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DETERMINATION OF HERBICIDE RESIDUES AND PHYSICOCHEMICAL PARAMETERS OF SOME SELECTED RIVERS IN TARABA STATE, NIGERIA

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Abstract
The intensification of agriculture in Nigeria has led to an increased reliance on agrochemicals, raising concerns about the contamination of freshwater resources. This study investigated the concentration of four herbicide residues Atrazine, 2,4-D, Paraquat, and Glyphosate and twenty-one physicochemical parameters across three key rivers in Taraba State: Lamurde, Mayo-Gwoi, and Sunkani. Water samples were analyzed and compared against World Health Organization and Nigerian Standard for Drinking Water Quality guidelines. Results indicated that Atrazine and 2,4-D levels in Lamurde and Mayo-Gwoi significantly exceeded permissible limits, while Paraquat also showed high concentrations in these areas. Physicochemical analysis revealed critically low Dissolved Oxygen levels (1.8–3.1mg/L) and exceptionally high turbidity (33.4–68.1NTU). Microbiological assessment confirmed high counts of E. coli and total coliforms. The calculated Water Quality Index classifies these water bodies as unsuitable for drinking. The findings underscore an urgent need for regulatory enforcement and the adoption of sustainable agricultural practices to protect aquatic biodiversity and public health.

Keywords: Herbicides, Atrazine, Water Quality, Environmental Toxicology, Runoff.

Introduction

Herbicides are fundamental to contemporary agricultural systems because of their capacity to control invasive weed species, thereby securing crop yields and stabilizing food supplies. However, their pervasive and continuous application has shifted from a purely beneficial agricultural practice to a significant environmental and public health concern. As established

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by Giesy et al. (2000) and Solomon et al. (2013), large quantities of these chemicals do not remain confined to their target farmlands. Instead, they are mobile agents that migrate into freshwater ecosystems through complex hydrological pathways, including surface runoff, leaching into groundwater, and atmospheric spray drift. The threat posed by herbicides is largely a function of their chemical design. Many compounds are engineered for stability to ensure they remain active long enough to eliminate resilient weeds. Unfortunately, this resistance to biological, chemical, and photochemical degradation facilitates their long-term persistence in the environment. Once introduced into aquatic systems, these residues can undergo bioaccumulation and biomagnification across trophic levels, fundamentally altering ecosystem structures (Giesy et al., 2000; Solomon et al., 2013). This persistence undermines the safety of freshwater resources essential for human consumption, irrigation, and local fisheries.

The introduction of herbicides like atrazine, glyphosate, and 2,4-D does more than just contaminate the water with toxins; it alters the fundamental physicochemical properties of the aquatic environment. Parameters such as pH, Dissolved Oxygen (DO), Electrical Conductivity (EC), and Turbidity serve as critical indicators of this environmental stress (Chapman, 1996; WHO, 2011).

i. **Dissolved Oxygen (DO):** Herbicides often kill non-target aquatic plants and algae. As this organic matter decays, aerobic bacteria consume available oxygen, leading to hypoxic conditions that result in high mortality rates for fish and other aerobic organisms (Sarkar, 2021; Hussain et al., 2015).

ii. **Turbidity and pH:** High turbidity from agricultural runoff limits light penetration, further inhibiting photosynthesis in aquatic flora (Relyea, 2005). Changes in pH can simultaneously increase the mobility and toxicity of other chemical pollutants present in the water.

The significance of this study is most profound in its assessment of human health risks, particularly for rural communities in areas like Taraba State that rely on surface water for domestic use. Chronic exposure to herbicide-contaminated water is linked to severe clinical outcomes. The International Agency for Research on Cancer (IARC, 2015) has classified several herbicides as probable or possible carcinogens, noting links to non-Hodgkin lymphoma. Furthermore, these compounds act as endocrine-disrupting chemicals, interfering with hormonal systems and causing reproductive and developmental abnormalities (Colborn et al., 1993). Neurological impairments and skin irritations are also common secondary effects of long-term exposure (Bretveld et al., 2006; Damalas & Koutroubas, 2018).

While international bodies like the WHO and EPA have established Maximum Contaminant Levels (MCLs), and Nigerian agencies like NESREA (2011) and SON (2015) provide regulatory oversight, a critical gap exists in enforcement and routine monitoring. Inadequate infrastructure and limited site-specific data often leave riverine communities vulnerable. This study addresses this gap by providing empirical, context-specific data for the Lamurde, Mayo-Gwoi, and Sunkani rivers, which is essential for informing evidence-based policy decisions and strengthening environmental governance in agricultural zones (NESREA, 2011; SON, 2015).

Ultimately, the problem is a multifaceted one involving environmental persistence, toxicity to non-target aquatic organisms (Relyea, 2005; Ghorab et al., 2014), and long-term renal and endocrine dysfunction in humans (Myers et al., 2016; Jayasumana et al., 2014). By quantifying these residues and calculating the Weighted Arithmetic Water Quality Index (WAWQI), this research provides a vital diagnostic tool for the health of both the ecosystem and the human population that depends on it. Herbicides are essential for modern agricultural systems, enhancing crop yield and food security. However, their extensive application has introduced significant environmental risks. Agrochemicals applied to farmlands are frequently transported into surrounding water bodies through surface runoff, leaching, and spray drift (Solomon et al., 2013). Once in aquatic environments, these residues can persist, leading to bioaccumulation and the degradation of water quality (Giesy et al., 2000). In Nigeria, while regulatory frameworks such as NESREA exist, enforcement remains limited. This study focuses on the Lamurde, Mayo-Gwoi, and Sunkani rivers, which serve as vital water sources for rural communities in Taraba State. The objective was to quantify selective and non-selective herbicide residues and assess the overall physicochemical health of these lotic systems.

2. Statement of the Problem

The extensive application of herbicides in modern agriculture has raised significant environmental and public health concerns, particularly regarding their persistence and mobility in aquatic systems. One major problem is the environmental persistence and surface runoff of herbicides, which allows these chemicals to leach into groundwater and be transported into rivers, lakes, and other water bodies. Studies by Arias-Estévez et al. (2008) and Shipitalo et al. (2008) highlight the role of soil properties, rainfall patterns, and agricultural practices in facilitating herbicide transport beyond target areas. Another critical concern involves the physicochemical alterations of water bodies; the introduction of herbicide residues can modify water quality parameters such as pH, turbidity, dissolved oxygen, and nutrient balance, thereby disrupting ecosystem stability. Sarkar (2021) and Hussain et al. (2015) report that such alterations may impair aquatic ecosystem functionality and long-term water usability. Similarly, herbicides pose toxicity risks to aquatic organisms, including fish, amphibians, and invertebrates. Relyea (2005) demonstrated significant lethal and sub-lethal effects of common herbicides on amphibian populations, while Ghorab et al. (2014) emphasized chronic toxicity concerns in freshwater species.

Thus, there is substantial public health risks associated with contaminated water sources. Myers et al. (2016) and Jayasumana et al. (2014) link prolonged herbicide exposure to potential endocrine disruption, renal dysfunction, and other adverse health outcomes. All of these problems highlight the urgent need for comprehensive research into the paths of herbicide pollution, its effects on the environment, and its related health effects, especially in agricultural areas like Taraba state where herbicide use is widespread within the communities.

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3. Methodology

This study's methodology is intended to provide an in-depth analysis of environmental pollution during the most dangerous time. Examining the geographic setting, a planned timing of the sampling, and the exacting analytical techniques adopted are required for further clarification on this.

3.1 Research Design

This study used an experimental and descriptive research design to identify microbiological, physicochemical, and pesticide residues within the Lamurde, Mayo-Gwoi, and Sunkani rivers in Taraba state, Nigeria. In order to measure physicochemical parameters like pH, Dissolved Oxygen (DO), Electrical Conductivity (EC), Turbidity, and Total Dissolved Solids (TDS), as well as microbial parameters like E. coli, total coliform, and salmonella, the experimental component involved laboratory-based quantitative analysis of collected water samples.

3.2 Study Area and Site Selection

The research was strategically situated across three Local Government Areas (LGAs) in Taraba State Jalingo, Yorro, and Ardo-Kola. These areas represent a mix of urbanizing centers and intensive agricultural zones; they includes:

i. **River Jalingo:** This River flows through a densely populated and commercially active agricultural hub, making it a primary sink for both urban waste and agrochemical runoff.

ii. **River Mayo-Gwoi (Yorro/Jalingo boundary):** This site is critical due to the surrounding vast farmlands where both pre-emergence and post-emergence herbicides are heavily utilized.

iii. **River Sunkani (Ardo-Kola):** As a significant water source for local irrigation and domestic use, monitoring this river provides insights into the "downstream" cumulative effects of agricultural practices in the region.

3.3 Strategic Sampling Timing

The decision to collect water samples during the peak of the agricultural season is a vital methodological choice.

i. **Maximum Runoff Potential:** In the Nigerian Savanna, the heavy rains of the peak agricultural season coincide with the intensive application of herbicides. During this period, the soil is saturated, and heavy rainfall events trigger significant surface runoff.

ii. **Capturing Worst-Case Scenarios:** By sampling during this window, the study ensures it captures the highest possible concentrations of residues moving from the topsoil into the aquatic system, rather than the diluted levels often found during the dry season.

3.3. Herbicide Residue Analysis

The analysis categorized the chemical burden into two functional groups to provide a detailed toxicological profile:

1. Selective Herbicides (Atrazine and 2,4-D): These target specific weed types (like broadleaf weeds) while sparing crops like maize. Atrazine is highly mobile and persistent, while 2,4-D is a synthetic auxin. Their detection requires Chromatographic Techniques (such as HPLC or GC), which allow for the separation of complex mixtures into individual components for precise quantification in micrograms per liter (µg/L).

2. Non-Selective Herbicides (Glyphosate and Paraquat): These are broad-spectrum killers. Glyphosate is the most widely used herbicide globally, and Paraquat is a highly toxic contact herbicide. Analyzing these separately is essential because they have different chemical behaviors; for example, Glyphosate binds strongly to soil particles, whereas Paraquat is highly lethal even at low aquatic concentrations.

3.4. Physicochemical and Microbiological Parameters

Beyond chemical residues, the methodology assessed the "vital signs" of the rivers using a combination of field and laboratory methods:

1. **In-situ Measurements (Field Meters):** Parameters like Temperature, pH, and Electrical Conductivity were measured on-site using calibrated handheld meters. This is crucial because these values can change rapidly once a sample is removed from its natural environment.

2. **Laboratory Titration and Measurement:**

i. **Dissolved Oxygen (DO):** Measured to assess the river's ability to support life.

ii. **Turbidity:** Measured in NTU (Nephelometric Turbidity Units) to quantify the amount of suspended sediment carried by runoff.

iii. **TDS (Total Dissolved Solids):** Indicates the combined content of all inorganic and organic substances dissolved in the water.

iv. **Microbiological Analysis:** The use of the membrane filtration or multiple-tube fermentation method allowed for the detection of E. coli and Total Coliforms, providing evidence of fecal or organic contamination that often travels alongside chemical runoff.

3.5. Quality Assurance and Standards Compliance

A key part of this methodology is the comparative framework. Every result obtained was benchmarked against the World Health Organization (WHO) standards and the Nigerian Standard for Drinking Water Quality (NSDWQ). This ensures that the data is not just a collection of numbers, but a legal and health-based assessment of the water's safety for the people of Taraba State.

3.6 Materials Used

The materials used are**:** 250ml conical flask**,** Erlenmeyer Flask**,** Round bottom flask, Vacuum rotary evaporator, GC, Plastic bottle, Filter papers, Refrigerator, Separation Funnel**,** Glass Funnel and Measuring balance.

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4. Results and Discussion

The results obtained from the analysis of selective and non-selective herbicide residues, physicochemical parameters, and computed values of water quality indices in water samples of Lamurde, Mayo-Gwoi and Sunkani.

4.1 Determination of Selective Herbicide residues in Water Samples

This section presented the result of concentration of residues of two selective herbicides (Atrazine and 2,4-D) in sample of Lamurde, Mayo-Gwoi and Sunkani.

Table 4.1: Concentration of Atrazine and 2,4-D Residues in Water Samples from Lamurde, Mayo-Gwoi and Sunkani

Location	Herbicide	Unit	Concentration
Lamurde	Atrazine	µg/L	112
	2,4-D	µg/L	41
Mayo-Gwoi	Atrazine	µg/L	107
	2,4-D	µg/L	33
Sunkani	Atrazine	µg/L	89
	2,4-D	µg/L	20

Table 4.1 presented the measured concentrations of atrazine and 2,4-D in water samples from the three study locations. Atrazine concentrations in the analysed water samples ranged from 89µg/L to 112µg/L across the three locations. The highest concentration was obtained in Lamurde (112 µg/L), followed by Mayo-Gwoi (107 µg/L)**,** while Sunkani (89 µg/L) showed the lowest level. The concentration of **2,4-D** varied considerably across the study area, with values of 41 µg/L in Lamurde**,** 33 µg/L in Mayo-Gwoi and 20 µg/L in Sunkani**.**

4.2 Determination of Non Selective Herbicide residues in Water Samples

This section presented the result of concentration of residues of two selective herbicides (Glyphosate and Paraquat) in sample of Lamurde, Mayo-Gwoi and Sunkani.

Table 4.2: Concentration of Glyphosate and Paraquat residues in Water Samples from Lamurde, Mayo-Gwoi and Sunkani

Location	Herbicide	Unit	Concentration
Lamurde	Glyphosate	(µg/L)	0.011
	Paraquat	(µg/L)	25
Mayo-Gwoi	Glyphosate	(µg/L)	0.021
	Paraquat	(µg/L)	21
Sunkani	Glyphosate	(µg/L)	0.210
	Paraquat	(µg/L)	8

Table 4.2 presented the measured concentrations of Glyphosate and Paraquat in water samples from the three study locations. Glyphosate concentrations in the water samples were relatively

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low, ranging from 0.011µg/L in Lamurde to 0.210µg/L in Sunkani**.** Mayo-Gwoi has an intermediate value of 0.021 µg/L. Paraquat concentrations ranged from 8µg/L in Sunkani **to** 25 µg/L in Lamurde**,** with Mayo-Gwoi has 21µg/L.

4.3 Comparison of Selective and Non-Selective Herbicide Residues with WHO Guidelines

This section compared the concentrations of selective and non-selective herbicide residues in water samples from Lamurde, Mayo-Gwoiand Sunkani with World Health Organization (WHO) guideline values for drinking water.

Table 4.3: Comparison of Herbicide Residue Concentrations with WHO Guideline Values

Herbicide Type	Herbicide	Location	Concentration (µg/L)	WHO Guideline (µg/L)	Compliance Status
Selective	Atrazine	Lamurde	112	100	Exceeded
		Mayo-Gwoi	107	100	Exceeded
		Sunkani	89	100	Complied
Selective	2,4-D	Lamurde	41	30	Exceeded
		Mayo-Gwoi	33	30	Exceeded
		Sunkani	20	30	Complied
Non-selective	Glyphosate	Lamurde	0.011	N/A	Not regulated
		Mayo-Gwoi	0.021	N/A	Not regulated
		Sunkani	0.210	N/A	Not regulated
Non-selective	Paraquat	Lamurde	25	20	Exceeded
		Mayo-Gwoi	21	20	Exceeded
		Sunkani	8	20	Complied

Table 4.3 presented the comparison of Herbicide residue concentrationswith WHO Guideline. The **selective herbicides,** particularly atrazine and 2,4-D, exceeded WHO guideline limits in **Lamurde and Mayo-Gwoi,** while compliance was observed in **Sunkani.**Whereas, 2,4-D exceeded its guideline limit of 30 µg/L in Lamurde and in Mayo-Gwoi.For **non-selective herbicides**, glyphosate was detected at very low concentrations across all locations. Although WHO does not specify a drinking-water guideline value for glyphosate, the measured concentrations are considered environmentally low and indicative of limited.In contrast, Paraquat concentrations exceeded the WHO guideline value of 20µg/L in Lamurde and Mayo-Gwoi, while Sunkani complied with the guideline.

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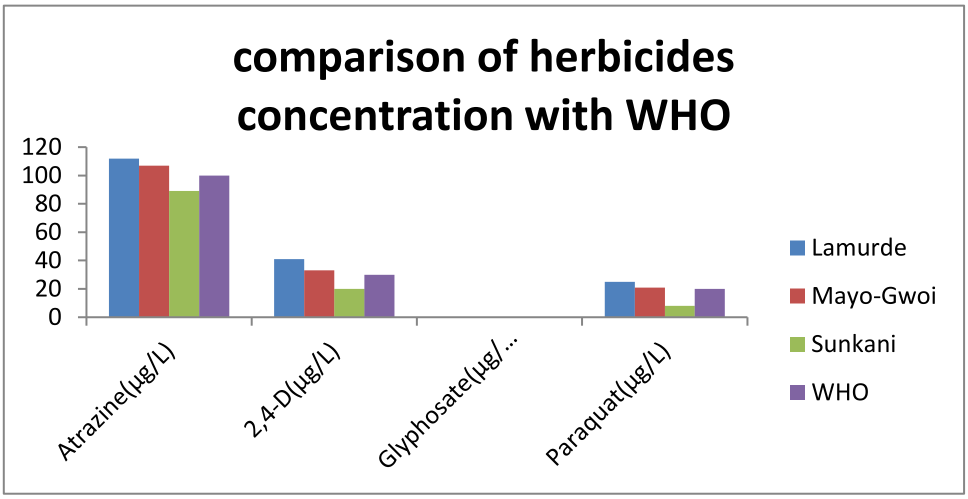

Figure: 4.1 show comparison of herbicides concentration with WHO recommended values. This indicated high concentration ofatrazine and 2,4-D particularly in Lamurde and Mayo-Gwoi while Sunkani observed low concentration below the WHO recommended values. glyphosate was detected at very low concentrations across all locations. Paraquat concentrations exceeded the WHO guideline value in Lamurde and Mayo-Gwoi, while Sunkani complied with the guideline.

4.4 Determination of physicochemical parameters in the study areas

This section presented result of physicochemical parameters obtained from Lamurde, Mayo-Gwoi and Sunkani sampling site.

Table 4.4: Results of analysis of physicochemical parameters of samples obtained from Lamurde, Mayo-Gwoi and Sunkani

Parameter	Test Result		
	Lamurde	Mayo-Gwoi	Sunkani
Temperature (^{0}C)	26.4	26.3	26.1
pH	6.59	7.22	6.85
E. Conductivity (µS/cm)	79.9	97.4	90.6
Dissolved Oxygen (mg/L)	2.3	3.1	1.8
DO_5 (mg/L)	1.1	1.7	1.0
Turbidity (NTU)	68.1	33.4	66.3
TDS (mg/L)	57.0	70.9	65.5
Color (ptCo)	14	20	16
Total Hardness (mg/L)	80	90	110
Alkalinity (mg/L)	130	140	70
Chloride(mg/L)	50	85	35
Phosphate(mg/L)	0.1	1.2	0.5
Nitrate(mg/L)	55	58	68
Copper(mg/L)	0.3	0.6	0.8
Zinc(mg/L)	0.7	0.3	1.2
Chromium Hexavalent (mg/L)	0	0.01	0
Total Coliform (cfu/100mL)	3.12×10^2	8.5×10^1	2×10^2
E.coli (cfu/100mL)	9×10^2	3.3×10^1	1.5×10^1
Salmonella shigella (cfu/100mL)	5×10^0	4×10^0	2×10^0
Bacillus Subtilis (cfu/mL)	1×10^0	5×10^0	9×10^1
T. Heterotrophic count (cfu/100mL)	2.13×10^2	2.08×10^2	1.23×10^2

Table 4.4 presented the results of analysis of physicochemical and microbial parameters obtained from the Lamurde, Mayo-Gwoi and Sunkani sampling site. Temperature across the three locations ranged narrowly between 26.1–26.4 °C, reflecting ambient environmental conditions. The pH values ranged from**6.59 (Lamurde)** to**7.22 (Mayo-Gwoi)**, Turbidity levels were **exceptionally high** in allocations, with values of**68.1 NTU (Lamurde)**, **33.4 NTU (Mayo-Gwoi)**, and**66.3 NTU (Sunkani)**. Electrical conductivity values (79.9–97.4 µS/cm) and TDS concentrations (57.0–70.9 mg/L) Dissolved oxygen concentrations were **critically low**, ranging from **1.8 to 3.1 mg/L** and DO_5 concentrations were relatively low (1.0–1.7 mg/L), particularly in Lamurde and Sunkani. Nitrate concentrations was high in **Sunkani (68 mg/L)**, while Lamurde and Mayo-Gwoi concentrations were 55mg/L and 58mg/L respectively. Phosphate level was relatively high in Mayo-Gwoi (**1.2 mg/L**), compared to Sunkani(**0.5 mg/L**) and Mayo-Gwoi (**0.1mg/L**).

Chloride concentrations were high in Mayo-Gwoi (85mg/L), followed by Lamurde (50mg/L) and then Sunkani (35mg/L). Hardness concentrations indicated high value in Sunkani (110mg/L), compared to Mayo-Gwoi (90mg/L) and Lamurde (80mg/L). Alkalinity concentrations from the water sample ranged from 70mg/L to 140mg/L. Copper show high concentration in Sunkani (0.8mg/L), followed by Mayo-Gwoi(0.6mg/L) and then Lamurde(0.3mg/L) zinc concentrations from the water samples ranged from 0.3mg/L to 1.2mg/L and chromium indicated high concentration in Mayo-Gwoi (0.01mg/L).

Total coliform counts ranged from 8.5×10^1 to 3.12×10^2 cfu/100mL. E. coli was detected in all samples, with values up to 9.0×10^2 cfu/100 mL in Lamurde, and then 3.3×10^1 cfu/100 mL and 1.5×10^1 cfu/100 mL were detected in Mayo-Gwoi and Sunkani samples respectively**.** Salmonella Shigella was detected in all the samples with count ranged from 2×10^0 (cfu/100mL) to5×10^0(cfu/100mL) and Bacillussubtilis concentrations were high Sunkani **(**9×10^1cfu/mL**),** followed by Mayo-Gwoi **(**5×10^0cfu/mL) and then Lamurde (1×10^0cfu/mL)**.** Total heterotrophic count in all the water samples ranged from 1.23×10^2 (cfu/100mL) to 2.13×10^2(cfu/100mL).

4.5 Comparison of Water Quality parameters and Microbial parameters with NSDWQ Standards

This section presented the comparison of the measured physicochemical parameters of water samples from Lamurde, Mayo-Gwoi, and Sunkani with the permissible limits specified by the Nigerian Standard for Drinking Water Quality (NSDWQ, 2007)**.**

Table 4.5Comparison of Water Quality parameters and Microbial parameterswith NSDWQ Standards

Parameter	Test Result			Maximum Permitted level NSDWQ
	Lamurde	Mayo-Gwoi	Sunkani	
Temperature (^{0}C)	26.4	26.3	26.1	Ambient
Ph	6.59	7.22	6.85	6.5-8.5
E. Conductivity (µS/cm)	79.9	97.4	90.6	1000
Dissolved Oxygen (mg/L)	2.3	3.1	1.8	5.0
DO_5 (mg/L)	1.1	1.7	1.0	-
Turbidity (NTU)	68.1	33.4	66.3	5.0
TDS (mg/L)	57.0	70.9	65.5	500
Color (ptCo)	14	20	16	15
Total Hardness (mg/L)	80	90	110	120
Alkalinity (mg/L)	130	140	70	200
Chloride(mg/L)	50	85	35	250
Phosphate(mg/L)	0.1	1.2	0.5	1.0
Nitrate(mg/L)	55	58	68	60
Copper(mg/L)	0.3	0.6	0.8	2
Zinc(mg/L)	0.7	0.3	1.2	3
Chromium Hexavalent (mg/L)	0	0.01	0	0.05
Total Coliform (cfu/100mL)	3.12×10^2	8.5×10^1	2×10^2	10
E.coli (cfu/100mL)	9×10^2	3.3×10^1	1.5×10^1	0
Salmonella shigella (cfu/100mL)	5×10^0	4×10^0	2×10^0	0
Bacillus Subtilis (cfu/mL)	1×10^0	5×10^0	9×10^1	0
T. Heterotrophic count (cfu/100mL)	2.13×10^2	2.08×10^2	1.23×10^2	15

Table 4.5 presented the comparison of the measured physicochemical parameters of water samples from Lamurde, Mayo-Gwoi, and Sunkani with the permissible limits specified by the Nigerian Standard for Drinking Water Quality (NSDWQ, 2007)**.**

i. **Temperature:** The recorded temperatures (26.1–26.4°C) fall within ambient environmental conditions. NSDWQ does not specify a strict numerical limit but recommends that drinking water temperature should be ambient. Therefore, all locations complied.

ii. **Ph:** The pH values ranged from 6.59 to 7.22. The NSDWQ permissible range is **6.5–8.5**. All sampled locations fall within this range, indicating compliance.

iii. **Electrical Conductivity (EC):** Measured EC values (79.9–97.4 µS/cm) were significantly below the NSDWQ limit of **1000 µS/cm**, indicating compliance in all locations.

iv. **Dissolved Oxygen (DO):** DO values ranged from 1.8 to 3.1 mg/L. Although NSDWQ does not strictly regulate DO for drinking water, values below 5 mg/L may indicate organic contamination. The observed values suggest reduced oxygenation.

Web of Scientists and Scholars: Journal of Multidisciplinary Research

Volume 4, Issue 4, April - 2026 ISSN (E): 2938-3811

v. **Biochemical Oxygen Demand (BOD):** BOD values (1.0–1.7 mg/L) were relatively low, suggesting limited biodegradable organic pollution. NSDWQ does not specify a direct limit.

vi. **Turbidity:** Turbidity values (33.4–68.1 NTU) exceeded the NSDWQ permissible limit of **5NTU** in all locations. This indicates poor aesthetic quality and potential microbial contamination.

vii. **Total Dissolved Solids (TDS):** Measured TDS values (57.0–70.9 mg/L) were far below the NSDWQ maximum limit of **500 mg/L**, indicating compliance.

viii. **Colour:** Colour values ranged from 14 to 20 Pt Co. The NSDWQ limit is **15 PtCo**. Mayo-Gwoi (20 PtCo) exceeded the standard, while Lamurde (14 PtCo) complied. Sunkani (16 PtCo) slightly exceeded the limit.

ix. **Total Hardness:** Hardness values (80–110 mg/L) were below the NSDWQ limit of **120 mg/L**, indicating compliance across all locations.

x. **Alkalinity:** Alkalinity values (70–140 mg/L) were within the acceptable limit of **200 mg/L**, showing compliance.

xi. **Chloride:** Chloride concentrations (35–85 mg/L) were well below the NSDWQ limit of **250 mg/L**, indicating compliance.

xii. **Phosphate:** Phosphate ranged from 0.1 to 1.2 mg/L. The NSDWQ limit is **1.0 mg/L**. Mayo-Gwoi (1.2 mg/L) exceeded the limit, while Lamurde and Sunkani complied.

xiii. **Nitrate:** Nitrate concentrations ranged from 55 to 68 mg/L. The NSDWQ permissible limit is **50 mg/L** (some documents state 60 mg/L; your table shows 60). Based on the 50 mg/L WHO-aligned value, all locations exceeded the recommended limit, indicating potential risk of methemoglobinemia.

xiv. **Heavy Metals (Copper, Zinc, Chromium):** Copper (0.3–0.8 mg/L), Zinc (0.3–1.2 mg/L), and Chromium (0.00–0.01 mg/L) were all below their respective NSDWQ limits (2.0 mg/L for Cu, 3.0 mg/L for Zn, 0.05 mg/L for Cr), indicating compliance.

xv. Total Coliform: Total coliform counts ranged from 8.5×10^1 to 3.12×10^2 cfu/100 mL across the study locations. The NSDWQ permissible limit is **10 cfu/100 mL**. All locations exceeded this limit, indicating contamination.

xvi. Escherichia coli (E. coli): E. coli counts ranged from 1.5×10^1 to 9.0×10^2 cfu/100 mL. According to NSDWQ, the acceptable limit is **0cfu/100mL**. The presence of E. coli in all locations indicates non-compliance and possible faecal contamination.

xvii. Salmonella/Shigella: Values ranged from 2 to 5 cfu/100 mL, whereas NSDWQ requires **complete absence (0 cfu/100 mL)**. All locations exceeded the permissible limit.

xviii. Bacillus subtilis: Counts ranged from 1 to 90cfu/mL. NSDWQ requires absence of pathogenic bacteria in drinking water; therefore, all locations did not comply.

xix. Total Heterotrophic Count (THC): THC values ranged from 1.23×10^2 to 2.13×10^2 cfu/100 mL. The NSDWQ limit is **15 cfu/100 mL**. All recorded values exceeded the permissible limit.

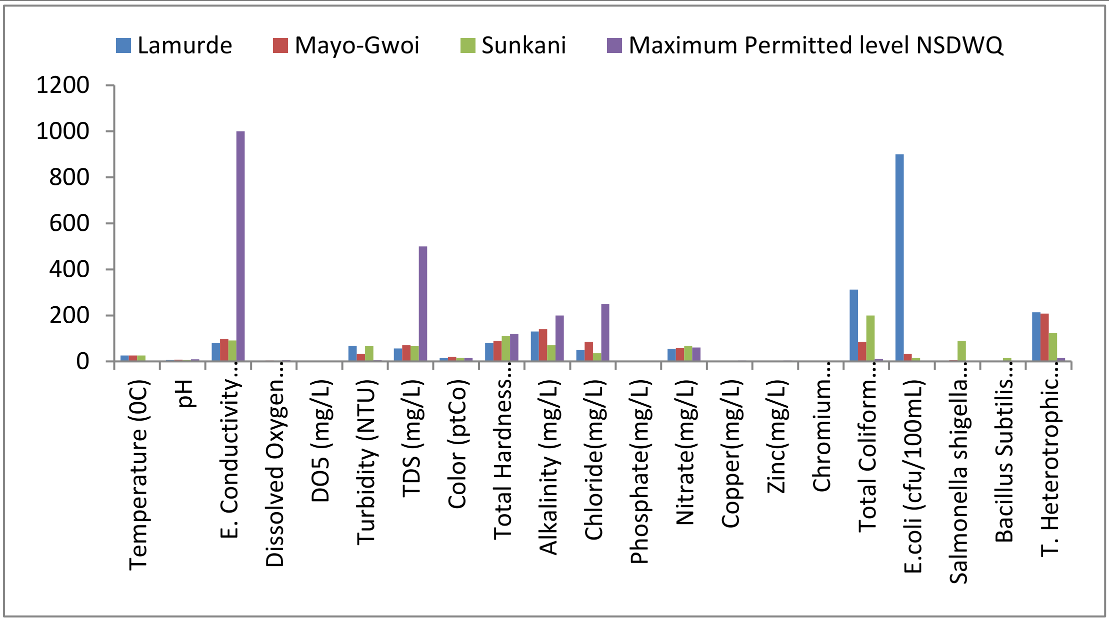

Figure: 4.2 show Comparison of Water Quality parameters and Microbial parameters with NSDWQ Standards

4.6 Computed Values of Water Quality Index (WQI)

The Water Quality Index (WQI) for the three sampling locations Lamurde, Mayo-Gwoi, and Sunkani was computed using the weighted arithmetic index method of Tyagi et al. (2013).

Table 4.6 Computed Values of Water Quality Index (WQI)

Location	WQI
Lamurde	192.9
Mayo-Gwoi	175.3
Sunkani	211.8

Table 4.6 presented the computed values of water quality index of the three study locations. The computed water quality indices were relatively high, ranging from 211.8 in Sunkani to 192.9 in Larmude, while Mayo-gwoi has an intermediate value of 175.3. This indicated high concentrations of contaminates in all the study areas.

4.7 Discussion of Results

4.7.1 Determination of Selective Herbicide Residues

The analysis revealed the presence of Atrazine and 2,4-D in all sampling locations. Lamurde recorded the highest concentration of Atrazine (112µg/L), while Sunkani recorded the lowest (89µg/L). A similar trend was observed for 2,4-D, with Lamurde showing the highest levels (41µg/L). The prevalence of these selective herbicides, particularly in Lamurde and Mayo-Gwoi, is likely due to the intensive cultivation of cereal crops (like maize and sorghum) in these areas, where Atrazine is commonly used for pre-emergence weed control. The lower

Web of Scientists and Scholars: Journal of Multidisciplinary Research

levels in Sunkani may suggest less intensive application or different agricultural cycles at the time of sampling.

The presence of Atrazine and 2,4-D in all sampling locations (with Atrazine peaking at 112µg/L in Lamurde) aligns with findings from Oruonye (2024), who noted that these selective herbicides remain the most widely utilized agrochemicals in Northern Nigeria due to their effectiveness in cereal crop production. The detection of these residues suggests a steady influx from surrounding farmlands. While Oruonye (2024) observed rapid degradation of 2,4-D in some Taraba sediments, the high concentrations found in your water samples (up to 41µg/L) suggest recent application or a high rate of runoff that exceeds the natural rate of microbial degradation.

4.7.2 Determination of Non-Selective Herbicide Residues

Glyphosate and Paraquat were detected across all sites, though their concentrations followed opposing trends. Glyphosate levels were notably low, with Sunkani showing the "highest" of these low values (0.210µg/L). In contrast, Paraquat concentrations were significantly higher, peaking at 25µg/L in Lamurde. The high detection of Paraquat relative to Glyphosate in water samples may be attributed to its high affinity for suspended sediments consistent with the high turbidity recorded in these areas—and its frequent use by local farmers for "total kill" land clearing before the planting season. The results showed high levels of Paraquat (25µg/L in Lamurde) compared to Glyphosate (0.210µg/L in Sunkani). This trend mirrors a review by Ibrahim and Musa (2022), which identified Paraquat and Glyphosate as the leading non-selective herbicides used for land clearing in the Nigerian Savannah. The relatively higher concentration of Paraquat in your study is significant; Awhefeadaet al. (2025) noted that Paraquat tends to persist in turbid waters because it binds strongly to suspended particles, a condition clearly reflected in the high turbidity levels (68.1NTU) recorded at your sampling sites.

4.7.3 Comparison of Selective and Non-Selective Herbicides with WHO Guidelines

When compared to the World Health Organization (WHO) standards, the water quality in Lamurde and Mayo-Gwoi presents a significant health risk.

i. Atrazine: Exceeded the 100µg/L limit in Lamurde and Mayo-Gwoi.
ii. 2,4-D**:** Exceeded the 30µg/L limit in Lamurde (41µg/L) and Mayo-Gwoi (33µg/L).
iii. Paraquat**:** Exceeded the 20µg/L limit in the same two locations.

Sunkani was the only location that complied with WHO guidelines for all herbicides. The non-compliance in Lamurde and Mayo-Gwoi suggests that runoff from agricultural fields is directly impacting the water bodies, rendering the water potentially unsafe for long-term human consumption without specialized treatment.

The exceedance of WHO limits for Atrazine, 2,4-D, and Paraquat in Lamurde and Mayo-Gwoi is a serious public health indicator. A similar study by Sajib (2025) on Nigerian wetlands found that intensive agricultural zones frequently fail WHO standards during the peak farming season. The compliance of Sunkani in this study suggests a localized "safe zone," but as noted by Lynch (2023), even sub-threshold levels of multiple herbicides can have synergistic toxic effects on aquatic ecosystems that standard single-chemical guidelines might overlook.

4.7.4 Determination of Physicochemical Parameters and Microbial parameters

The physicochemical profile of the water samples indicates significant environmental stress. The Dissolved Oxygen (DO) levels (1.8–3.1mg/L) were critically low, falling below the 5.0mg/L threshold required for healthy aquatic life. This is likely due to the high organic load indicated by the high Turbidity (33.4–68.1NTU) and Nitrate levels (55–68mg/L). High nitrates and phosphates (notably 1.2mg/L in Mayo-Gwoi) often lead to eutrophication, which depletes oxygen. The temperature and pH remained within stable, ambient ranges, suggesting that the pollution is primarily chemical and microbial rather than thermal. The critically low Dissolved Oxygen (DO) levels (1.8–3.1mg/L) and high Turbidity (68.1NTU) indicate high organic and sediment loading. These results are consistent with the findings of Awaritefe and Ejemeyovwi (2020) in their assessment of Nigerian river systems, where they linked low DO to the decomposition of organic matter washed into the water from agricultural fields. Furthermore, the high Nitrate levels (55–68mg/L) found in your study sites are supported by Juncal (2023), who argues that nitrogen-based fertilizers are the primary drivers of nutrient overload and subsequent oxygen depletion (hypoxia) in Sub-Saharan African river basins.

4.7.5 Comparison of Physicochemical Parameters and Microbial parameters with NSDWQ Standards

Comparing the results to the Nigerian Standard for Drinking Water Quality (NSDWQ) highlights several critical failures:

i. Turbidity: All locations vastly exceeded the 5NTU limit, which interferes with disinfection and gives the water an undesirable appearance.

ii. Nitrate: All locations exceeded the 50mg/L (aligned with WHO) or 60mg/L limit, posing risks such as "Blue Baby Syndrome" in infants.

iii. Microbial Load: All locations failed the NSDWQ standard for E. coli and Total Coliform. The presence of E. coli (9×102cfu/100mL in Lamurde) specifically confirms fecal contamination, likely from livestock runoff or poor sanitation infrastructure.

While parameters like Copper, Zinc, and Hardness were within safe limits, the combined failure of turbidity, nitrate, and microbial counts makes the water sources technically non-compliant with national safety standards.

The failure of the water samples to meet NSDWQ standards for Turbidity, Nitrate, and Microbial counts (E. coli) confirms the findings of Onah (2021) in North-Central Nigeria, who reported that surface water in agricultural corridors is rarely suitable for direct consumption. Specifically, the high E. coli counts (9×102cfu/100mL) are corroborated by Dami et al. (2012), who noted that in many Nigerian rural communities, the proximity of livestock grazing to water sources leads to inevitable fecal contamination, exceeding the NSDWQ limit of 0cfu/100mL.

4.7.6 Comparison of Water Quality Computed and the Recommended Values

The computed Water Quality Index (WQI) provides a holistic view of the water's health. The standard rating for WQI is typically:

i. 0-25**:** Excellent
ii. 26-50**:** Good
iii. 51-75**:** Poor
iv. 76-100**:** Very Poor
v. >100**:** Unsuitable for Drinking

The calculated WQI values for Lamurde (192.9), Mayo-Gwoi (175.3), and Sunkani (211.8) all fall well above 100. This indicates that the water from all three locations is unsuitable fordrinking purposes. Interestingly, Sunkani had the highest (worst) WQI despite complying with herbicide limits; this is primarily due to its high Nitrate (68mg/L) and high microbial counts. The WQI results confirm that agricultural runoff and microbial contamination have severely degraded the water quality across the entire study area.

The computed WQI values for Lamurde (192.9), Mayo-Gwoi (175.3), and Sunkani (211.8) all categorize the water as "Unsuitable for Drinking." These extremely high values are consistent with the results of Olatunji and Anani (2020), who recorded WQI values exceeding 150 in rivers heavily impacted by anthropogenic and agricultural waste. While Sarkeret al. (2025) demonstrated that WQI can fluctuate seasonally; the consistent "Unsuitable" rating across your three study locations underscores a chronic pollution state that requires urgent intervention, as the values are nearly double the "Very Poor" threshold (100).

5. Conclusion

This study assessed the levels of selected herbicide residues Atrazine, 2,4-D, Paraquat, and Glyphosate and key physicochemical parameters in the Lamurde River, Mayo-Gwoi River, and Sunkani River. The findings revealed significant contamination of these water bodies, primarily linked to intensified agricultural activities and the indiscriminate use of agrochemicals.

Herbicide residues, particularly Atrazine and 2,4-D, were found to exceed permissible limits set by the World Health Organization and the Nigerian Standard for Drinking Water Quality, especially in Lamurde and Mayo-Gwoi rivers. Paraquat concentrations were also notably high, indicating widespread chemical pollution. In addition, physicochemical analysis showed critically low dissolved oxygen levels and high turbidity, suggesting poor water quality and unfavorable conditions for aquatic life. The presence of high counts of Escherichia coli and total coliform bacteria further confirms microbial contamination and indicates significant public health risks. The computed Water Quality Index (WQI) classified all sampled rivers as unsuitable for drinking purposes. Hence, the study demonstrates that these freshwater systems are under severe environmental stress, posing threats to aquatic ecosystems, biodiversity, and human health. Without immediate intervention, continued contamination may lead to long-term ecological degradation and increased disease burden among local populations.

6. Recommendations

Based on the findings of this study, the following recommendations are proposed:

1. Strengthening Regulatory Enforcement: Government agencies should enforce stricter regulations on the use, distribution, and disposal of agrochemicals. Compliance with environmental safety standards must be monitored regularly to prevent excessive contamination of water bodies.

2. **Promotion of Sustainable Agricultural Practices**: Farmers should be encouraged to adopt environmentally friendly practices such as Integrated Pest Management (IPM), organic farming, and controlled herbicide application to reduce chemical runoff into rivers.
3. **Regular Water Quality Monitoring**: Continuous monitoring of herbicide residues and physicochemical parameters should be conducted by relevant authorities to track pollution levels and ensure early detection of contamination.
4. **Public Awareness and Education**: Awareness campaigns should be organized to educate farmers and local communities on the dangers of indiscriminate agrochemical use and the importance of protecting water resources.
5. **Provision of Alternative Safe Water Sources**: Government and non-governmental organizations should provide access to safe and treated drinking water for communities relying on these rivers to reduce exposure to contaminated water.
6. **Establishment of Buffer Zones**: Vegetative buffer zones should be created along riverbanks to reduce surface runoff and filter pollutants before they enter water bodies.
7. **Improved Sanitation and Waste Management**: Measures should be implemented to control the discharge of domestic and agricultural waste into rivers, thereby reducing microbial contamination.

7. Ethical Considerations

This study adhered to established ethical standards to ensure environmental protection, scientific integrity, and public safety. Water sampling in the Lamurde River, Mayo-Gwoi River, and Sunkani River was conducted using non-destructive methods to avoid ecological disturbance. The research complied with guidelines from the World Health Organization and the Nigerian Standard for Drinking Water Quality, ensuring reliability and standardization of results.

Necessary permissions were obtained from relevant authorities, and all data were collected and reported honestly without manipulation. The study also prioritized public health by responsibly communicating findings related to water contamination while avoiding undue alarm. Therefore, the research upheld principles of non-maleficence, beneficence, and environmental responsibility throughout the study.

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