater. Therefore, it is necessary to improve the plant's capacity to treat this presence before discharge. This will ensure that harmful microbes are eliminated and the receiving canal remains safe.

3.1.6 pH Assessment: During the investigation period, the wastewater coming in had pH levels mostly in the basic range, varying from 7.120 to 7.760. The wastewater going out, however, had levels in the neutral to slightly basic range, varying from 7.020 to 7.520. The uniformity of the effluent wastewater concentrations could be attributed to the pH adjustment that occurs during the wastewater treatment process. It is worth noting that this pH value falls within the recommended standards by NESREA, which recommended that effluent concentration should be between 6.5 and 8.5.

4.0. Conclusion

The performance of the Oke Afa wastewater treatment plant was evaluated, and the results indicated that the plant is not operating at its optimum level. The analysis of the effluent from the plant showed that the concentration of effluent parameters such as fecal coliform (FC), total suspended solids (TSS), and chemical oxygen demand (COD) exceeded the permissible discharge limit set by NESREA for effluent wastewater before it is discharged into the environment. The discharge limit set by NESREA for TSS and COD is 0.75mg/L and 20mg/L, respectively, and that for FC is 1.0 MPN/100ml. The analysis revealed that the average weekly concentration of effluent TSS was

10.586mg/l, that of COD was 44.458mg/l, and FC was 31.250 MPN/100ml. The corresponding average removal efficiencies for COD, TSS, and FC are 78.08%, 93.05%, and 97%, respectively. The reliability factor (RF) of the treatment plant estimated was 2.2 for COD, 14.11 for TSS, and 31.250 for FC. Since the estimated reliability factor was greater than 1.0, it was concluded that the plant was not functioning optimally.

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