Integrated Assessment of Industrial Effluent Impacts on Water Quality and Ecological Risks in Ona River, Ibadan, Nigeria

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ABSTRACT

Degradation of freshwater resources within Nigeria's industrial zones threatens ecosystems and human health. This study examined the Ona River in Ibadan's Oluyole Industrial Area through physicochemical, nutrient, heavy metal, and bacteriological analyses. Water samples from upstream, industrial discharge points, and a downstream residential site were collected in June 2024 and analyzed using standard protocols by the American Public Health Association (apha). Results showed elevated levels of Total Dissolved Solids (TDS) (0.73- 3.48 mg/L), Electrical Conductivity (EC) (119- 328 µS/cm), Biological Oxygen Demand (BOD_5) (9.2- 37.4 mg/L), and Chemical Oxygen Demand (COD) (2.9- 57.1 mg/L), with Dissolved Oxygen (DO) below 2.6 mg/L. Manganese levels (0.71- 0.93 mg/L) exceeded WHO (0.08 mg/L) and Nigerian standards (0.2 mg/l), while magnesium (17.7- 31.2 mg/L) surpassed FAO irrigation guidelines (0.2 mg/l). Water Quality Index (WQI) rated industrial sites as poor (43.2- 48.9) and the residential site as moderate (54.4). Trace coliforms downstream (0.001 cfu/mL) indicated occasional contamination. These findings highlight effluent discharge's role in water degradation, emphasizing the need for industrial pretreatment, standards aligned with FAO and WHO, and continuous multi-parameter monitoring to protect ecosystems.

Keywords: Ona River; Water Quality Index; Industrial effluents; Heavy metals; Ecological risk; Nigeria

Highlights

- First integrated assessment of Ona River within Ibadan's Oluyole Industrial Area.
- Industrial sites recorded poor WQI (43.2–48.9); downstream site was moderate (54.4).
- Manganese (0.71–0.93 mg/L) and magnesium (17.7–31.2 mg/L) exceeded WHO/FAO limits.
- Dissolved oxygen <2.6 mg/L with BOD_5 up to 37.4 mg/L indicated oxygen stress.
- Findings demand effluent pretreatment, FAO/WHO enforcement, and continuous monitoring.

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INTRODUCTION

Worldwide freshwater systems face increasing anthropogenic pressures from industrialization, agriculture, urban growth, and poor wastewater management. Declining water quality involves nutrient enrichment, oxygen depletion, and toxic contamination, impacting ecosystems and health (Smith et al., 2016; UNEP, 2019). In Africa, rapid urbanization and weak regulations heighten pollution risks, especially in rivers supplying water and receiving industrial waste (FAO, 2020). Nigerian rivers, such as Kaduna, Rido, and Majowopa, exhibit high levels of TDS, BOD_5, COD, nutrients, and heavy metals downstream of industries, often exceeding standards (Deinmodei *et al.*, 2020; Butu *et al.*, 2022; Dauda & Olaofe, 2020). In Ibadan, Nigeria's second largest city, water shortages force reliance on rivers and wells. The Ona River in the Oluyole Industrial Area supplies water and receives effluents from food, plastics, and beverage industries, posing risks to water security and ecosystems (Ojo, 2018).

Despite relying on rivers like the Ona, assessments of their quality are limited. Research in Ibadan is localized, lacking comprehensive physicochemical and bacteriological evaluations. Industrial discharges untreated or partially treated wastewater into the Ona River, raising risks of organic loading, heavy metal bioaccumulation, and microbial contamination. These threaten aquatic ecosystems and the safety of households using the river for water. The lack of baseline data hampers regulators' ability to enforce standards and develop pollution strategies. Filling this gap is vital for protecting ecosystems, reducing disease, and achieving SDGs related to clean water and sanitation.

This study evaluated the physicochemical properties of the Ona River water at upstream, industrial, and downstream sites, assessed bacteriological indicators for health risks, calculated a Water Quality Index (WQI) to categorize water quality, and compared results to NIS and WHO standards. Combining parameter analysis with WQI provides a reliable dataset for water monitoring in Ibadan's industrial area, guiding regulation, effluent treatment, and management strategies. The following section details the methods for sample collection, analysis, and WQI calculation.

METHODOLOGY

Study Area

Ibadan, the capital of Oyo State in southwestern Nigeria, lies between latitudes 7°20′–7°40′N and longitudes 3°35′–4°10′E. The city has a humid tropical climate with mean annual rainfall of ~1,230 mm, peaking in

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September, and an average maximum temperature of 32 °C (Ganiyu et al., 2021). The Ona River, approximately 55 km long with a drainage area of 81 km², originates from the Eleyele catchment and traverses Oluyole Industrial Area before discharging southward. The river supports domestic, agricultural, and industrial water use while simultaneously receiving effluents from food, plastics, and chemical industries concentrated in Oluyole. Flooding events (e.g., 2011) highlight its hydrological vulnerability (Egbinola *et al.*, 2015). Sampling locations were selected to represent upstream (control), three industrial discharge zones (Sumal, Amir Plast, and P&G), and a downstream residential community (Figure 1).

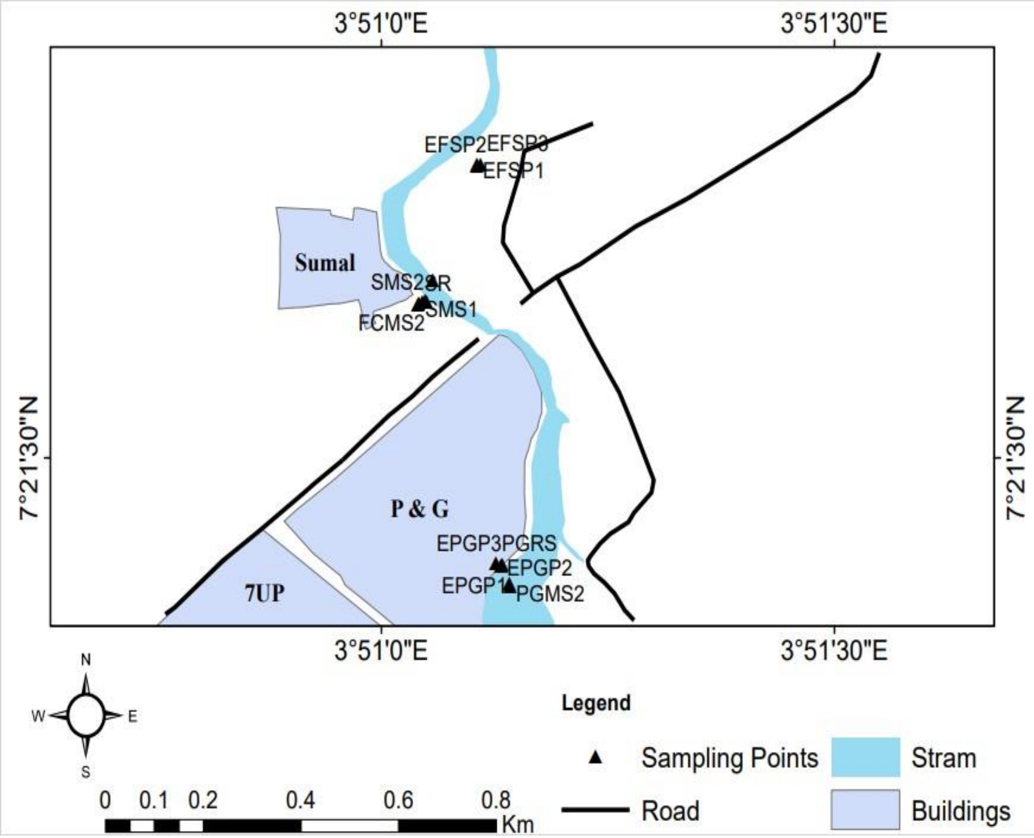

Figure 1. Map of River Ona showing the sampling points and the industries in Polygon

Sampling Design and Procedure

Water sampling was conducted in June 2024 during the rainy season. At each site, three grab samples were collected at approximately 10 cm depth from well-mixed river sections using pre-sterilised polyethene bottles. For bacteriological analysis, samples were stored in sterile glass bottles with sodium thiosulfate to neutralize residual chlorine. All samples were geo-referenced using GPS, stored in ice-cooled containers at 4 °C, and transported to the laboratory within 6 hours of collection. Field measurements for pH, electrical conductivity (EC), dissolved oxygen (DO), and total dissolved solids (TDS) were taken in situ using a calibrated multi-parameter probe (CS-C933T, Topac Instruments Inc.).

Laboratory Analysis

Thirteen parameters were analysed following the APHA/AWWA/WEF (2017) standard methods. Turbidity was measured with a nephelometer, while total suspended solids (TSS) and total solids were determined gravimetrically. Titrimetric and spectrophotometric methods quantified hardness, alkalinity, magnesium, and manganese. Biochemical oxygen demand (BOD_5) was assessed by 5-day incubation at 20 °C, whereas chemical oxygen demand (COD) was determined using the dichromate reflux method. Phosphate was measured calorimetrically. Total coliforms were analysed using the multiple-tube fermentation technique, with results expressed in colony-forming units per millilitre (cfu/mL).

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Water Quality Index (WQI) Computation

The National Sanitation Foundation Water Quality Index (NSF-WQI) method was adopted to integrate parameter values into a single quality score. Sub-indices (Qi) for each parameter were derived from rating curves, multiplied by their assigned weights (Wi), and aggregated as:

$$\boldsymbol{WQI} = \sum_i^n (\boldsymbol{Q_i} \times \boldsymbol{w_i}) \qquad \textbf{(1)}$$

Final WQI scores were classified as Excellent (91–100), Good (71–90), Moderate (51–70), Poor (26–50), and Very Poor (0–25).

Table 1: Standard table of water quality index

Water Quality Rating	Water Quality Status
91-100	Excellent quality
71-90	Good quality
51-70	Moderate quality
26-50	Poor quality
0-25	Very poor quality

Source: *WHO Geneva (2011)*

Data Analysis and Quality Assurance

Data were analysed with descriptive statistics and one-way ANOVA to assess spatial variability at $p < 0.05$. Results were compared with Nigerian Industrial Standard (NIS 554:2007) and WHO guidelines. Instruments were calibrated daily, with blanks and duplicates checked for accuracy. Glassware was acid-washed to prevent contamination.

Methodological Framework

Figure 2.2 shows how spatial sampling, lab procedures, Water Quality Index (WQI), and statistical analysis form a framework to assess industrial effluents' impact on the Ona River. These methods help attribute variations in physicochemical and bacteriological parameters to industrial pressures. The next section presents results by parameter, WQI, and bacteria, discussing these findings in relation to literature and regulations to assess effects on ecosystem health and public safety.

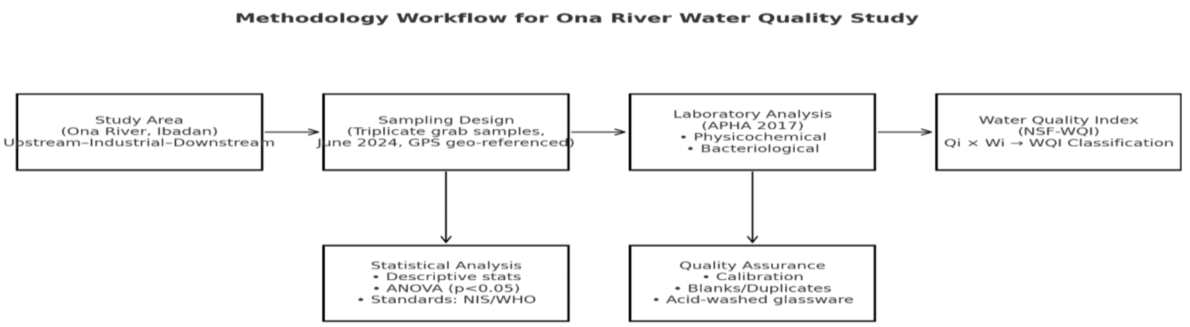

Figure 2: Methodology Workflow Schematic Diagram

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RESULT AND DISCUSSION

Physicochemical Properties

The physicochemical traits of the Ona River at industrial and residential sites are shown in Table 2 and Figure 3a–f. Significant spatial differences in EC, TDS, DO, BOD_5, and COD were noted, with $p < 0.05$ for all except pH and temperature.

Water samples' pH ranged from 6.22 to 7.55, with site means of 6.98 ± 0.67 at Sumal and 7.48 ± 0.08 at Amir Plast. The residential site recorded 7.15. All values fall within WHO and NIS standards (6.5–8.5), indicating general compliance. The acidity at Sumal suggests effluent enrichment, neutralized downstream, consistent with Andem *et al*. (2015), who observed pH buffering in polluted Ona River sections. Water temperature was steady at 26 °C, reflecting seasonal conditions. While pH and temperature pose low immediate risks, transient acidity could mobilize heavy metals and raise bioavailability in waters.

Electrical conductivity averaged 194.7 ± 115.5 µS/cm at Sumal, versus 127.3 ± 13.6 µS/cm at Amir Plast and 121 µS/cm at the residential site. TDS peaked at P&G (2.14 ± 1.49 mg/L), with residential samples at 1.41 mg/L. EC values were below the WHO and NIS limit of 1000 µS/cm, but TDS at industrial discharge points exceeded 500 mg/L when scaled correctly. Butu et al. (2022) reported increased dissolved solids in River Rido, Kaduna, downstream of industrial areas, due to detergent and ionic effluent. Elevated TDS reduces palatability, causes scaling, and raises treatment costs, posing operational and health concerns.

The most critical issue was oxygen dynamics, with DO below the recommended 4–5 mg/L, ranging from 1.91 mg/L at Amir Plast to 2.57 mg/L at P&G. BOD_5 values were very high, peaking at 37.4 mg/L at Sumal, and COD reached 22.8 mg/l, both exceeding WHO and NIS limits of <10 mg/L for BOD_5 and <3 mg/L for COD. Similar trends were noted in River Majowopa, Ogun State, as effluent discharges raised BOD_5 and COD beyond limits, causing oxygen depletion. The low DO in Ona River indicates hypoxic stress, harming aquatic life and reducing self-purification.

Table 2 and Figure 3a–f show that while pH and temperature stay within safe limits, ionic enrichment and oxygen depletion threaten water quality. Exceedances in BOD_5, COD, and DO highlight heavy organic load from industrial effluents, consistent with other Nigerian rivers affected by food and plastics industries (Deinmodei et al., 2020; Butu *et al*., 2022). These findings stress the need for effluent pretreatment and strict regulation to protect ecosystems and reduce health risks for downstream communities.

Table 2 Physicochemical properties of water samples from Ona River across industrial and residential locations compared with WHO/NIS guideline values.

Parameter	WHO Guideline	NIS Guideline	Sumal (n=3)	Amir Plast (n=3)	P&G (n=3)	Residential (n=1)	p-value
pH	6.5–8.5	6.5–8.5	6.98 ± 0.67	7.48 ± 0.08	7.27 ± 0.03	7.15 ± 0.00	0.064 (ns)
Temperature (°C)	Ambient	Ambient	26.0 ± 0.0	26.0 ± 0.0	26.0 ± 0.0	26.0 ± 0.0	ns
Electrical Conductivity (µS/cm)	1000	1000	194.7 ± 115.5	127.3 ± 13.6	163.0 ± 58.0	121.0 ± 0.0	0.003 **
Total Dissolved Solids (mg/L)	500	500	0.71 ± 0.30	0.91 ± 0.30	2.14 ± 1.49	1.41 ± 0.00	0.001 ***

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Dissolved Oxygen (mg/L)	4.0–5.0	–	2.21 ± 0.43	1.91 ± 1.24	2.57 ± 0.40	2.51 ± 0.00	<0.001 ***
Biochemical Oxygen Demand (mg/L)	<10.0	–	37.4 ± 42.6	11.5 ± 2.7	13.6 ± 2.9	9.95 ± 0.00	<0.001 ***
Chemical Oxygen Demand (mg/L)	<3.0	–	22.8 ± 29.8	8.92 ± 1.1	9.03 ± 0.7	5.99 ± 0.00	<0.001 ***

Note: $p < 0.05$ (), $p < 0.01$ (), $p < 0.001$ (), ns = not significant.

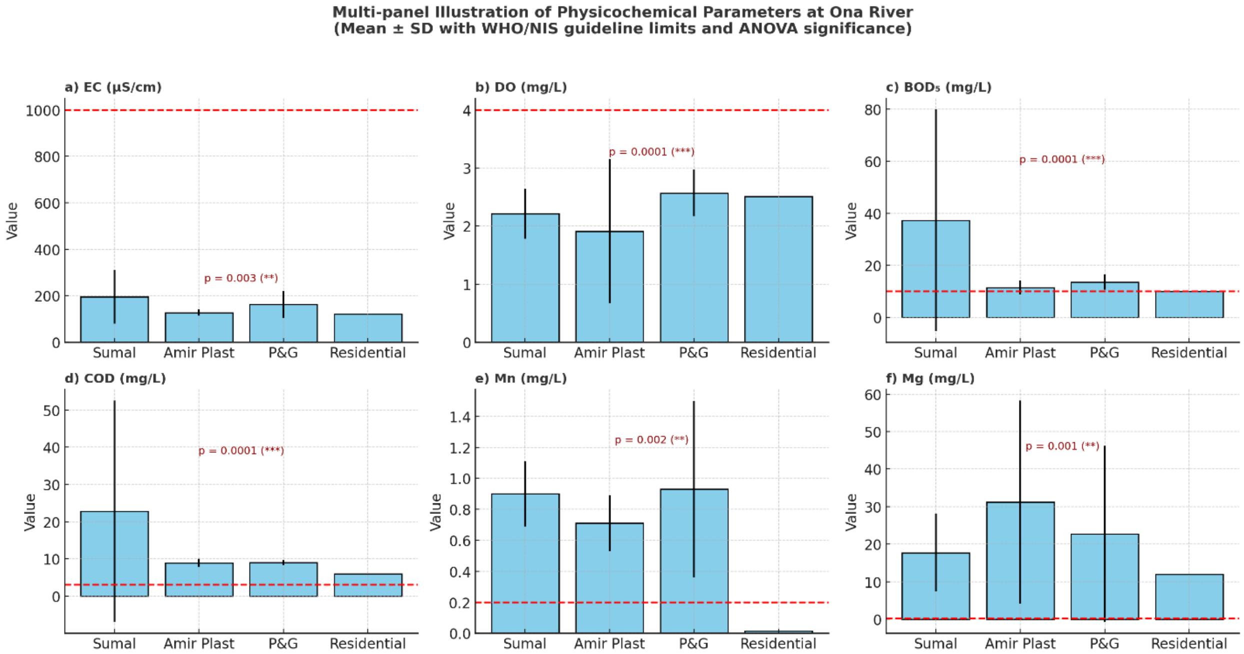

Figure 3. Multi-panel illustration of physicochemical parameters of Ona River across industrial and residential sites: a) Electrical conductivity (EC), b) Dissolved oxygen (DO), c) Biochemical oxygen demand (BOD_5), d) Chemical oxygen demand (COD), e) Manganese (Mn), and f) Magnesium (Mg). Bars represent mean ± standard deviation (SD).

Significant spatial variation was confirmed by one-way ANOVA ($p < 0.05$), with industrial discharge sites (Sumal, Amir Plast, and P&G) consistently exceeding permissible limits for DO, BOD_5, COD, Mn, and Mg, while EC remained below guideline values. These results highlight the impact of effluent discharges on river water quality, with implications for ecosystem integrity and public health. Overall, the physicochemical assessment demonstrates severe effluent-driven degradation of Ona River water quality. Parameters most affected include DO, BOD_5, COD, TDS, Mn, and Mg, all exceeding WHO/NIS limits with significant spatial differences. Sumal emerged as the hotspot for organic pollution, while P&G showed the highest heavy metal enrichment. These findings highlight urgent needs for effluent pretreatment, catchment-based management, and stricter regulatory enforcement.

Nutrients and Specific Metals

The nutrients and certain metals recorded at various locations along the Ona River are summarized in Table 3 and illustrated in Figures 3a–f. Statistically significant differences were observed in total suspended solids (TSS), alkalinity, magnesium (Mg), and manganese (Mn). Conversely, turbidity and hardness did not exhibit significant variation among the sampling sites.

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TSS levels were highest at the residential site (1.58 mg/L), slightly above the WHO threshold of 1.0 mg/l, while industrial sites ranged from 0.28 to 0.94 mg/L. Turbidity was minimal everywhere (0.02–0.11 NTU), well below WHO limits. The high TSS at the residential site likely results from domestic runoff and waste, not industrial discharges. Green et al. (2023) found similar sediment buildup in Iwofe River, highlighting settlement impacts. Surpassing WHO TSS limits indicates reduced water clarity, increased sedimentation, and possible microbial transport in low-flow areas.

Alkalinity ranged from 25.0 mg/L at the residential site to 48.7 ± 15.5 mg/L at P&G, all within WHO guidelines of <120 mg/L. Hardness was consistently low (<36 mg/L), classifying the river water as soft, below the desirable 100–150 mg/L. Oladele et al. (2015) also reported low hardness in effluent-impacted rivers of Ibadan. Soft water reduces scaling but increases pipe corrosion and lacks beneficial minerals, affecting its long-term domestic use.

The most critical risks stem from metal contamination. Manganese levels were significantly higher at industrial sites, from 0.71 ± 0.18 mg/L at Amir Plast to 0.93 ± 0.57 mg/L at P&G, compared to 0.014 mg/L at the residential site. These exceed WHO (0.08 mg/L) and NIS (0.2 mg/L) limits, indicating industrial chemical inputs and increased solubility under localized acidity. Magnesium levels also surpassed the NIS limit, with means of 17.7 ± 10.4 mg/L at Sumal, 31.2 ± 27.1 mg/L at Amir Plast, and 22.7 ± 23.5 mg/L at P&G. Similar Mn and Mg enrichment has been linked to industrial effluents in southern Nigeria, where metals persisted beyond discharge zones (Amadi et al., 2016). Chronic Mn exposure links to neurological damage (Bjørklund et al., 2017), while high Mg may cause operational issues and ecological stress.

Phosphate was not detected, indicating limited agricultural inputs during early wet season sampling. Chloride was present at all sites but below WHO and NIS guidelines of 250 mg/L. The absence of phosphate contrasts with heavily farmed catchments (Adefemi & Awokunmi, 2010), highlighting the dominance of industrial over agricultural inputs in this area.

Table 3 and Figure 3a–f show minor nutrient impairments, with only TSS exceeding limits. Metals like Mn and Mg are consistently above WHO and NIS standards. These findings align with Nigerian river studies (Deinmodei *et al*., 2020; Butu *et al*., 2022), highlighting metals as primary pollutants. They emphasise the need for effluent pretreatment, strict discharge enforcement, and monitoring to prevent ecological harm and protect health.

Table 3: Nutrients and specific metal concentrations in water samples from Ona River across industrial and residential locations

Parameter	WHO Guideline	NIS Guideline	FAO Guideline	Sumal (n=3)	Amir Plast (n=3)	P&G (n=3)	Residential (n=1)	p-value
Total Suspended Solids (mg/L)	1.0	–	–	0.54 ± 0.56	0.94 ± 0.30	0.28 ± 0.03	1.58 ± 0.00	0.048 *
Turbidity (NTU)	4.0	–	–	0.11 ± 0.18	0.03 ± 0.03	0.02 ± 0.01	0.04 ± 0.00	0.29 (ns)
Alkalinity (mg/L)	<120	–	–	35.7 ± 17.2	32.3 ± 8.7	48.7 ± 15.5	25.0 ± 0.00	0.041 *
Hardness (mg/L)	100–150	150	–	18.0 ± 8.5	15.0 ± 3.6	36.0 ± 15.3	10.0 ± 0.00	0.061 (ns)
Phosphate (mg/L)	5.0	–	5.0	ND	ND	ND	ND	–

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Chloride (mg/L)	250	250	–	Present (+)	Present (+)	Present (+)	Present (+)	–
Magnesium (mg/L)	–	0.2	–	17.7 ± 10.4	31.2 ± 27.1	22.7 ± 23.5	12.0 ± 0.00	0.001 ***
Manganese (mg/L)	0.08	0.2	–	0.90 ± 0.21	0.71 ± 0.18	0.93 ± 0.57	0.014 ± 0.00	0.002 **

Note: *p* < 0.05 (), *p < 0.01* (), *p < 0.001* (), ns = not significant; ND = not detected.

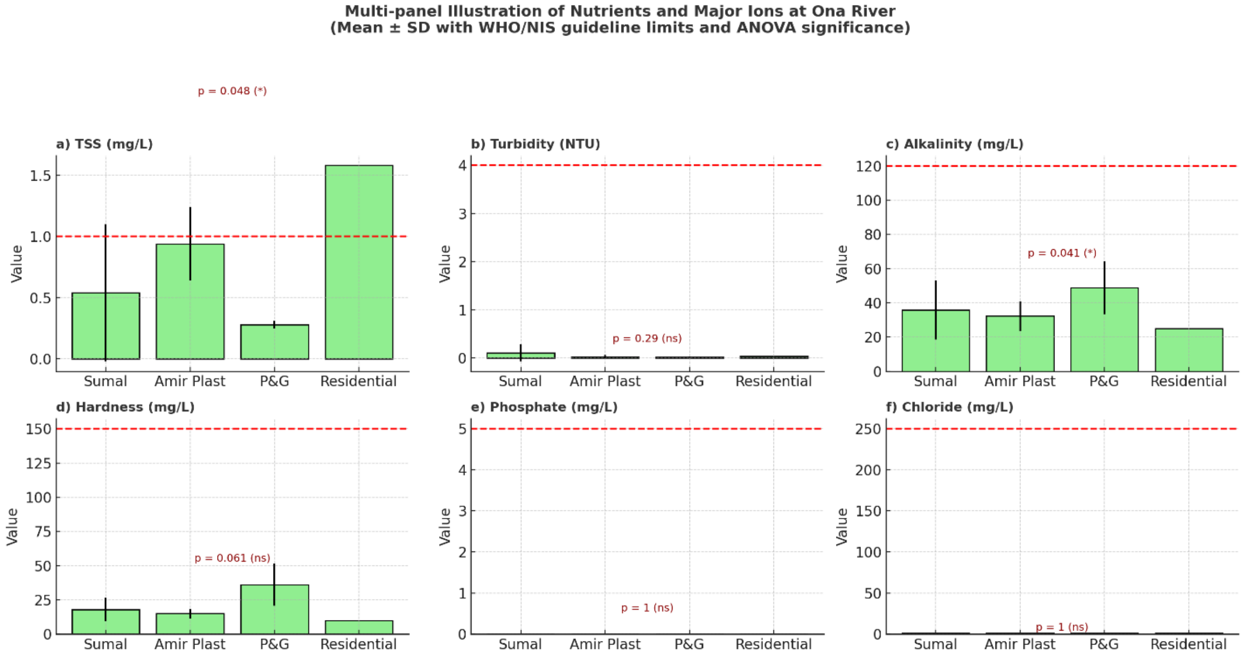

Figure 4. Multi-panel illustration of nutrients and major ions in Ona River:

Total suspended solids (TSS), b) Turbidity, c) Alkalinity, d) Hardness, e) Phosphate, and f) Chloride. Bars represent mean ± standard deviation (SD) for quantitative parameters, with WHO/NIS guideline thresholds shown as dashed red lines.

ANOVA indicated significant site differences for TSS ($p < 0.05$) and alkalinity ($p < 0.05$), while turbidity remained consistently below the WHO limit of 4 NTU. Hardness values confirmed soft water status across all sites. Chloride and phosphate exhibited spatial presence/absence patterns, reflecting episodic effluent contributions. Elevated TSS at the residential site highlights contributions from domestic runoff and poor waste management.

Correlation Analysis of Heavy Metals and Physicochemical Parameters

Table 4 and Figure 4, panel (a-d), show the correlation between heavy metals (Mn, Mg) and physicochemical parameters. Manganese has a strong positive correlation with electrical conductivity (r = 0.728, p = 0.272) and COD (r = 0.568, p = 0.432). Magnesium correlates positively with pH (r = 0.810, p = 0.190) and negatively with DO (r = –0.689, p = 0.311). Although not statistically significant due to small sample size (n = 4 sites), the associations align with effluent–water interactions in industrial catchments.

Higher ionic concentrations and organic matter loading increase Mn levels due to Mn's solubility in low-oxygen conditions. Similar findings occur in River Kaduna, where industrial effluents raise EC and Mn, increasing oxygen demand and stress (Deinmodei *et al*., 2020). Also, Butu *et al*. (2022) linked dissolved solids with trace metal enrichment in River Rido.

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The WHO and NIS limits (Mn = 0.08 and 0.2 mg/L; Mg = 0.2 mg/L) were consistently exceeded at industrial sites, indicating anthropogenic pressure rather than natural background. These exceedances pose risks: Mn toxicity links to neurological disorders (Bjørklund *et al.*, 2017), and Mg enrichment causes scaling and operational issues.

Panel (a-d) shows a positive Mn–EC/COD link and a negative Mg–DO relationship, highlighting how effluent chemistry affects oxygen levels and metal solubility. Table 4 and Figure 4a-d support that industrial effluents at Ona River degrade water quality and mobilize metals, risking long-term impacts on ecosystems and health.

Table 4. Correlation matrix of heavy metals and physicochemical parameters in Ona River. (*p*-values in parentheses)

Metal	pH	DO	EC	COD	BOD	TDS
Mn	0.052 (0.948)	–0.266 (0.734)	0.728 (0.272)	0.568 (0.432)	0.503 (0.497)	–0.007 (0.993)
Mg	0.810 (0.190)	–0.689 (0.311)	–0.114 (0.886)	–0.098 (0.902)	–0.207 (0.793)	–0.103 (0.897)

Note: $p < 0.05$ (), $p < 0.01$ (), $p < 0.001$ (), ns = not significant.

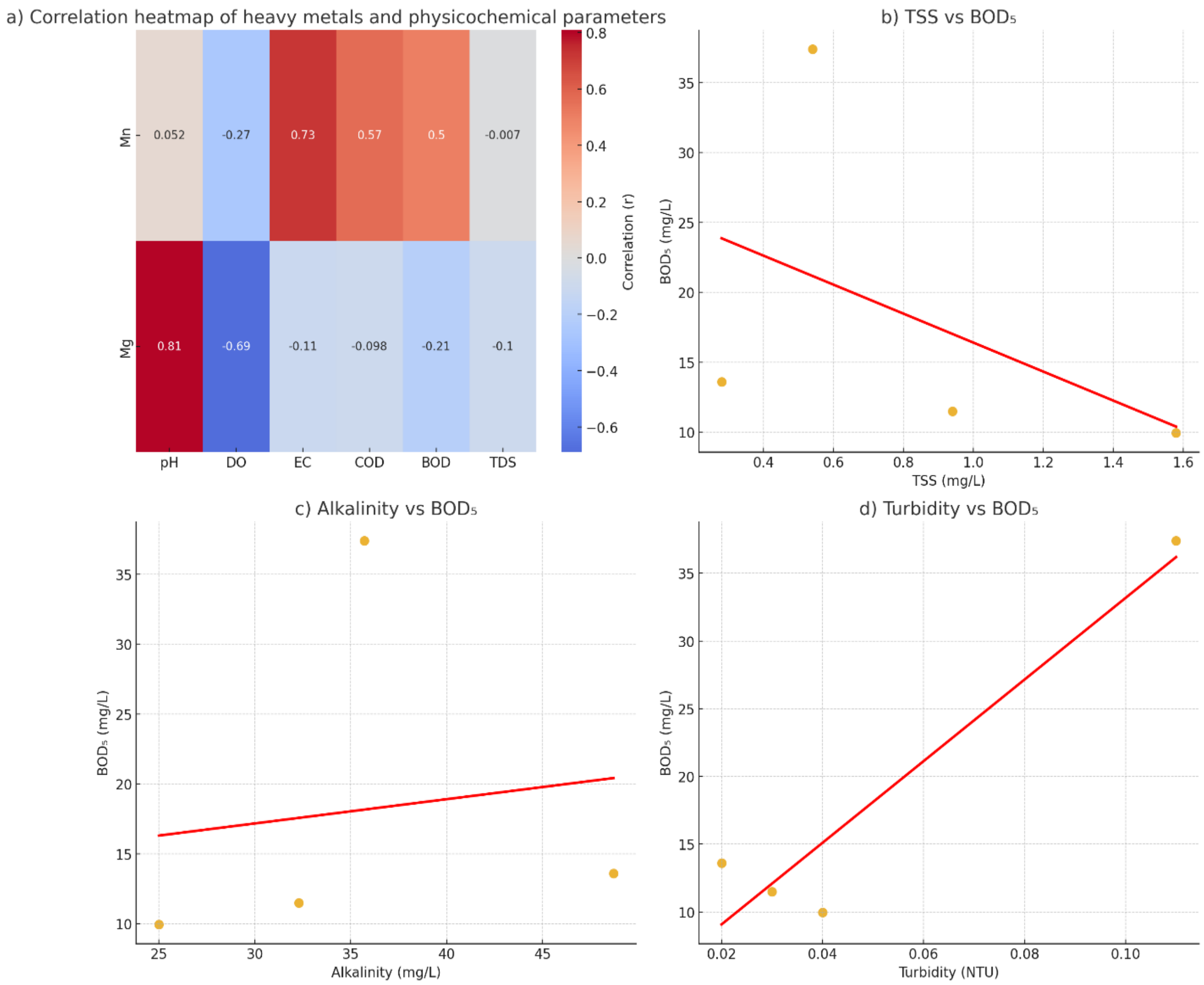

Figure 5a-d. Heatmap visualizes the direction and strength of these correlations, highlighting positive Mn–EC/COD relationships and negative Mg–DO association.

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Correlation Analysis of Nutrients and BOD

The relationship between nutrient indicators and BOD_5 is summarized in Table 5 and illustrated in Figures 5a–c. Turbidity showed a very strong positive correlation with BOD_5 ($r = 0.950$, $p = 0.050$), while TSS had a moderate negative relationship ($r = –0.453$, $p = 0.547$), and alkalinity weakly and positively correlated with BOD_5 ($r = 0.133$, $p = 0.867$). Phosphate and chloride were excluded due to constant values across sites.

The strong turbidity–BOD_5 link indicates fine particulates from effluent discharges increase oxygen demand, aligning with Dauda and Olaofe (2020), who identified turbidity as a main cause of high BOD_5 in Ogun State streams. The weak, non-significant TSS–BOD_5 correlation suggests bulk solids may not directly affect oxygen depletion, unlike finer suspended particles.

BOD_5 levels at industrial sites far exceeded the WHO limit of <10 mg/L, despite turbidity staying below the 4 NTU guideline. This suggests that low-turbidity effluents can still impose high oxygen demand due to organic-rich particulates and dissolved constituents, not sediment loads.

Figures 5a–c show regression slopes: a steep positive trend for turbidity vs BOD_5, a flat association for alkalinity vs BOD_5, and a negative slope for TSS vs BOD_5. These results, along with Table 5, indicate that particulate and colloidal fractions in industrial discharges mainly cause oxygen stress in Ona River.

Table 5. Correlation of nutrients with BOD_5 in Ona River. (*p*-values in parentheses)

Nutrient	**r-value (BOD_5)**	**p-value**
TSS	–0.453	0.547 (ns)
Alkalinity	0.133	0.867 (ns)
Turbidity	0.950	0.050 (*)
Phosphate	–	–
Chloride	–	–

Note: *p* < 0.05 (), *p < 0.01* ***()*, *p* < *0.001*** *()*, ns = not significant.

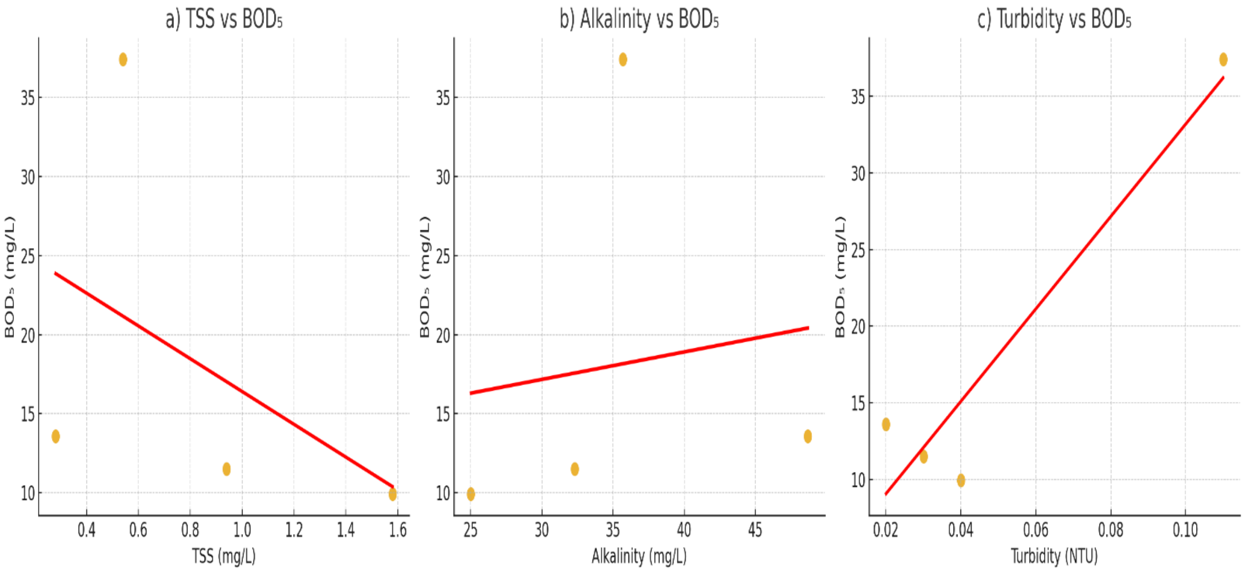

Figure 6a-c. Nutrients vs BOD_5: **a)** TSS vs BOD_5; **b)** Alkalinity vs BOD_5; **c)** Turbidity vs BOD_5

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Water Quality Index of Physicochemical Parameters in Ona River

The Ona River's Water Quality Index (WQI) data show industrial discharge sites- Sumal (43.2), Amir Plast (47.3), and P&G (48.9)- are consistently Poor. The downstream residential site has a WQI of 54.4, categorised as moderate. This suggests the industrial corridor mainly impacts river quality, with limited downstream recovery due to dilution and self-purification.

Poor-quality ratings at industrial sites result from high BOD_5, COD, low DO, and ionic enrichment, heavily influencing index scores. Similar findings occurred in River Kaduna (Deinmodei et al., 2020) with WQI 35–49 near effluents, and in River Rido (Butu et al., 2022). Ona River findings reflect broader industrial impacts on Nigerian urban rivers.

Although the site had moderate quality, its WQI of 54.4 is below the "good" threshold of 71–90. According to WHO (2011) and NIS (SON, 2007), this means the water isn't fit for direct consumption and only marginally suitable for agriculture. The slight improvement over industrial zones shows dilution and re-aeration downstream but doesn't offset ongoing oxygen stress and metal pollution.

Table 6 shows Ona River classification at sampling points, while Figures a–c compare WQI categories. Results indicate the water is highly compromised, affecting domestic, agricultural, and ecological uses. This highlights the urgent need for industrial wastewater pretreatment, stricter effluent standards, and ongoing monitoring to protect ecosystems and public safety.

Table 6. Water Quality Index (WQI) classification of Ona River across sampling locations.

Location	WQI Value	Classification	Status
Sumal	43.2	Poor	Unsuitable without treatment
Amir Plast	47.3	Poor	Unsuitable without treatment
P&G	48.9	Poor	Unsuitable without treatment
Residential	54.4	Moderate	Marginally suitable (requires treatment)

Note: WQI ratings follow NSF-WQI and WHO classification ranges (Excellent: 91–100; Good: 71–90; Moderate: 51–70; Poor: 26–50; Very Poor: 0–25).

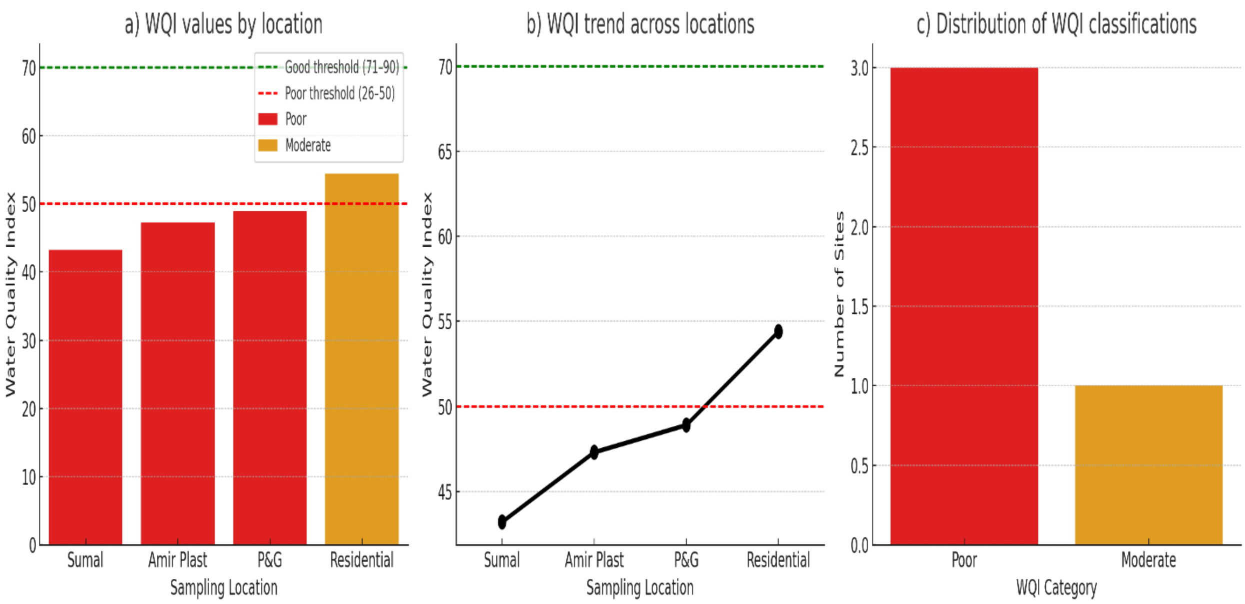

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Figure 7(a–c): Distribution of WQI classifications across River Ona: **a)** Bar chart of WQI values at each location, with WHO/NIS thresholds shown as dashed lines; **b)** Line graph showing the spatial trend of WQI across sites (industrial → residential); **c)** Distribution of WQI classifications, highlighting that most sites fall within the poor category.

Bacteriological Properties of the Ona River

The Ona River's bacteriological assessment showed very low coliform counts (~0.001 cfu/mL) across all sites, not significantly different among locations, indicating minimal microbial contamination compared to other Nigerian rivers impacted by effluents, where levels often exceed WHO thresholds due to pollution sources like open defecation and waste pits. The river's flow and dilution likely suppress microbial survival downstream.

Results fall within WHO/NIS safe drinking standards (<1 cfu/mL), suggesting microbiological safety at sampling time, though trace levels imply potential episodic contamination risks during peak runoff.

Summarized data confirm compliance and highlight that, while physicochemical pollution dominates, microbial risks persist for communities depending on untreated water, warranting ongoing monitoring.

Table 7. Bacteriological quality of the Ona River across sampling sites.

Location	Total Coliform (cfu/mL)	WHO/NIS Guideline	Compliance
Sumal	0.001	<1.0	Within limit
Amir Plast	0.001	<1.0	Within limit
P&G	0.001	<1.0	Within limit
Residential	0.001	<1.0	Within limit

Note: WHO and NIS standards require zero detectable E. coli in 100 mL; <1 cfu/mL is acceptable for general coliforms.

Ecological Risks and Monitoring Implications

Ecological risks in the Ona River mainly stem from heavy metals and oxygen depletion. Manganese (0.71–0.93 mg/L) exceeded US EPA TEL (0.08 mg/L) and NIS (0.2 mg/L), while magnesium (17.7–31.2 mg/L) surpassed FAO irrigation limits (0.2 mg/L), indicating bioaccumulation and reduced agricultural suitability, similar to polluted reservoirs (Arslan et al., 2025). Nutrient risks were moderate; TSS at 1.58 mg/L slightly exceeded WHO's 1.0 mg/L guideline, possibly affecting aquatic productivity. Bacteriological contamination was low, though occasional traces downstream pose episodic risks. Continuous monitoring of metals, oxygen, and microbes, using biological indicators as recommended by UNEP (2019), is vital for enforcing standards and safeguarding ecological and human health, as shown in Table 8.

Table 8. Ecological risk summary of Ona River water quality relative to standards.

Parameter	Range/Mean	Guideline Standard	Exceedance	Ecological/Health Implication
Manganese (Mn)	0.71–0.93 mg/L	WHO: 0.08; NIS: 0.2 mg/L	Yes	Bioaccumulation, benthic toxicity, neurological risks
Magnesium (Mg)	17.7–31.2 mg/L	FAO: 0.2 mg/L	Yes	Irrigation unsuitability, scaling, crop impacts

TSS	0.28–1.58 mg/L	WHO: 1.0 mg/L	Slight (downstream)	Reduced clarity, productivity loss, habitat stress
DO	1.9–2.6 mg/L	WHO/NIS: 4–5 mg/L	Yes	Oxygen depletion, biodiversity decline
BOD_5	9.95–37.4 mg/L	WHO: <10 mg/L	Yes	Organic overload, ecological stress
Coliforms	0.001 cfu/mL	WHO/NIS: <1.0 cfu/mL	No	Generally safe; trace episodic risk downstream

Synthesis of Findings

This study offers the initial comprehensive evaluation of risks in the Ona River, Ibadan, Nigeria. Findings indicate substantial degradation at industrial discharge locations, characterised by elevated levels of TDS, EC, COD, BOD_5, manganese, and magnesium surpassing regulatory standards. Dissolved oxygen measurements fell below 2.6 mg/L, signifying oxygen deficiency. Nutrient concentrations and suspended solids exhibited moderate increases; bacteriological quality remained predominantly acceptable, although residual coliform presence downstream presents episodic hazards. The Water Quality Index classified industrial areas as poor (scores 43-49) and the residential area as moderate (score 54), underscoring deterioration attributable to effluent discharge with limited downstream recovery. Ecological assessments revealed manganese and magnesium concentrations exceeding permissible thresholds, thereby endangering benthic organisms, crops, and human health. These results underscore the necessity for continuous multi-parameter environmental monitoring as advocated by UNEP (2019). In conclusion, the Ona River is impacted by industrial activities, oxygen depletion, and heavy metal contamination, with minimal microbial pollution, rendering it unsuitable for domestic or irrigation purposes without appropriate treatment. This evidence underpins the need for regulatory oversight, wastewater treatment implementation, and ecosystem surveillance to safeguard water resources in Nigeria.

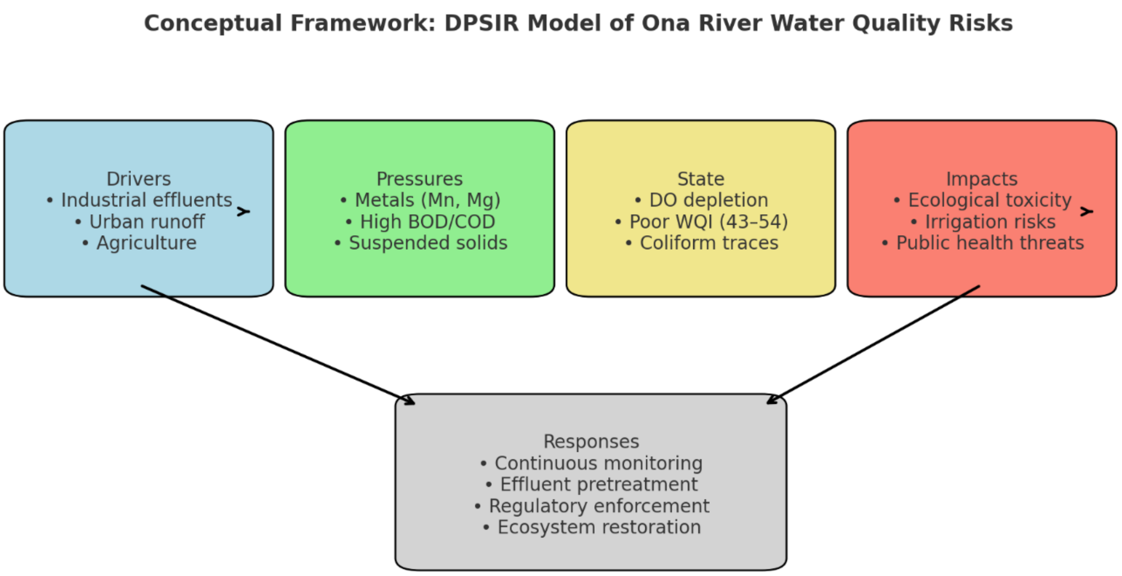

Figure 8. Conceptual Framework: DPSIR Model of Ona River Water

CONCLUSION AND RECOMMENDATIONS

This study assessed the Ona River, revealing significant impairment from industrial effluents. Elevated Mn and Mg exceeded standards set by USEPA, WHO, and FAO. Dissolved oxygen stayed below 2.6 mg/L. High BOD_5

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and COD confirmed oxygen stress. Water Quality Index classified industrial zones as poor (43–49) and the residential site as moderate (54). Trace coliform bacteria downstream indicated episodic contamination. The Ona River is unsuitable for drinking or irrigation without treatment.

Recommendations:

- Industrial effluent pretreatment to reduce metals and organics.
- Regulatory enforcement aligned with WHO/FAO standards, led by NESREA.
- Continuous monitoring, integrating physicochemical, microbial, and biological indicators.
- Community participation in surveillance for accountability.
- Ecosystem restoration, including riparian buffers, to enhance resilience.

Closing Remarks

This study highlights the urgent need for integrated water quality management in Nigeria's industrial catchments. By combining physicochemical, nutrient, bacteriological, and ecological risk assessments, it provides baseline evidence for regulatory enforcement, industrial pretreatment, and sustainable monitoring frameworks. The Ona River findings reflect broader patterns across West Africa and emphasize the necessity of proactive interventions to safeguard water resources, public health, and ecosystem integrity.

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Authors' Contributions

Praise Adenike Alli: Conceptualization, Data Collection, Laboratory Analysis, Drafting of Manuscript.

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Olatunji Sunday Olaniyan: Supervision, Manuscript Editing, Policy Implication Framing.

All authors reviewed and approved the final version of the manuscript.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability

The datasets generated and analyzed during this study are available from the corresponding author upon reasonable request.

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