Assessment of the efficiency of wastewater treatment plant in oil and gas firm in Eleme Rivers State, Nigeria.

ABSTRACT

The aim of the study was to determine the efficiency of a wastewater treatment plant and the quality of effluent discharged by the plant into the receiving water body (Okochiri River) in Eleme, Rivers State. The study lasted for a period of four months. Wastewater samples were collected at various stages of the treatment unit and tested for major water quality parameters such as Biological Oxygen Demand, oil/grease, phenol, Dissolved Oxygen (DO), Total Suspended Solids (TSS), and sulphide. In general, the composite wastewater treatment system (comprising dissolve air floatation, Rotary Bio-Disk, and sedimentation unit) were effective in pollutant removal, with the exception of sulphide, which had a negative efficiency (-238%). However, some individual system units were inconsistent in removing specific pollutants, such as the dissolve air flotation unit (-25% average efficiency of sulphide removal); and the rotary bio disk, which was inefficient in maintaining DO and pH within optimal levels. Except for phenol, which measured 2.37mg/l against a 0.5mg/l DPR limit, and TSS, which measured 298mg/l against a 200mg/l DPR limit, the characteristics of effluent discharged into recipient water were generally within their respective DPR limits. In line with Pearson Correlation there are strong positive relationships between several parameters, such as pH and Sulphide (0.93), Phenol and Oil/grease (1.00), and Phosphate and Sulphide (0.91). The Principle Component Analysis yielded four principle components (PC1-4): PC1 parameters with the highest loadings on the first factor (D1) were sulphates and phenols, whereas Chemical Oxygen Demand and Biological Oxygen Demand had the highest loadings on the second factor (D2). Dissolved oxygen was most strongly associated with the third factor (D3), and pH was the parameter with the highest loading on the fourth factor (D4). It is recommended that the wastewater treatment system's overall efficiency be improved in order for the system to consistently meet regulatory limits for pollutant control. Recommendations for improving system efficiency include: (1) ensuring regular maintenance of individual units in the treatment plant; and (2) maintaining optimal operating conditions for the rotary bio-disk unit in terms of temperature, pH, nutrient, and dissolved oxygen to ensure effective biological removal of pollutant.

Keywords: Waste water treatment plant, BOD, TSS, Biological treatment, Removal efficiency.

1. INTRODUCTION

Water is a valuable commodity that is scarce in most countries, and protecting water resources is one of the challenges that engineers, hydrologists, technologists, and scientists face (Garbowski, Winiewski, & Bawiec, 2018). According to the World Health Organization (WHO) citeyear, 80% of illnesses and infections in the world are caused by inadequate sewage treatment, and pathogens living in the aquatic environment kill more than 3.4 million people each year (Kumar, Kumar, & Babu, 2016). Wastewater is essentially liquid waste that has been contaminated by a variety of uses. During its application, the water supplied to a specific region or apartment contains several chemical substances and microbial organisms, causing the wastewater to have a polluting potential and become a health and environmental hazard. Untreated wastewater disposal spreads communicable diseases of the gastrointestinal tract such as cholera, typhoid, dysentery, and water-borne diseases such as infectious hepatitis, so the primary goal of sanitary wastewater disposal is to prevent communicable diseases and protect public health (Kumar, Kumar, & Babu, 2016). However, due to population growth and a lack of sanitation and wastewater management practices, one of the major challenges confronting developing countries has been the management and handling of wastewater. In developing countries, 80-90% of wastewater is discharged directly into bodies of water.citation? Because of a lack of sanitation infrastructure, 62% of the urban population in Sub-Saharan Africa disposes of wastewater directly into water bodies.

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Wastewater treatment is the process and technology used to remove the majority of the contaminants found in wastewater in order to maintain a healthy environment and public health. Wastewater management thus entails handling wastewater in order to protect the environment and ensure public health, economic, social, and political stability (Metcalf and Eddy, 1991). In most cases involving domestic wastewater, treatment consists of removing total suspended solids and BOD_5, which are the two most important parameters. When treated effluent is discharged into a watercourse or land, the degree of treatment provided to the wastewater is primarily based on the effluent standards prescribed by regulatory agencies. If the effluent is reused, the effluent quality required to support such reuse will indicate the level of treatment required. The complete wastewater treatment procedure that involves a sequential combination of several physical unit operations as well as chemical and biological unit processes.The statementis hangingThe degree of reduction of BOD and suspended solids, which constitute organic pollution, is the general indicator used to evaluate the performance of a sewage treatment plant (Choksi, Sheth, & Mehta, 2015). The treatment plant's efficiency is determined not only by proper design and construction, but also by proper maintenance and operation (Kumar, Kumar, & Babu, 2016).

The economic effects of hazardous waste discharge on urban cities can be classified into direct, indirect, and induced impact (Abere et al., 2020). Direct impacts include revenues and added-value. Indirect impacts are mainly caused by crude oil and natural gas production activities. Induced effects include income and added-value addition caused by the income of waste management. According to Abere et al., 2020, if properly managed, hazardous waste could become a source of huge economic benefit to both the generator and the host community. Waste is a result of businesses, government, and household activities or by material or energy recovery (Gu et al., 2014). Hence, the environment and government are affected by waste management. For instance, hazardous waste management can generate employment through job Creation. Countries like India and the United States of America generate between 15- 18% of employment (full-time or part-time) employment. Needs citation. The sector applies individuals throughout the world for high wages to be spent and tax the government. However, Hazardous waste management can pose a great danger to human life if not properly managed. Far be it from exaggeration that between 15-20% of death recorded in a petrochemical related occupation results from the miss-management of hazardous chemicals (Wang et al., 2015). The

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corrosiveness of hazardous waste varies in terms of effectiveness, tonnage, combustion, ignitibility, etc. Tonnage is essential in impact assessment, so the more the tonnage increases, and the risk probability for human and animal increases. This implies a relative difference in the level of danger by a particular element in a discharge. In terms of tonnage, some low tonnage waste may be more dangerous than others with higher tonnage. For instance, Cadmium, Lead, Nitrogen, Zinc compounds, and wastes fall into the higher risk element category. Alkali's acute results could refer to skin, mouth, throat, or eyes burns (Roy and Mcdonald, 2015).

Nigeria has four operational oil refineries with an estimated total refining capacity of 445,000 barrels per day (Oluwatomiwa et al., 2017). The four refineries came under the ownership and management of the Nigerian National Petroleum Corporation (NNPC) in 1986. The Niger Delta is home to three of these oil refineries. These refineries regularly make use of water for most processes including, distillation, hydrotreating, desalting, boiler feed water required for the generation of steam, cooling water used for water-cooled condensers, product coolers, and other heat exchangers (Oluwatomiwa et al., 2017). This results to the production of wastewater which is discharged to the environment after treatment. Typically, the effluent is regulated by environmental protection agencies by setting up the discharge standards as well as performing a regular check. In Nigeria, the Federal Environmental Protection Agency (FEPA) is responsible for setting the minimum standards for industrial effluents and consequently, industries are obligated to monitor and control their effluents to ensure they meet this standard. This involves analysis of the effluents to determine its composition and a possible treatment before discharge into inland water (Nkwocha et al., 2013). According to Basheer et al. 2011, a typical refinery wastewater treatment plant consists of three major processes which include the primary treatment, followed by biological treatment, and tertiary treatment (if necessary), commonly known as advanced treatments.

However, these conventional techniques are not adequate and efficient to solve the problem of massive oil contamination. In recent years, nanotechnology has been found to be a potential and promising source of novel solutions for oil spill cleanup, with several approaches involving a vast range of nanomaterials (nano-catalysts, nano-adsorbents, and nanomembranes), which have been proven to be very effective due to their increase surface area and, in turn, a higher reactivity (Kharisov et al., 2014). As regards to oil refinery wastewater treatment, this technology has shown a great potential as a low-cost, environmentally friendly, and sustainable treatment technology to remove persistent organic pollutants (POPs) to overcome the shortcomings of the conventional technologies. For example, the photocatalytic degradation process has attracted increasing attention during the past decades due to its effectiveness in rapidly degrading and mineralizing recalcitrant organic compounds (Miranda-Garcia et al., 2011). This treatment technology has advantage over other conventional treatments, including other AOPs, such as homogeneous photo-Fenton, UV/H2O2, UV/O3, and UV/H2O2/O3 (Rajeshwar et al., 2008), as it overcomes the problems of incomplete pollutant removal, high consumption of chemical reagent, high treatment cost, long duration, and generation of toxic secondary pollutants (Zhou et al., 2014).

Eleme City's wastewater management system is incapable of meeting current demands. The city's private residential areas lack an elaborate sewerage network. However, poor plant management has resulted in the discharge of raw untreated and partially treated sewage into the environment. This has resulted in river pollution, poor health, and a lower quality of life within the treatment area and among other users. As a result, it is necessary to assess the efficiency of the wastewater treatment plant and propose any potential improvements or solutions. There is an incoming wastewater flow at any wastewater treatment plant; this flow is treated before it is allowed to be returned to the environment, lakes, or streams. Wastewater treatment plants treat waste at a critical point in the water cycle, protecting nature from pollution (Al-Dosary, Galal, & Abdel-Halim, 2015).

2. METHODOLOGY

2.1 STUDY AREA

This study was carried out in Alesa Eleme which is in River State, Nigeria. Eleme Local Government Area (LGA) of Rivers State is a satellite town lying 31 kilometers from Port Harcourt (Figure 1). On the south-eastern Nigeria map Eleme can be found between coordinates 7E and 8E ,4N and 5N. It is surrounded by different ethnic groups: Igbos to the Northwest, Baan to the west and Gokana to the south. Eleme Local Government is an administrative Subdivision of Rivers State, it covers an area of $138km^2$ and at the last census (2006) had a population of 190,884 (www.wikipedia.org). Eleme has two of Nigeria's four petroleum refineries and one of the Nigerian's sea ports and the largest sea port in west Africa located in one of the most famous Town called Onne (Udogu, 2005).

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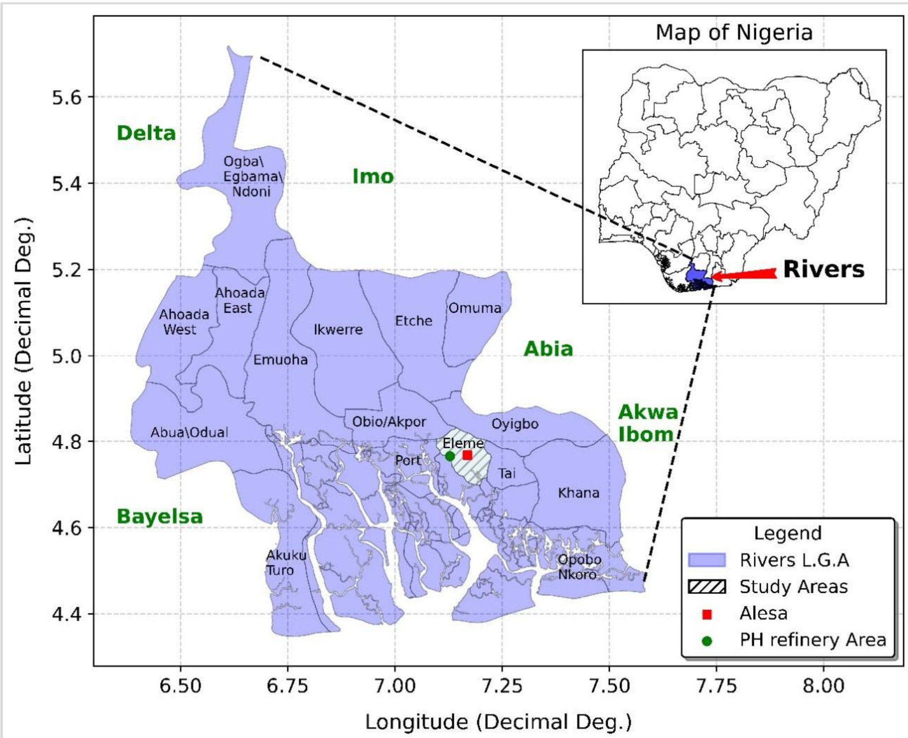

Figure 1: Map of the Study Area

2.2 Sampling collection

Influent and Effluent grab samples comprising of waste water samples were collected from the different units of the treatment plant comprising of RBD's (A,C,D,E,F), CPI A, CPI B,DAF basin, sedimentation basin of Waste Water Treatment Plant (WWTP) and analyzed for selected physico-chemical parameters, from May – September (Rainy season).

Samples were collected in bottle containers previously cleaned by washing in non-ionic detergent, rinsed with tap water and later soaked in 10%HNO_3 for 24 hours and finally rinsed with deionised water prior to usage. Before sampling, the bottles were rinsed three times with sample water before being filled with the sample. Samples were accompanied with proper identification and labeling at point of sampling then transported to the laboratory for analysis.

In collecting the samples, airspace was left in the bottles to facilitate mixing by shaking and aseptic techniques were adopted to avoid contamination.

Samples for laboratory analyses were transported in iced-packed coolers to POCEMA and, NNPC laboratories for analysis. Sample storage was carried out according to standard laboratory procedures as recommended by the American Society for Testing and Material (ASTM)Reference?. In situ measurements were carried out on some physico-chemical parameters such as, Temperature, pH, Conductivity and DO. Hach Test Kit CE1890 was used for pH, Conductivity and Dissolved oxygen. All these measurements were carried out in-situ after proper calibration of the meters, while the remaining parameters were analyzed in the laboratory.

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2.3 Methods of Data Analysis

Efficiency of the unit (average concentration of oil/grease in RW-average concentration of oil/grease in TW)/ (average concentration of oil/grease in RW) x100)The formulashould beput better.Pearson Correlation coefficient was carried to establish the relationship between the physiochemical parameters of raw wastewater. In order to carry out the Principal Component Analysis (PCA), Bartlett's sphericity test was conducted to assess the suitability of the dataset for PCA computation. The PCA is a factor reduction technique adopted to identify the principal factors adjudged by eigen value greater or equal to one (Nwaogazie, 2021).

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3. RESULTS AND DISCUSSION

3.1 Performance Evaluation of DAF and RBD Units

Results of analysis showing the performance of the wastewater treatment units are presented;

two units were evaluated. The Dissolved Air Floatation (DAF) unit and the Rotary Bio-Disk (RBD). Wastewater is first skimmed of oil and grease in the CPI and then flows to the Dissolved Air Flotation unit. The oil and grease level in the inlet is usually not monitored and the raw water is pumped into the CPI.WhatisCPI? However, the oil and grease in the outlet before flowing to the DAF unit was measured, thus the performance of the DAF unit and the RBD unit in treating the wastewater was evaluated. Table 1 shows the result of the CPI outlet.

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Table 1: Result of CPI outlet

Monitoring Month	Outlet (PPM)
May	2
June	4.5
July	4.4
August	1.5
September	3.75

Several parameters such as oil and grease, Total Suspended Solids (TSS) and Sulphides were monitored to evaluate the removal efficiency of the DAF unit. The parameters phenol, phosphate, and ammonia were generally not complaint with the design specifications for the treatment unit. However, for DAF, oil/grease , Total Suspended Solids (TSS), and sulphide removal are of primary importance. The importance of the DAF unit with regards to those parameters are presented in the Figures 2- 4.

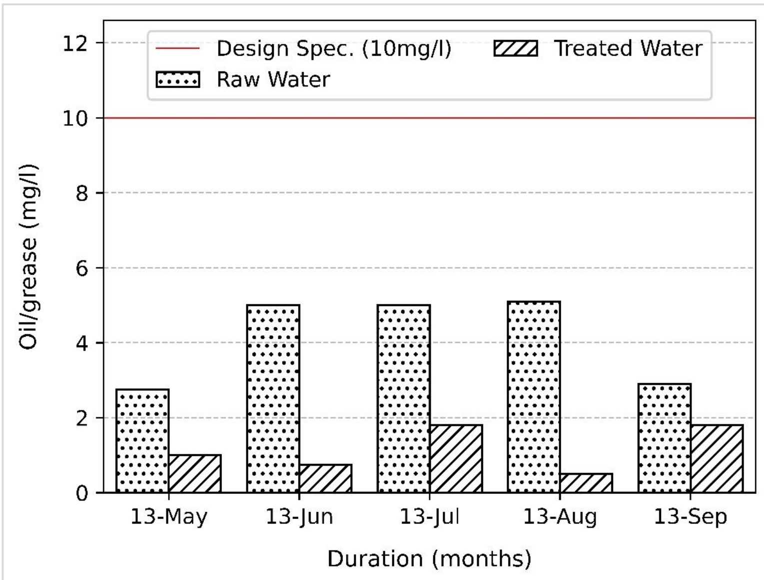

Figure 2: Performance of DAF Unit - Oil/ Grease Removal

The performance of the DAF unit with regards to removal of total suspended solids (TSS) is presented in Figure 3.

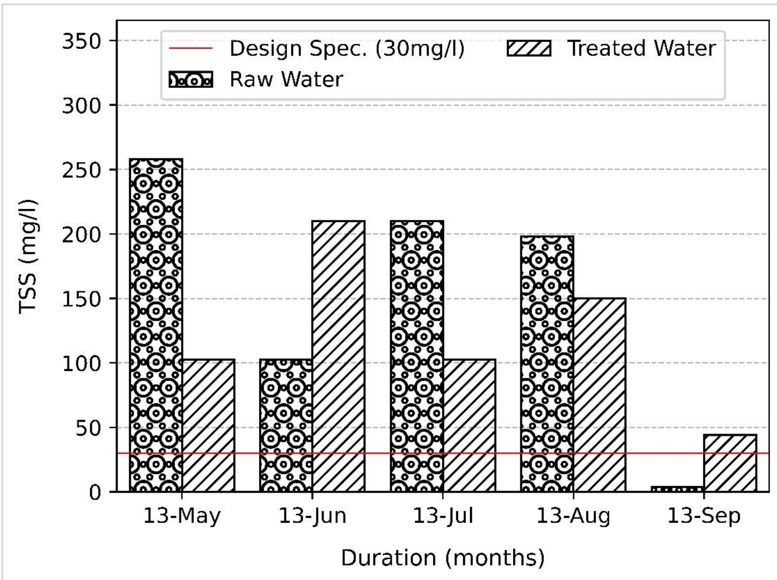

Figure 3: Performance of DAF Unit- TSS removal

The results show a general removal of TSS from DAF unit except for the months of June and September when levels of TSS in treated water were greater than in raw water.Why?Give a probable reason The average efficiency of unit, was (155-122/155) X 100 =21.3% (POSITIVE EFFICIENCY). On average therefore, the DAF unit was efficient (for the period investigated) with regards to TSS removal. It is noteworthy that the TSS contents of raw water far exceeded the design specification for the DAF unit. It is Similar for the treated water effluent. The performance of the DAF unit with regards to removal of sulphides is presented in Figure 4.

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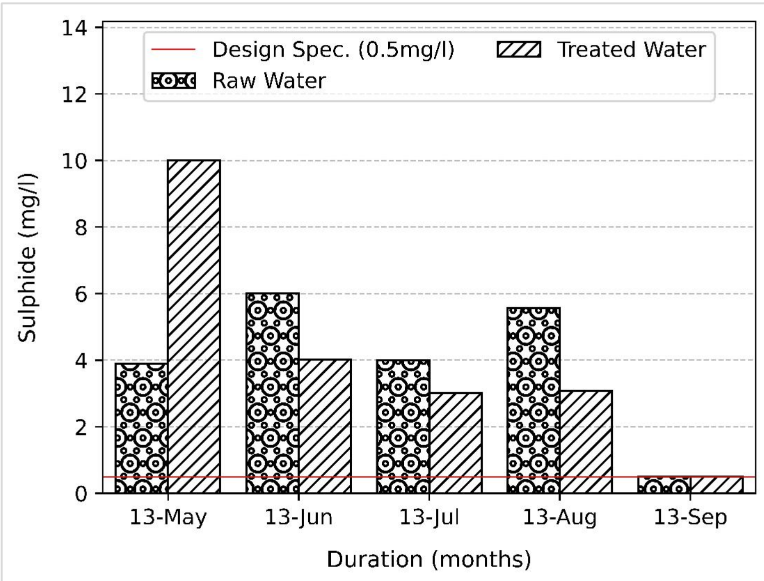

Figure 4: Performance of DAF Unit- Sulphide removal

The results show that the DAF unit reduced oil/grease content of wastewater (Positive efficiency) for the months that were investigated. On average, the efficiency was calculated as (3.67-1.34/3.67) x100= 63.5%. Therefore, the DAF unit was efficient with regards to oil/grease removal. The oil/grease content of raw and treated water effluents was within the design specification of the DAF unit. Similarly, TSS removal efficiency was positive as the average removal efficiency was (155-122/155) X 100 =21.3%. Therefore, the DAF unit was efficient (for the period investigated) with regards to TSS removal. It is noteworthy that the TSS contents of raw water far exceeded the design specification for the DAF unit. Conversely, the sulphide content of the treated water was lower than the raw water except for in the month of May and September. The average efficiency of removal of sulphides was, (4-5/4) x 100=-25% (negative efficiency). However, if the exceptionally poor performance in May is ignored, the efficiency of the unit of June-September becomes, (4.02-2.65/4.02) x 100= 39%. The DAF unit therefore removed sulhides but efficiency of removal was inconsistent. It is noteworthy that the levels of sulphides in both raw and treated water effluents were above the design specification for the unit.

3.2 Rotary Bio Disk (RBD) Unit

Only Five (5) out of twelve 12 Rotary Bio- Disks were functional at the period of the research. Three parameters DO, Phenol and BOD_5 were monitored to evaluate their removal efficiency in the RBD.

The performance of the units with reference to dissolved oxygen conditions is presented in Figure 5.

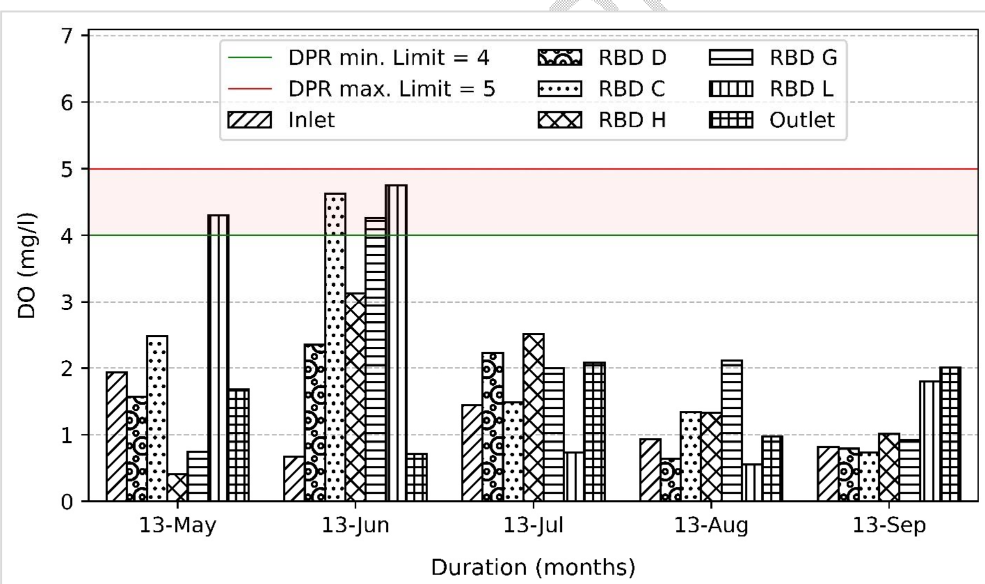

Figure 5: Performance of RBD Units- Dissolved Oxygen (mg/l)

3.3 Pearson Correlation

Table 2 presents the relationship between the physiochemical parameters of raw wastewater. There are strong positive relationships between several parameters, such as pH and Sulphide (0.93), Phenol and Oil/grease (1.00), and Phosphate and Sulphide (0.91). These relationships indicate that the presence of one variable is associated with a high presence of another.

Table 3 shows the relationship between the physiochemical parameters of treated wastewater. After treatment, the relationships between several parameters have weakened or changed. For example, the relationship between Phosphate and Sulphide has decreased to 0.72, and the relationship between Oil/grease and Phenol has become negative (-0.14). Additionally, the relationship between Temperature and Conductivity has become strongly negative (-0.68).

The results of this study demonstrate that wastewater treatment processes can significantly alter the relationships between physiochemical parameters. The weakened relationship between Phosphate and Sulphide after treatment may suggest that the treatment process has successfully reduced the concentrations of these pollutants in the wastewater. However, the emergence of negative relationships, such as between Oil/grease and Phenol, may indicate that the treatment process has introduced new interactions between the parameters that were not present in the raw wastewater.

Table 2: Relationship between the physiochemical parameter of the raw waste water

Variables	PH	Phenol	Oil/grease	Temp	TSS	Cond.	Sulphide	TDS	Phosphate
pH	**1.00**								
Phenol	0.84	**1.00**							
Oil/grease	0.83	**1.00**	**1.00**						
Temp	0.10	-0.02	0.06	**1.00**					
TSS	0.62	0.17	0.18	0.40	**1.00**				
Cond.	0.78	0.84	0.78	-0.50	0.12	**1.00**			
Sulphide	**0.93**	0.73	0.74	0.27	0.55	0.63	**1.00**		
TDS	0.72	0.55	0.56	0.23	0.82	0.41	0.51	**1.00**	

Phosphate	0.83	0.66	0.64	-0.09	0.29	0.76	**0.91**	0.23	**1.00**

Values in bold are different from 0 with a significance level alpha=0.05

Table 3: Relationship between the physiochemical parameter of the treated waste water

Variables	PH	Phenol	Oil/grease	Temp	TSS	Cond.	Sulphide	TDS	Phosphate
pH	**1.00**								
Phenol	0.50	**1.00**							
Oil/grease	-0.47	-0.14	**1.00**						
Temp	0.16	-0.56	-0.57	**1.00**					
TSS	0.64	0.68	-0.76	-0.06	**1.00**				
Cond.	0.58	0.79	0.27	-0.68	0.35	**1.00**			
Sulphide	0.68	-0.27	-0.38	0.55	0.17	0.03	**1.00**		
TDS	0.54	0.25	-0.57	0.62	0.33	-0.06	0.25	**1.00**	
Phosphate	**0.93**	0.43	-0.33	-0.03	0.60	0.66	0.72	0.20	**1.00**

Values in bold are different from 0 with a significance level alpha=0.05

3.4 Principal Component Analysis

Bartlett's sphericity test was conducted to assess the suitability of the dataset for PCA. The results (Table 2) showed a significant chi-square value (106.644) compared to the critical value (50.998), indicating that the data were suitable for PCA. Four principal components were retained after the PCA, accounting for 75.01% of the total variance in the data (Table 3). The first two factors explained 51.22% of the total variance before Varimax rotation and 40.31% after rotation. The selection of the principal component was based on Eigen One and the proportion of variance retained by each component.

Table 4 presents the factor loadings of the physiochemical parameters onto the four principal components. High factor loadings indicate a strong association between the parameter and the principal component. The parameters with the highest loadings on the first factor (D1) were sulphates and phenols, whereas Chemical Oxygen Demand and Biological Oxygen Demand had the highest loadings on the second factor (D2). Dissolved oxygen was most strongly associated with the third factor (D3), and pH was the parameter with the highest loading on the fourth factor (D4). The PCA results identified four principal components representing different aspects of water quality. The first component was dominated by sulphates and phenols, which are often associated with industrial pollution. The second component was characterized by chemical and biological oxygen demand, indicating the presence of organic matter and the potential impact of microbial activity. The third component was mainly driven by dissolved oxygen, an essential factor for maintaining aquatic life. Finally, the fourth component was heavily influenced by pH, a critical parameter affecting the solubility and availability of nutrients and contaminants in water.

Table 4: Bartlett's sphericity test

Chi-square (Observed value)	106.644
Chi-square (Critical value)	50.998
DF	36
p-value	< 0.0001
alpha	0.05

Table 5: Eigen values and Proportion of Eigenvalue retained

Principal Components	Eigenvalue	Before Varimax Rotation		After Varimax Rotation	
		Variability (%)	Cumulative %	Variability (%)	Cumulative %
F1	2.80	31.12	31.12	22.75	22.75
F2	1.81	20.10	51.22	17.56	40.31
F3	1.20	13.33	64.55	17.00	57.32
F4	0.94	10.46	75.01	17.69	75.01
F5	0.75	8.29	83.30	8.29	83.30

Table 6: Factor Loading

Physiochemical	D1	D2	D3	D4

Parameters				
PH	-0.21	0.24	-0.35	-0.75
TEMP	0.65	0.27	0.51	-0.15
DO	0.14	0.03	0.82	0.13
COD	-0.06	0.87	0.01	0.03
BOD5	0.29	0.83	0.06	-0.10
Phenol	0.79	0.09	-0.19	0.29
Sulphate	0.91	0.04	0.16	0.14
Phosphate	0.13	0.08	0.01	0.85

The result of the biplot shows principal components 1 and 2 with the loading of the physiochemical parameters on each component. Also, the loading of the various units of the Rotary Bio Disk unit on the principal axis was also represented in Figure 6. The result from the biplot showed that unit D of the Rotary Bio Disk unit had a higher concentration of phenol and sulphate compared to other units of the Rotary Bio unit. The result suggests that more industrial waste component was found in the wastewater in that unit. The result indicates that unit D was not efficient at the removal of both phenol and sulphate. Similarly, the result from the biplot showed that the wastewater had higher organic content at the inlet of the Rotary Bio unit than in any other unit of the Bio unit. The result indicates that as the wastewater enters the unit less organic matter can be found in the wastewater.

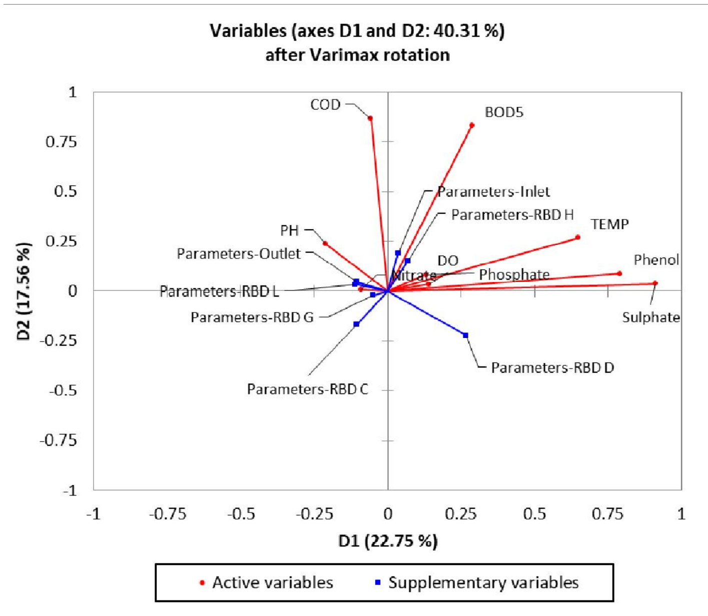

Figure 6: Biplot

4. CONCLUSION

Several parameters such as oil and grease, Total Suspended Solids (TSS) and sulphides were monitored to evaluate the removal efficiency of the Dissolved Air Floatation (DAF) unit and the Rotary Bio-Disk (RBD). Phenol levels in the individual RBD units did not show any consistent pattern, as RBD values showed differing values (increases/ decreases) for monthly phenol levels in inlet stream. The levels of BOD_5 in the individual RBD units were within the inlet specification but generally exceeded the outlet design specification. The results show that the DAF unit reduced oil/grease content of wastewater (Positive efficiency) for the months that were investigated. On average, the efficiency was calculated as 63.5%. Therefore, the DAF unit was efficient with regards to oil/grease removal. The oil/grease content of raw and treated water effluents were within the design specification of the DAF unit. Similarly, TSS removal efficiency was positive as the average removal efficiency was 21.3%. Therefore, the DAF unit was efficient (for the period investigated) with regards to TSS removal. In line with Pearson Correlation there are strong positive relationships between several parameters, such as pH and Sulphide (0.93), Phenol and Oil/grease (1.00), and Phosphate and Sulphide (0.91). The Principle Component Analysis yielded four principle components (PC1-4): PC1 parameters with the highest loadings on the first factor (D1) were sulphates and phenols, whereas Chemical Oxygen Demand and Biological Oxygen Demand had the highest loadings on the second factor (D2). Dissolved oxygen was most strongly associated with the third factor (D3), and pH was the parameter with the highest loading on the fourth factor (D4).

Interview with top management revealed poor management practice in maintaining the RBDs.Where arethedata for the interview? However, some individual units of the system were inefficient with pollutant levels exceeding regulatory limits. Factors contributing to under performance of some of the system's units include: pH, temperature, and dissolved oxygen instability as well as nutrient dosing. Recipient water (Okochiri River) characteristics were usually within their respective DPR limits except for parameters such as phenol, ammonia, TSS, TDS whose level exceeded DPR regulatory limits.

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5. RECOMMENDATION

An improvement in efficiency of the wastewater treatment system would result in complying with regulatory limits for pollutants, improvement actions should include:

1. Redesigning the CPI, to monitor the amount of oil/grease coming in;

2. Maintaining optimal operating conditions of temperature, pH, nutrient, dissolved oxygen for the RBD units to ensure effective biological removal of pollutant;
3. Identifying (if any) the source of phenol in the RBD units (considering the phenol levels in the inlet was within design specification but the levels in the RBD units were higher than both inlet and design specifications);
4. Treating wastewater effluent to meet regulatory units before discharge into recipient water body (as current practice may result into cummulative environmental impact on the Okochiri riversisit a river or more thanone river? and associated health/social implications for water users);
5. By constructing an effluent retention and recycling facility. This will enable in reprocessing of poorly treated effluent; and
6. Ensuring regular and effective maintenance of individual units in the WWTP.

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