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Article

Water quality and palm oil mill effluents—Analysis of the effect of palm oil mill effluents (POME) on consumption of bore-hole water in Nigeria

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Abstract: Nigeria's palm oil processing industry poses significant environmental pollution risks, jeopardizing the country's ability to meet the UN's 17 Sustainable Development Goals (SDGs) by 2030. Traditional processing methods generate palm oil mill effluent (POME), contaminating soil and shallow wells. This study investigated water samples from five locations (Edo, Akwa-Ibom, Cross River, Delta, and Imo states) with high effluent release. While some parameters met international and national standards (WHO guidelines, ASCE, NIS, and NSDWQ) others exceeded acceptable limits, detrimental to improved water quality. Results showed, pH values within acceptable ranges (6.5–8.5), high total conductivity and salinity (800–1150 µS/cm), acceptable hardness values (200–300 mg/L), nitrite concentrations (10–45 mg/L), excessive magnesium absorption (> 50 mg/L), biochemical oxygen demand (BOD) indicating significant pollution (75–290 mg/L), total dissolved solids (TDS) exceeding safe limits in four locations, total solids (TS) exceeding allowable limits for drinking water (310–845 mg/L), water quality index (WQI) values ranged from "poor" to "very poor". POME contamination by metals like magnesium, nitrite, chloride, and sodium compromised shallow well water quality. Correlation analysis confirmed robust results, indicating strong positive correlations between conductivity and TDS ($r = 0.85$, $p < 0.01$) and pH and total hardness ($r = 0.65$, $p < 0.05$). The study emphasizes the need for environmentally friendly palm oil processing methods to mitigate pollution, ensure safe drinking water, and achieve Nigeria's SDGs. Implementation of sustainable practices is crucial to protect public health and the environment.

Keywords: palm oil effluents; water; consumption; BOD; physiochemical parameters

1. Introduction

The agricultural sector has been identified as the biggest user of groundwater and an important source of sediment, nutrients, pesticides, salts, and pathogens in Nigeria. The presence of these materials in water resources can impose costs on water users. Research has been undertaken in specific areas where the quality of groundwater has had an impact on agricultural activities but a dearth of quantified information is evident as to the impact of agricultural practices on groundwater resources and the status of such resources (United States Department of Agriculture (USDA), 2022). Oil palm remains the most productive oil-producing crop globally, yielding 10–35 tons of fresh fruit bunches per hectare (Ahmad et al., 2023; Mohd et al., 2023). West African countries, such as Ghana and Nigeria, significantly rely on oil palm production, primarily used as cooking oil (Agyemang et al., 2022). Oil palm is a versatile crop, with various products derived from it, including pomade (Ogunniyi et al., 2023).

As a crucial aspect of Nigeria's economy and trade, oil palm is highly sought after globally due to its affordability, ease of processing, and simplicity (Ibrahim et al., 2020). Wastewater/waste discharge, whether treated or untreated, that exists in a treatment facility, sewage system, or industrial outfall and enters surface water is called effluent. It also refers to sewage or liquid waste that is dumped into a river or the ocean. According to Scott (2015), effluents can also be water or gas that is released from a man-made building or a natural body of water. Water is used in the palm oil extraction process to separate the oil in a tank from the particles and sludge. Once the oil has been removed, the mill releases its waste water, or effluent. The effluent from palm oil production contains particles that require treatment before environmental release.

As presented in **Figure 1**, Palm oil mill effluent (POME) is the wastewater generated by the palm oil industry, composed of approximately 95%–96% water, 0.6%–0.7% oil, and 4%–5% particles, including 2%–4% suspended solids (Wahid et al., 2022). Studies have shown that POME's oil and grease content exceeds the permitted limit, posing significant environmental concerns (Ahmed et al., 2023; Ismail et al., 2020). This highlights the need for effective treatment and management of POME to mitigate its environmental impact. Furthermore, the manufacturing process generates waste from palm fruit, which is a common issue for processors. Although not toxic, these substances are highly acidic and cannot be directly discharged into nearby water bodies, requiring proper treatment to mitigate environmental impact. Nigeria ranked third globally in palm oil production, with 2.3 million hectares under cultivation as of 2011 (Oladimeji et al., 2020).

Figure 1. Effluents from processed oil palm.

Sustainable development is the management and conservation of the natural resource base and the orientation of technological and institutional change in such a manner as to ensure the attainment and continued satisfaction of human needs for the present and future generations. Such Sustainable development (in the agriculture, forestry, and fisheries sectors) conserves land, water, plant, and animal genetic resources, which is environmentally non-degrading, technically appropriate, economically viable, and socially acceptable. However, palm oil production's environmental impacts, such as deforestation and habitat loss, have raised concerns, endangering species like orangutans (Shears and Richard, 2022). The palm oil industry has grown into a major global agro-industry, producing more oil than any other plant. Recent studies highlight the environmental concerns associated with palm oil mill effluent (POME). Ajalla et al. (2021) and Wang et al. (2022) identified sterilization and clarifying processes as primary sources of POME. Singh et al. (2023) reported inadequate treatment of solid wastewater by small-scale traditional operators. The environmental impacts of palm oil production, including deforestation and habitat loss, have sparked criticism (Ahmed et al., 2023; Shears and Richard, 2012). These effects jeopardize critically endangered species, such as orangutans, and contaminate terrestrial and aquatic ecosystems, leading to biodiversity loss and increased chemical oxygen demand (COD) and biological oxygen demand (BOD) levels (Ismail et al., 2022; Wahid et al., 2022). Palm oil mill effluents entering waterways disrupt the food chain and impact water consumption (Foo and Hameed, 2010; Singh et al., 2023). Recent studies have investigated the environmental effects of palm oil mill effluents (POME), but few have examined their impact on borehole water quality and compliance with World Health Organization (WHO) drinking water standards in Nigeria (Edem, 2020; Oladimeji et al., 2020).

Specifically, this study sets to:

- Determine the physiochemical parameters of water samples;
- Determine the grading water quality, solids, and biochemical oxygen demand (BOD) from water samples;
- Determine the water quality index in those locations.

2. Methodology

2.1. Study area

Nigeria is located in West Africa, spanning latitudes 4°–14° N and longitudes 2°–15° E. The country has a diverse climate, with two main seasons: wet and dry. Nigeria's climate is characterized by a wet season spanning April to October, with annual rainfall ranging from 1000 mm to 2000 mm (Ogunniyi et al., 2022). Temperature fluctuations range from 22 °C to 36 °C, with a mean annual temperature of 28 °C (Adeyemo et al., 2020). Recent trade data reveals Nigeria's significant reliance on crude palm oil imports. In 2022, Nigeria imported $256,017.19K worth of crude palm oil (OEC, 2022).

As presented in **Figure 2**, the study focused on five traditional palm oil processing locations with renowned palm oil production in Nigeria, spanning across five states comprising, Edo, Akwa Ibom, Cross River, Delta, and Imo states, and located in the south/south-eastern part of Nigeria.

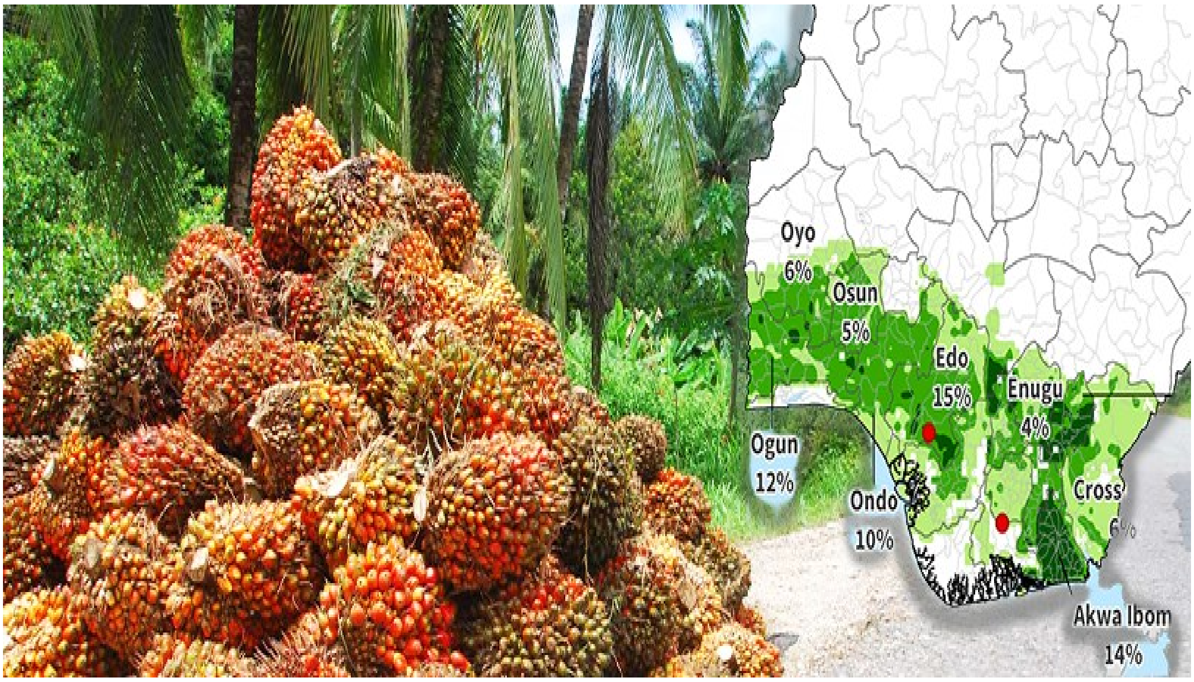

Figure 2. Map of Nigeria showing areas predominantly known for traditional oil palm processing.

2.2. Sampling frequency

Sampling was conducted during the peak period of processing activity, to assess its impact (palm oil processing) on water quality. Water samples were drawn from boreholes adjacent to or near palm oil processing sites using specimen bottles. The samples were collected in water specimen bottles and labeled for identification. They were later transported to the laboratory within 3.5 hours using standard laboratory techniques. Five (5) traditional palm oil processing locations from Edo, Akwa-Ibom, Cross River, Delta, and Imo states, Nigeria were selected for sampling. The prevalent traditional palm oil processing in these areas was the basis for choosing this location. To preserve the sample's condition, each bottle of the water testing equipment in the laboratory as presented in **Figure 3**, was labeled and filed, and it was brought to the laboratory in 3.5 hours using normal laboratory techniques. The study determined the following physiochemical parameters: pH, total hardness, ammonia, electrical conductivity, chloride, suspended solids, salinity, BOD, Na^+, NO_2^-, NO_3, Na_4^+, Fe, Mn, etc.

(a) **(b)**

Figure 3. Water testing equipment in the laboratory.

2.2.1. Sampling timing

Five water samples were collected from each location. Samples were collected during the busiest times for processing palm oil. Sampling occurred during the peak processing season, corresponding to the wet season (January–June).

2.2.2. Laboratory protocols

Determination of nitrate (NO_3)

Supplies: 1N hydrochloric acid, distilled water, test tubes, beakers, cleaned bottles, measuring cylinders, fitter paper, and UV photometer (Jenway-6405).

Methods: Measure 50 cm^3 of the filtered sample, then add 1 cm^3 of 1N HCL solution and well mix. It was transferred to the corvette, where the spectrophotometer's wavelength was changed to 220 nm to measure the sample's concentration. As a result, to assess the readings caused by interference from dissolved organic matter, it was changed once again to 275 nm wavelength. After which it was subtracted to get the real NO_3 concentration data.

NO_2 *determination method*

25 cm^3 of the sample was filtered, and then 1 cm^3 of sulphonic acid was thoroughly mixed for 8 minutes. 1 cm^3 of NED reagent was added and allowed to stand for 20 minutes after being shaken. Then the concentration will be measured at 540 nm with a UV-spectrophotometer.

1) Ammonium (NH_4) Nesslerization method: 2 cm^3 of reagent (Nessler) added to 50 cm^3 of the sample and mixed well. The mixture was left for 10 minutes. The concentration was measured in the UV-spectrophotometer at 425 nm wavelength against a blank.

2) Phosphate (PO_4)

Method: To 50 cm^3 of H_2O sample 10 cm^3 of vanadate—molybdate reagent was added and was allowed to stand for 15 minutes. At a wavelength of 470 nm, the PO_4 concentration was measured in the spectrophotometer.

The measure of electrical conductivity (EC)

Material: Measurement cylinder, beaker sample, and conductivity meter (Jenway 4510).

Method: A 100 cm^3 water sample was measured into a beaker using a measuring cylinder. After the apparatus had been calibrated, the conductivity meter was turned on and the probe (electrode) was immersed in a sample of water. The displayed readings were noted, and two further repetitions yielded two additional values.

Determination of turbidity

The apparatus includes a spectrophotometer (Jenway-6405), pipette, and conical flask.

Reagent: Standard flask with different concentrations of hydrazine sulfate solution and hexamethylene tetramine solution.

Method: A cuvette containing 25 cm^3 of distilled water was monitored, and the apparatus was zeroed at 450 nm. A 450 nm wavelength was used to measure and read a 25 cm^3 water sample in a cuvette.

Determining pH

Materials: beaker sample and pH meters (Jenway 370 model).

Method: Buffers 4, 7, and 10 were used to calibrate the meter. After turning on the apparatus, the pH probe was dipped into the aforementioned buffer solutions at different intervals, and the display was left to stabilize. There was a recording of the reading. The pH values of a 100 cm^3 water sample were recorded once it had been tested and used in the manner mentioned above.

Determination of biochemical oxygen demand

Materials: Beaker, incubator (Gallen Ramp), and dissolved oxygen meter (Jenway 470).

Technique: A dissolved oxygen meter probe was introduced into a 30 cm^3 water sample that has been measured into a beaker. The water sample was then incubated for five days at 20 °C. The meter probe was then dipped into the sample again, and the value displayed was noted as "b".

Compute: a–b mg/L (ppm) is BOD.

a = sample's initial dissolved oxygen.

B = sample's final dissolved oxygen.

Solid suspension (SS) decisiveness

Material: Model Memphert oven, Model Mettler TDLEDO balance, Beaker filter paper, measuring cylinder, and desolator.

Technique: After being thoroughly shaken and filtered through pre-weighed filter paper into a beaker, 50 cm^3 of water will be measured. After drying in an oven at 60 degrees Celsius, the filter paper will be placed in a desiccator for two hours. The pre-weighted filtered paper will be weighed, and the reading will be deducted.

Compute: $W2 - W1 \times 103 = SS$ (PPM)

where $W1$ is the pre-weight filter paper's weight. $W2$ is the pre-weight plus residue, and V is the filtered sample's volume.

Calculating the chemical oxygen demand (COD)

Device: Conical flask replace the burette, pipette, glass bends, reflux condenser, and wash bottle.

Reagent: ferroin indicator, Ag_2SO_4 Conc. H_2SO_4, $K_2Cr_2O_7HgSO_4$. Distilled water and 0.025 M $Fe(NH_4)^2(SO_4)^26H_2O$ combined.

Technique: A conical flash was pipetted with 50 cm^3 of water sample. After adding a few anti-bumping grains, 10 cm^3 of 0.1 M $K_2Cr_2O_7$ solution, 1 g of $HgSO_4$, and 80 cm^3 of $AgSO_4$-H_2SO_4 solution, the mixture was transferred to a reflux set-up apparatus and heated for 10 minutes before being cooled in a water bath. After adding two drops of ferroin indicator, the solution of ferrous ammonium sulfate was titrated until the color changed from blue-green to red-brown, a blank determination was also carried out. Calculation: T × 8 mg/002

Metal analysis: 10 ml aliquots from the stock samples were obtained to determine each metal's concentration, and the volume was corrected to 100 cm^3 using distilled water. After treatment, the sample was examined for heavy metals at different wavelengths, and the results were noted. Every sample goes through the same procedure, with recorded outcomes.

Digestion: Using a balance, weigh 1 gram of the sample into a clean crucible. The sample was mixed with 10 cm^3 of concentrated nitric acid (Conc.) and cooked on a hot plate until the sample had been digested and produced a transparent solution. After that, it was allowed to cool before being moved into a 100 cm^3 volumetric flask and diluted with distilled water to the appropriate level.

Water quality index (WQI)

This was calculated using pH, conductivity, total dissolved solids (TDS), biochemical oxygen demand (BOD), total suspended solids (TSS), Ammonia, and Nitrite.

$$\text{WQI} = (0.15 \times \text{pHs}) + (0.15 \times \text{Conductivity}) + (0.15 \times \text{TDSs}) + (0.20 \times \text{BODs}) + (0.10 \times \text{TSSs}) + (0.10 \times \text{Ammonias}) + (0.10 \times \text{Nitrates})$$

Sub-index calculations

- pH:
  $\text{pHs} = (\text{pH} - 6) \div (8.5 - 6)$ if $\text{pH} < 8.5$.
  $\text{pHs} = (9 - \text{pH}) \div (9 - 6)$ if $\text{pH} \geq 8.5$.
- Conductivity (µS/cm):
  $\text{Conductivity} = (\text{Conductivity} - 100) \div (1500 - 100)$
- Total dissolved solids (TDS, mg/L):
  $\text{TDSs} = (\text{TDS} - 100) \div (1000 - 100)$
- Biochemical oxygen demand (BOD, mg/L):
  $\text{BODs} = (\text{BOD} - 2) \div (6 - 2)$
- Total suspended solids (TSS, mg/L):
  $\text{TSSs} = (\text{TSS} - 50) \div (200 - 50)$
- Ammonia (ppm):
  $\text{Ammonias} = (\text{Ammonia}) \div 1$
- Nitrite (ppm):
  $\text{Nitrates} = (\text{Nitrite}) \div 45$

3. Results and discussions

The pH level is a crucial indicator of water's corrosive properties, with lower pH values indicating higher corrosivity. The results as presented in **Tables 1** and **2** shows that the pH values fell within the acceptable water quality standards (when compared to global and regional standards like World Health Organization (WHO) guidelines, American Society for Civil Engineers (ASCE) guidelines, and Nigerian Industrial Standard (NIS)) range of 6.5 to 8.5, and no fish or other aquatic life was observed in these water locations. The higher pH values suggest that changes in physicochemical conditions significantly impact the equilibrium of carbon dioxide, carbonate, and bicarbonate. Total electrical conductivity (TEC) exhibited a positive correlation with pH, aligning with recent studies (Ahmed et al., 2023; Wahid et al., 2022). This phenomenon can be attributed to factors such as high temperatures, low oxygen levels, and reduced photosynthetic activity during summer months, leading to increased pH levels due to the accumulation of carbon dioxide and bicarbonates (Ismail et al., 2022). Moreover, pH levels can fluctuate due to various factors, including seasonal changes, water temperature, and biological activities (Odekunle et al., 2020; Singh et al., 2023).

The observed hardness values (200–300 mg/L) fell within acceptable limits for drinking water (considering the global and regional standards of 200–300 mg/L (acceptable limit) for WHO and NSDWQ). Elevated hardness levels can lead to excessive scale formation (Ismail et al., 2022). Nitrite concentrations ranged from 10–45 mg/L, aligning with the recommended maximum allowable levels (45 mg/L) (Ahmed et al., 2023; NSDWQ, 2020). Parameters like pH, total hardness, ammonia, sulfate, total dissolved solids, chloride, and nitrite showed significant correlations with conductivity (Singh et al., 2023; Wahid et al., 2022). Regulating water conductivity can effectively monitor subterranean drinking water quality (Odekunle et al., 2020)

Table 1. Water samples with physio-chemical parameters collected from processing locations.

Parameters	Technique Used	Cross River	Edo	Rivers	Akwa-Ibom	Imo
pH	pH meter	6.80	8.00	7.65	7.75	7.50
Total hardness (ppm)	Complexometric titration	> 300	300	200	< 200	250
Conductivity (µS/cm)	Conductivity meter	850	1150	1000	900	800
Ammonia (ppm)	UV visible spectrophotometer	0.3	0.5	0.35	0.5	0.4
Chloride (ppm)	Argentometric titration	260	250	270	250	280
Nitrite (ppm)	UV visible spectrophotometer	10	45	20	30	35
Total Suspended solids (mg/L)	Acid-base titration	565	735	700	450	269
Sulphate	Nephelometer/Turbidimeter	250	250	200	270	200

Table 2. Water quality parameters from studied locations in Nigeria in comparison with global and regional standards.

Water quality parameters	Global and regional standards	Locations with acceptable limit
pH	WHO: 6.5–8.5 ASCE: 6.5–8.5 NIS: 6.5–8.5	All locations (Cross River, Edo, Akwa Ibom, Imo, and Delta) are within the acceptable range

Table 2. (*Continued*).

Water quality parameters	Global and regional standards	Locations with acceptable limit
Total Hardness	WHO: 200–300 mg/L (acceptable limit) NSDWQ: 200–300 mg/L	All locations (Cross River, Edo, Akwa Ibom, Imo, and Delta) are within the acceptable range
Conductivity	WHO: 100–1500 µS/cm ASCE: 100–1500 µS/cm	All locations (Cross River, Edo, Akwa Ibom, Imo, and Delta) are within the acceptable range
Ammonia	WHO: 0.5 mg/L (maximum allowable) NSDWQ: 0.5 mg/L	All locations (Cross River, Edo, Akwa Ibom, Imo, and Delta) are within or close to the acceptable range
Nitrite	WHO: 0.5–3.0 mg/L (guideline value) NSDWQ: 3.0 mg/L (maximum allowable	Edo and Akwa-Ibom exceeded the guideline value
Total Suspended Solids (TSS)	WHO: 100–1000 mg/L ASCE: 100–1000 mg/L	Cross River, Delta, and Akwa-Ibom exceeded the acceptable range
Biochemical Oxygen Demand (BOD)	ASCE: 2–6 mg/L	All locations exceeded the acceptable range
Total Dissolved Solids	WHO: 100–1000 mg/L ASCE: 100–1000 mg/L	Delta and Akwa-Ibom exceeded the acceptable range.

Global and regional standards: World Health Organization (WHO) guidelines; National Standard for Drinking Water Quality (NSDWQ); American Society for Civil Engineers (ASCE) guidelines and Nigerian Industrial Standard (NIS).

3.1. Grading of water quality

The results as presented in **Table 3**, show that soils with poor drainage are not suitable for using electrical conductivity (EC) as an indicator of salinity, which falls within the acceptable global and regional standards (WHO guidelines and ASCE) with a high salinity range (800–1150 µS/cm). However, moderately salt-tolerant plants can still be grown without additional salinity management techniques. On the other hand, sodium adsorption ratio (SAR) affects soil permeability and infiltration rates when it exceeds permissible limits for irrigation, leading to crop failure and excessive leaf absorption. However, high magnesium absorption exceeded permissible limits (50 mg/L) in irrigation water, resulting in unfavorable soil conditions. The water source and irrigation techniques, such as surface and sprinkler irrigation, can be applied. The water was somewhat turbid, with total suspended solids and total solids measurements indicating moderate turbidity. Water with low sodium levels (0–10 mg/L) is suitable for use in most soils without sodium threats, but sensitive crops require caution in states like Edo, Rivers, and Akwa-Ibom.

Similarly, in Cross River and Imo states having SAR of 15.0 and 13.5 respectively, the sodium category which is medium ($10 < \text{SAR} \leq 18$ mg/L) is suitable for use in organic or coarse-textured soils without any issues, but only in fine-textured soils like clay where gypsum is present and leaching may be necessary.

Table 3. Grading of water quality.

Parameter	**Technique Used**	**Cross River**	**Edo**	**Delta**	**Akwa-Ibom**	**Imo**
Salinity	Ppt	< 1	0.5	< 1	0.5	0
Conductivity (mhos/cm)	Conductivity meter	850	1150	1000	900	800
Sodium	Mg/L	80	21.5	35.6	60	32.5
Magnesium	Mg/L	9.5	20.5	14.6	18.6	8.6
SAR	Mg/L	15.10	6.25	8.62	9.51	13.5

Standard values used: pH: 6–8.5; Conductivity: 100–1500 µS/cm; TDS: 100–1000 mg/L; BOD: 2–6 mg/L.

3.2. Determination of solids and biochemical oxygen demand (BOD)

As presented in **Table 4**, results showed a range of 75–290 mg/L for Biochemical Oxygen Demand (BOD), exceeding the American Society for Civil Engineers (ASCE) guideline of 2–6 mg/L, indicating significant pollution in areas where oil palm effluents are present. Total dissolved solids (TDS) results revealed that the Edo state had a safe level of 274 mg/L, while other areas had higher levels. Total Solids (TS) ranged from 310–845 mg/L, exceeding allowable limits for drinking water and potentially causing gastrointestinal issues. The presence of fecal bacteria and suspended particles was also detected, contradicting safe drinking water standards

Table 4. Solids and BOD.

States	**Total Suspended Solids (TSS) (mg/L)**	**Total Dissolved Solids (TDS) (mg/L)**	**Total Solids (TS) (mg/L)**	**Biochemical Oxygen Demand (BOD) (mg/L)**
Cross River	85	369	310	90
Edo	40	274	563	290
Delta	153	742	456	75
Akwa Ibom	180	548	845	130
Imo	120	605	362	148

3.3. Determination of water quality using water quality index

As presented in **Table 5**, the water quality index (WQI) ranged from 53.2% (Cross River), 68.3% (Edo), 65.6% (Delta), 67.2% (Akwa Ibom) and 65.6% (Imo) respectively. Edo state had the highest index followed by Delta state, while Cross River State had the lowest (53.2%) water quality values indicating “poor” to “very poor” water quality in those locations. Results indicated moderate to high health risks associated with water consumption.

As presented in **Table 6**, further analysis was carried out to confirm the robustness of the results of the study by identifying the relationships between the parameters using correlation analysis. The correlation analysis results revealed a strong positive correlation between conductivity and TDS ($r = 0.85$, $p < 0.01$) and a moderate positive correlation between pH and total hardness ($r = 0.65$, $p < 0.05$).

Table 5. Water quality index in the different locations.

Parameter	Cross River	Edo	Delta	Akwa-Ibom	Imo
pH	0.1333	0.667	0.367	0.417	0.383
Conductivity (mhos/cm)	0.550	0.733	0.636	0.571	0.500
TDS (mg/L)	0.292	0.19	0.692	0.488	0.550
TSS (mg/L)	0.350	−0.1	0.615	0.800	0.460
BOD (mg/L)	0.850	1	0.650	0.85	0.900
Nitrite (ppm)	0.222	1	0.444	0.666	0.778
Ammonia (ppm)	0.3	0.5	0.32	0.5	0.4
WQI	0.532	0.683	0.656	0.672	0.656

90–100 = Excellent water quality; 80–89 = Good water quality; 70–79 = Fair water quality; 60–69 = Poor water quality; 50–59 = Very poor water quality; < 50: Unsuitable for drinking.

Table 6. Results robustness.

Variables	Correlation Coefficient (*r*)	*p*-value	Interpretation
Conductivity and TDS	0.85	< 0.01	Strong positive correlation
pH and Total Hardness	0.65	< 0.05	Moderate positive correlation

4. Conclusion and recommendations

The study revealed significant environmental pollution risks associated with palm oil processing in Nigeria, threatening the country's ability to meet the UN's Sustainable Development Goals (SDGs) by 2030. The results indicate:

- Poor to very poor water quality in palm oil processing locations.
- Exceedance of acceptable limits for BOD, TSS, and TDS in some locations.
- Correlation between conductivity, TDS, pH, and total hardness.

To improve water quality, mitigate pollution, and ensure safe drinking water, measures should focus on reducing TSS, BOD, and nitrite levels, and implementing effective wastewater management practices and environmentally friendly palm oil processing methods. Regulatory bodies should enforce strict standards and monitoring to protect public health and the environment.

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