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Physicochemical quality of pharmaceutical effluents from parts of south-eastern Nigeria

***[1]Nwoko, O.E., [2]Maduwuba, M.C., [2]Dike, K.S., & [2]Obiukwu, C.E.**
[1]Department of Biology Education, Alvan Ikoku Federal University of Education, Owerri, Imo State, Nigeria
[2]Department of Microbiology, Faculty of Biological Sciences, Imo State University, Owerri, Nigeria

***Corresponding author email**: ogadinma_njoku@yahoo.com

Abstract

The physicochemical quality of four pharmaceutical effluent samples (A-D) from three South-Eastern states were assessed. Physicochemical parameters like temperature, pH, redox potential, electrical conductivity, total dissolved solids, turbidity, dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids, chloride, nitrite, phosphate, and sulphate were monitored. Results obtained revealed that temperature ranged from 250 C - 320 C, pH 4.4 - 5.3, redox potential 80 mg/l - 128 mg/l), electrical conductivity 780 µs/cm – 1180 µs/cm, total dissolved solids 60mg/l – 636 mg/l, turbidity 55.6 mg/l -1000 mg/l, dissolved oxygen 2.51 mg/l - 3.22 mg/l, BOD 114.20 mg/l -442.6 mg/l, COD 303 mg/l – 1319 mg/l, TSS 1094 mg/l – 6426 mg/l, chloride concentration 0.014 mg/l -314 mg/l, nitrite concentration 0.14 mg/l - 1.026 mg/l, phosphate concentration 0.32mg/l - 5.344mg/l while sulphate concentration ranged from 0.865 mg/l - 17.302 mg/l. Results obtained were compared to the Federal Environmental Protection Agency (FEPA) and Federal Ministry of Environment limits for effluent. All samples showed an acidic pH. BOD, COD, and TSS values significantly exceeded the FEPA limit, while DO was very low in all samples. Chloride, nitrite, phosphate, and sulphate concentrations were within the acceptable FEPA limits for effluent. The findings of this study have elucidated the need for improved effluent treatment systems, stricter enforcement of environmental regulations, and routine water quality monitoring to mitigate ecological impact.

Keywords: Pharmaceuticals, Effluent, Physicochemical Parameters, Paracetamol, Environment, Ibuprofen.

Introduction

Pharmaceutical effluents are wastewater generated during the production of drugs by pharmaceutical industries. (Olaitan et al., 2014) Pharmaceutical effluents represent a significant environmental challenge in many developing regions, including parts of south-eastern Nigeria, where rapid industrial growth and inadequate wastewater treatment infrastructure exacerbate pollution risks. Their presence in the environment is a growing global concern because pharmaceutical effluents are a relevant class of emerging contaminants and have the potential to cause ecological problems and also affect human life. (Tan et al., 2018) The excessive use of medication globally, combined with the recalcitrance of pharmaceuticals in traditional wastewater treatment systems, has led to these compounds posing a severe environmental problem. (Ortúzar et al., 2022) These effluents contain a complex mixture of organic and inorganic substances such as active pharmaceutical ingredients, solvents, heavy metals, and other chemical additives. Moreover, pharmaceutical effluents may contain residual active pharmaceutical compounds, including antibiotics, which contribute to the emergence of antibiotic-resistant bacteria, complicating public health management (Sulaiman et al., 2024). The physicochemical quality of these effluents is critical to assess because their discharge into the environment without adequate treatment can lead to severe ecological and public health consequences.

The increase in the global population has led to a corresponding increase in the consumption of pharmaceuticals, which has also resulted in an increase in the number of pharmaceutical companies and an increase in the quality of wastewater generated, whose toxic effects on both human and aquatic organisms have been previously reported (Obasi et al., 2014; Idris et al., 2013). The sources of pharmaceuticals in the environment have been attributed to the discharge of untreated effluent from pharmaceutical industries into the aquatic environment. Other sources include ingestion of pharmaceuticals. After ingestion, most of these pharmaceuticals are not completely metabolized in the body; some are excreted in urine and feces as active substances or metabolites (Sui et al., 2015; Ausder Beek *et al.,* 2016). The discharge of raw, contaminated, and inadequately treated pharmaceutical wastewater into water supplies and river channels contributes to short, medium, and long-term environmental and human health impacts. (Shola et al.,2022).

Due to the nature and chemical composition, and characteristics of these pharmaceuticals, which include high lipophilic quality, which favors bioaccumulation, low biodegradability, and pseudo persistence, also promote their negative influence on microbial community. According to Alimba et al. (2019), pollutants of pharmaceutical effluents are emerging carcinogens and mutagens that are capable of increasing genome instability, altering blood cell indices, and causing pathological lesions in fish tissues. For instance, drugs like Ibuprofen, an NSAID, and paracetamol, an analgesic, are the most popular, highly prescribed, and most salable over-the-counter medicines in the world (Marchlewicz et al., 2015). They are among the drugs listed in the Essential Drugs List 2010 made by the World Health Organization (WHO). Different concentrations of these drugs have been detected in different environmental samples ranging from surface water, ground water, sediments, drinking water, waste water, and sludge across the globe. In Nigeria, (Anekwe et al., 2020; Olarinmoye et al., 2016; Olaitan et al., 2014). In USA River (Snyder et al.,2006) UK, River (Snyder *et al.*,2006), Ogunwole and Salihu (2020), surface water (Lan et al.,2019). China, Sweden, Britain, and the United States. (Lan et al.,2019, Luo et al.,2014, Zur *et al*.,2018). Similarly, antibiotics, widely used in both human and veterinary medicine, are often excreted into the environment as metabolites through feces and urine in their biologically active forms or as active metabolites (Wang et al., 2018). Different types of antibiotics have been detected at varying concentrations in environmental samples (Cheng et al.,2019; Kovalakova et al.,2020). Even at environmentally relevant low concentrations, antibiotics can disrupt aquatic bacterial communities, alter the symbiotic microbiota of fish, and promote the emergence of antibiotic-resistant pathogenic bacteria by exerting selective pressure that facilitates the spread of antibiotic resistance genes.(Bojarski et al.,*2*020) The toxicity of these drugs to different aquatic organisms has also been previously reported (Nicole,2014; Olaitan et al.,2014; Arnold et al.,2014; Backhaus, 2014). The cumulative effect of these pollutants can lead to the degradation of water quality in rivers, lakes, and groundwater sources, which are often utilized for drinking, agriculture, and recreation by local communities.

Despite these documented issues, many pharmaceutical industries in south-eastern Nigeria and other regions continue to discharge untreated or inadequately treated effluents due to a lack of stringent regulatory enforcement and insufficient treatment facilities (Olusegun et al., 2021; Oguntade et al., 2020). This gap underscores the urgent need for comprehensive monitoring and evaluation of the physicochemical characteristics of pharmaceutical effluents to inform policy and promote the adoption of effective wastewater treatment technologies.

Monitoring the physicochemical quality of effluent helps in understanding its impact on the environment, designing a treatment process, and ensuring regulatory compliance. These parameters also help assess the toxicity of the effluent and guide the mitigation of potential risk. Parameters such as pH, biochemical oxygen demand (BOD), chemical oxygen demand (COD), total dissolved solids (TDS), electrical conductivity (EC), turbidity, and the presence of pharmaceutical residues influence how the effluent interacts with environmental systems. For instance, high BOD and COD values indicate elevated levels of organic pollutants, which can deplete dissolved oxygen in water bodies, leading to hypoxic conditions detrimental to aquatic life (Verlicchi et al., 2012). Similarly, elevated TDS and EC affect the osmotic balance in aquatic organisms and may reduce soil productivity when such effluents are used for irrigation (Kümmerer, 2009). The presence of residual antibiotics and other active pharmaceutical ingredients (APIs) can exert selective pressure on microbial communities, promoting the development and spread of antibiotic-resistant genes (Khan et al., 2013). Furthermore, nutrients such as nitrates and phosphates may lead to eutrophication, while heavy metals and toxic compounds in the effluent can bioaccumulate, posing risks to both ecosystems and human health (Fent et al., 2006).

This study aims to study the physicochemical characteristics of the effluent from some pharmaceutical industries in southeastern Nigeria. Parameters such as temperature, pH, dissolved oxygen (DO), BOD, COD, TSS, TDS, nitrates, phosphates, and others were evaluated against FEPA standards. The findings will provide critical baseline data for environmental risk assessment and support the development of regulatory frameworks and pollution control strategies aimed at safeguarding aquatic ecosystems and public health in the region.

Materials and Methods

Study area / Sample collection

Effluent samples were collected from the discharge point of four pharmaceutical industries located in some parts of South-Eastern Nigeria (Imo, Abia, and Anambara). Effluent samples were collected in 10 L sterile screw cap bottles during the peak of the production period of the individual pharmaceutical companies and transported to the laboratory in an ice chest for physicochemical and pharmaceutical analysis.

Physicochemical analysis

pH was determined using a pH meter HANNA H18424. Electrical Conductivity was measured using a conductivity meter, HABBA HI9033, USA. Dissolved oxygen was determined by the Winkler titration method following the procedure of Helm et al. (2012). Biochemical Oxygen Demand (BOD) was determined by the method of Jouanneau et al. (2014). Chemical Oxygen Demand was done by the method of Lv et al. (2018, using the dichromate titration method. Total dissolved solid was determined by the method of Gilmore and Luong (2016) using HANNA H19835, USA. Total suspended solids were determined using the HACH DR890 colorimeter, USA. Nitrite, phosphate, sulphate, and chloride concentrations were determined using the methods adopted from APHA (4500). Also, turbidity was determined using a colorimeter, TP: HACHDR890, USA.

Results

Table 1 shows the physicochemical characteristics of the four different pharmaceutical industries' effluent. The results obtained were compared with the Federal Environmental Protection Agency (1991) and Federal Ministry of Environment limits.

Table 1: Result of some physicochemical properties of the effluent samples.

S/N	**Parameters(units)**	**Sample A**	**Sample B**	**Sample C**	**Sample D**	**FEPA Limits**	**FMEnv Limits**
1	**Temperature (oc)**	28	27	28	30		
2	pH	5.2±0.282	4.46±0.431	5.16±0.431	5.3±0.282	6.0-9.0	6.5-8.5
3	Redox potential(m/V)	83.66±0.588	128.13±0.431	80.3±0.282	82.6±0.282	NS	NS
4	Electrical Conductivity (µS/cm)	780.1±0.282	120.01±0.028	1270.0±0.0282	1180.01±0.0431	NS	<900
5	Total Dissolved Solids(mg/l)	390.13±0.431	60.16±0.431	636.16±0.588	590.16±0.431	2000	500
6	Turbidity (NTU)	>1000	55.6	613	>1000	NS	NS
7	Total Suspended Solids(mg/l)	1094.±0.431	238.1±0.282	1984.26±0.163	6426.01±0.043	30	NS
8	Chloride(mg/l)	314.24±0.074	17.59±0.195	0.014±0.0149	18.31±0.0282	600	600
9	Alkalinity(mg/l)	125.03±0.163	<1	<1	<1	NS	NS
10	Nitrite(mg/l)	0.864±0.0028	0.147±0.0028	0.912±0.0028	1.026.02±0.058	150	NS
11	Phosphate(mg/l)	3.442±0.00282	0.327±0.0028	0.4257±0.010	5.344±0.0036	5	NS
12	Sulphate(mg/l)	6.383±0.0058	0.865±0.0028	8.415.1±0.282	17.302±0.0028	500	200

Figures 1-3 show the results of oxygen-related water quality parameters.

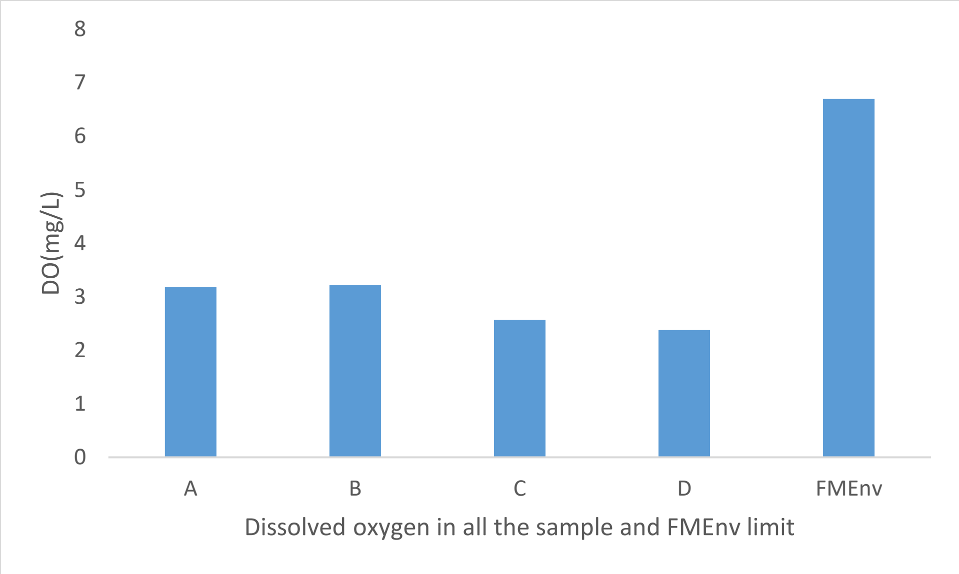

Figure 1: Dissolved oxygen of all the effluent samples.

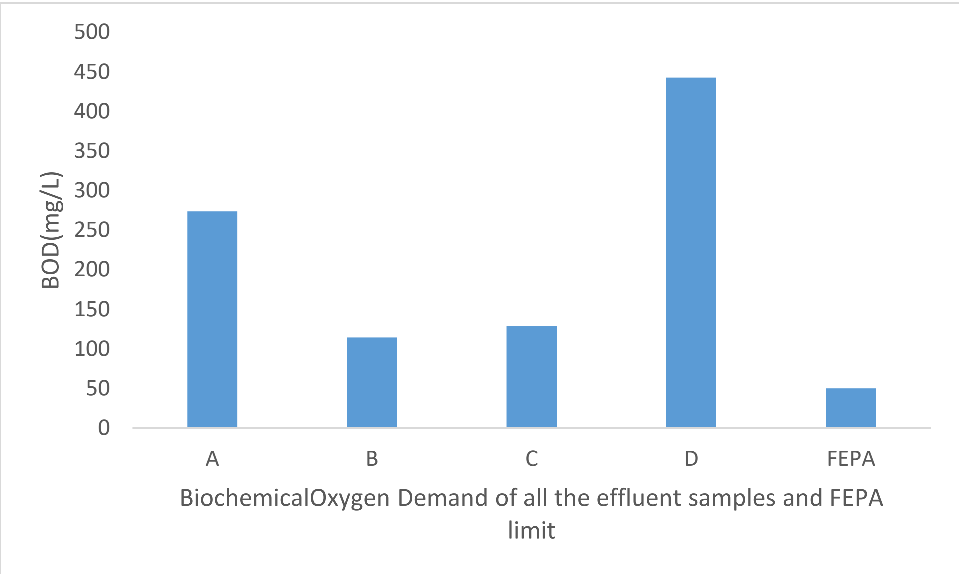

Figure 2: Biochemical oxygen demand of all the effluent samples and FEPA limit.

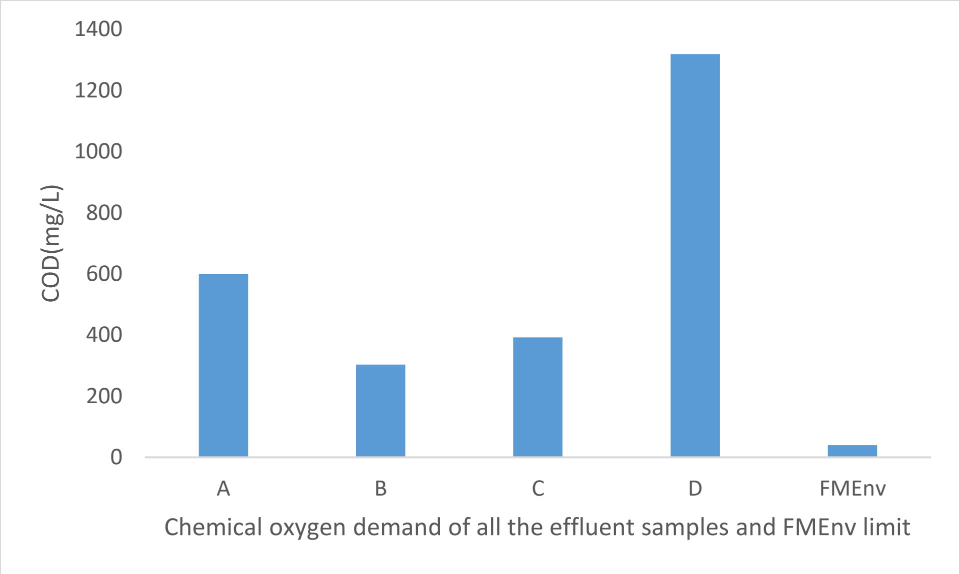

Figure 3: Chemical oxygen demand of all the effluent samples and FMEnv limit.

Discussion

Understanding these pollution metrics is critical for environmental protection and public health safety. The results of the physicochemical parameters of the effluent samples are presented in Table 1. In Nigeria, the temperature limit for pharmaceutical effluent discharges is regulated to ensure environmental protection and the proper functioning of sewage systems. According to environmental guidelines, the maximum allowable temperature for industrial wastewater, including pharmaceutical effluents, is either 45°C or no more than 5°C above the ambient temperature of the receiving water body—whichever is lower. The temperature in this study ranged from 27oC-30oC in all the samples, which is within the FEPA limit of <40oC. Sample D has the highest temperature of 30 °C, followed by sample C and A(28 °C) respectively, while sample B has the lowest temperature of 27O. Similar temperatures ranging from 27.5°C to 29°C were also reported in Sango-Ota, Ogun State (Oguntade et al.,2023) and (Olarinmoye et al.,2016), which were within the regulatory limits.

The pH of the samples ranged from 4.58-5.33, with sample B having the lowest pH (4.46±0.431), while sample A had the highest pH of (5.25±0.282). All samples showed acidic pH, which is quite below the FEPA and FMEnv limit of 6-9 and 6.5-8.5, respectively. pH which is the hydrogen ion concentration of a substance is one of the important abiotic factors that serves as a pollution index (Savita and Deepa, 2012; Oguntade et al.,2020) The acidic pH of the effluent is capable of steaming the pH of the receiving water body, thereby destabilizing fundamental properties such as alkalinity and metal solubility, (Olaitan et al., 2014) Similar results of acidic pH of range of 3.0-3.59 was also recorded by Adama et al. (2022) in Minna Niger State Nigeria. However, a higher pH range of 7.1-7.4 was reported by Olaitan et al. (2014) and Oguntade et al. (2020) in Nigeria.

Electrical conductivity represents the presence of dissolved salts, inorganic compounds, and other charged species in an effluent. Sample A has an EC of (780±0.028 µS/cm) and Sample B with (120.01±0.028 µS/cm) are within the permissible limits of < 900, stated by the FMEN, while Sample C has the highest value of electrical conductivity of 1270.0±0.282 µS/cm, followed by Sample D (1180.01±0.431 µS/cm), which is higher than the permissible limit. Higher electrical conductivity was also reported by Adama et al. (2022) in their study on the characterization of pharmaceutical effluent in Niger state. Higher electrical conductivity indicates a significant number of dissolved ions, which can be harmful to the environment If discharged without proper treatment. Similar values ranging from 1230-1830 µS/cm were also reported by Kumari and Tripathi (2019). However, Olaitan et al. (2014) and Placide et al. (2016) recorded a lower EC between 342.67and 659.33 µS/cm.

Total Dissolved Solids (TDS) is a critical parameter in assessing the characteristics of pharmaceutical effluents. It encompasses inorganic salts, organic matter, and other dissolved substances, reflecting the effluent's overall salinity and potential environmental problem. The mean value of the TDS ranged from 60.16±0.431mg/l - 636.16±0.558mg/l. The result shows that samples A to D were within the limit of 2000mg/l FEPA, while samples C and D had higher values of 636.16±0.588 and 590.16.431mg/l respectively, while samples A and B had lower

TDS values of 390.13±0.431 and 60.16±0.431. This is very important as higher TDS values could alter water chemistry, increasing salinity and conductivity. This can disrupt osmotic balance in aquatic organisms, impairing osmoregulation in species like fish and amphibians (Sackey et al.,2024). Excessive total dissolved solids (TDS) are associated with lower dissolved oxygen concentrations and increased stress on aquatic organisms, due both to oxygen-demanding substances and reduced photosynthetic oxygen production. Therefore, elevated TDS can exacerbate ecological stress in impacted waters. (Iwegbue et al., 2023) Similar low concentrations of TDS in samples A and B were also recorded by Oguntade et al. (2020) and Olaitan et al. *(*2014).

The results obtained for total suspended solids revealed that Sample D and C have the highest TSS of 6426.01 ± 0.043 and 1984.26 ± 0.163, respectively, followed by Sample A 1094.00 ± 0.431and Sample B238.10 ± 0.282. TSS levels were extremely high, especially in Sample D (6426.01±0.043 mg/L). TSS interferes with light penetration, reduces photosynthesis, and clogs fish gills (Akpor et al., 2014). The EPA recommends a TSS limit of less than 30 mg/L for treated discharges (USEPA, 2021), making all four samples non-compliant. Obasi et al. (2019), Owalude et al. (2020), and Woldeamanuale (2017) also recorded higher TSS in their study, while Oguntade et al (2023) recorded values below the permissible limit. Chloride concentration ranged from 0.014 ± 0.015 - 314.24 ± 0.074, with sample A having the highest concentration, while sample C had the lowest concentration. Sample A shows a particularly high chloride concentration, which can contribute to salinization of freshwater sources and impact aquatic osmoregulation (U.S. EPA, 2022). In Lagos, Olusegun et al (2021) reported a chloride concentration of 2.50 mg/L, 28.83 mg/L, and 70.00 mg/Lin different samples, all well below the FEPA permissible limit of 600 mg/L/for discharge into surface water.

Alkalinity concentration for sample A was 125.03 ± 0.163, while samples B, C, and D were <1. Only Sample A showed appreciable alkalinity, indicating a higher buffering capacity. Low alkalinity in others can lead to pH instability and greater toxicity of metal ions (Chapman, 1996). Another investigation of three pharmaceutical effluents in Ogun State found alkalinity levels of 30 mg/L,40 mg/L, and 30 mg/L/Lfor effluents A, B, and C, respectively. These values were described as relatively high and possibly linked to low dissolved oxygen levels (Olaitan et al.,2014). All samples show elevated nitrite levels, especially D, which exceed the WHO guideline limit of 0.1 mg/L. High nitrite levels are toxic to aquatic organisms and may form carcinogenic nitrosamines (WHO, 2017). Phosphate pollution leads to eutrophication, which causes algal blooms and oxygen depletion (Correll, 1998). Samples A and D greatly exceed acceptable phosphate levels. Sample D again showed the highest concentration. Although not highly toxic, excessive sulfate can lead to unpleasant taste, corrosion, and, in combination with other ions, ecological imbalance (Zhang and Angelidaki, 2015).

The dissolved oxygen obtained from this study and presented in Figure 1 was below the limit recommended by the FME (6.7), and the DO ranged from 2.38±0.028 - 3.23±0.028 mg/l. Similarly, low level of dissolved oxygen was also recorded by Obasi et al (2014), Oguntade et al. (2020), Olaitan et al. (2014), and Olusegun *et al* (2021). This result is an indication of a higher concentration of biodegradable organic matter, which can have a significant environmental impact. Low DO can cause oxygen depletion of the receiving water, leading to hypoxic conditions, which are detrimental to aquatic life. Studies have shown that DO levels below 2mg/l can be lethal to most fish species. (Rubei et al., 2019). It can also lead to the proliferation of filamentous bacteria, resulting in poor sludge settling and reduced treatment efficiency. (Singare & Dhabarde,2017).

The amount of dissolved oxygen needed by aerobic microorganisms to decompose organic matter in water over a specific time period (usually 5 days at 20°C) is known as biochemical oxygen demand. This is presented in Figure 2. It serves as a key indicator of organic pollution in wastewater and its potential impact on aquatic life. Sample D has the highest BOD at 442.61 ±0.028mg**/L**, indicating a very high organic load. Sample A also shows significantly high BOD at 273.62±0.107 mg/L. Samples B and **C** have comparatively lower values (114.20 ±0.016mg/L and 128.16±0.0282 mg/L, respectively) but are still elevated above environmental safety limits. According to the World Health Organization (WHO, 2017) and U.S. Environmental Protection Agency (USEPA, 2021), the recommended maximum BOD level in treated effluent discharged into surface water is typically **≤ 30 mg/L** and 50mg/l for the Federal Environmental Protection Agency. However, these samples are from untreated pharmaceutical effluent, which accounts for the high BOD. High BOD levels recorded in the samples mean more organic waste, leading to oxygen depletion in receiving waters, which harms fish and other aquatic organisms. Algal Blooms and Eutrophication occur when organic nutrients increase (often associated with high BOD), which promotes algal growth, which further decreases DO and alters aquatic food chains (Zhang et al., 2021). Oxygen-demanding wastes lead to fish kills and collapse of aquatic ecosystems, particularly in low-flow or stagnant water bodies.

Chemical Oxygen Demand (COD**),** presented in Figure 3, is the measure of the total quantity of oxygen required to oxidize both biodegradable and non-biodegradable organic and inorganic matter in water. It provides an estimate of the overall level of pollution in wastewater. COD is widely used in water quality monitoring, especially for industrial effluents, as it captures pollutants that Biochemical Oxygen Demand (BOD) may miss — such as synthetic chemicals, solvents, and complex pharmaceuticals. Sample D exhibits the highest COD level at 1319.03 ±0.028mg/L, indicating a very high concentration of oxidizable pollutants. Sample A has a high COD of 600.83±0.0028mg/L, suggesting a heavily contaminated effluent stream. Samples B and **C**, though relatively lower, still show COD levels of 303.54±0.048 mg/L and 392.22±0.028 mg/L, respectively, all above regulatory thresholds. Elevated COD correlates with high levels of chemical contaminants, many of which can be toxic, mutagenic, or endocrine-disrupting, posing severe risks to aquatic organisms (Aus der Beeket et al.,2016). High COD leads to oxygen depletion, which can result in hypoxia or anoxia, severely impairing fish and benthic invertebrates (Pal et al., 2010). Pharmaceutical effluents often contain non-biodegradable compound**s**, including antibiotics, hormones, and preservatives, which resist degradation and accumulate in the environment (Kümmerer et al., 2018). The high Sample D's COD of 1319.03 mg/L likely results from intensive formulation or synthesis processes involving solvents, dyes, and active pharmaceutical ingredients (APIs). while Sample A's high **COD** suggests similar high-load waste, possibly from formulation discharge without adequate pre-treatment. Lower COD in Samples B **and C**, though still above permissible limits, may indicate some level of treatment or less complex production processes. Similar high COD concentrations above regulatory limits were also reported by Anyakore et al. (2011) in Lagos State, Lawal et al. (2022) in Osun State, and Owalude et al. *(2021*) in Lagos State. Generally, elevated concentrations of TSS, BOD, COD, and ion concentrations can reduce biodiversity and destabilize aquatic food chains, which is an ecological risk. Human health risks can occur as a result of consumption or exposure to contaminated water can leading to gastrointestinal issues, endocrine disruption, and long-term chronic illnesses. All tested parameters exceeded national and international limits, necessitating stricter controls and better waste treatment technologies.

Conclusion

The results of this study revealed that most physicochemical parameters exceeded FEPA regulatory limits, indicating significant pollution from pharmaceutical effluents. Such elevated levels pose serious ecological and public health risks, including oxygen depletion, toxicity to aquatic life, and potential long-term environmental persistence. These findings underscore the urgent need for the implementation of more effective wastewater treatment technologies, strict regulatory compliance, and continuous environmental monitoring. In addition, raising public and industry awareness is essential to reduce the release of untreated effluents and to safeguard both ecosystem integrity and human health.

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