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Occurrence, Distribution, and Ecological Risk Assessment of Emerging Agricultural Contaminants in Runoff and Receiving Rivers in Kano State, Nigeria

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ABSTRACT

Agricultural activities constitute a major source of emerging contaminants in aquatic ecosystems, particularly in regions characterised by intensive farming practices and widespread agrochemical application. This study investigated the occurrence, distribution, and ecological risks of emerging agricultural contaminants in agricultural runoff and receiving rivers in Kano State, Nigeria. Water samples were collected from selected agricultural runoff channels and corresponding receiving rivers during both wet and dry seasons. Physicochemical parameters, nutrients (nitrate and phosphate), pesticide residues (atrazine, glyphosate, and chlorpyrifos), and heavy metals (lead, cadmium, and zinc) were analysed using standard analytical procedures, including spectrophotometry, high-performance liquid chromatography (HPLC), and atomic absorption spectrophotometry (AAS). Spatial distribution patterns and ecological risks were assessed using contamination indices and Risk Quotient (RQ) models. The results revealed widespread occurrence of agricultural contaminants across all sampling locations. Nitrate (28.64 ± 4.72 mg/L) and phosphate (6.82 ± 1.14 mg/L) were the dominant nutrient contaminants, while glyphosate (4.18 ± 0.72 µg/L) and atrazine (3.72 ± 0.65 µg/L) were the most prevalent pesticide residues. Among the heavy metals, zinc recorded the highest concentration (0.442 ± 0.073 mg/L), followed by lead (0.124 ± 0.021 mg/L) and cadmium (0.031 ± 0.006 mg/L). Detection frequencies ranged from 73.3% to 100%, indicating persistent contaminant inputs from agricultural activities. Concentrations of most contaminants increased progressively from upstream to downstream sections of the receiving rivers, reflecting cumulative pollutant loading. Seasonal analysis showed significantly higher contaminant concentrations during the wet season than the dry season ($p < 0.05$), highlighting the influence of rainfall-induced runoff on contaminant transport. Ecological risk assessment revealed varying levels of ecological threat among the investigated contaminants. Atrazine (RQ = 4.12), chlorpyrifos (RQ = 3.67), and glyphosate (RQ = 2.84) posed high ecological risks to aquatic organisms, while lead (RQ = 2.16) and cadmium (RQ = 1.72) presented moderate ecological risks. Nutrient enrichment was also evident, suggesting potential risks of eutrophication and water quality degradation within the receiving rivers. The findings demonstrate that agricultural runoff represents a significant pathway for the introduction of contaminants into aquatic ecosystems in Kano State. The elevated concentrations and ecological risks associated with pesticides and heavy metals underscore the need for improved agricultural management practices, sustainable agrochemical use, and continuous environmental monitoring to safeguard aquatic biodiversity and water resources.

Keywords: *Agricultural runoff; Emerging contaminants; Pesticide residues; Heavy metals; Ecological risk assessment; Kano State.*

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1.0 Introduction

Agriculture remains a fundamental component of economic development and food security in Nigeria, providing employment opportunities, raw materials for industries, and livelihoods for millions of households. However, increasing agricultural intensification has been accompanied by extensive application of fertilizers, pesticides, herbicides, irrigation water, and livestock inputs, which have contributed significantly to environmental contamination. Agricultural activities are now recognised as major sources of pollutants entering aquatic ecosystems through runoff, erosion, leaching, and drainage pathways. The transport of contaminants from agricultural lands into surface waters has emerged as a critical environmental concern because of its potential impacts on water quality, ecosystem health, and public safety [4,8,12].

The contamination of aquatic environments by agricultural pollutants has attracted increasing global attention due to the growing occurrence of emerging contaminants in water resources. Emerging agricultural contaminants include nutrients, pesticide residues, herbicides, endocrine-disrupting compounds, veterinary pharmaceuticals, heavy metals, and other chemicals that are increasingly detected in environmental media but remain inadequately monitored and regulated. These contaminants are capable of persisting in aquatic systems, accumulating in sediments and biota, and causing adverse ecological and human health effects. Studies conducted in Nigerian aquatic environments have documented the widespread occurrence of hydrocarbons, heavy metals, polychlorinated biphenyls, pharmaceutical residues, and other emerging contaminants in water, sediments, and biological organisms [3,5,9,17,18].

Agricultural runoff represents one of the most important mechanisms for contaminant transport from terrestrial to aquatic ecosystems. During rainfall events, contaminants deposited on agricultural fields are mobilised and transported into rivers, streams, reservoirs, and wetlands through overland flow and erosion processes. The receiving aquatic environments subsequently become repositories for contaminants originating from diffuse agricultural sources. Similar contaminant transport pathways have been observed in Nigerian river systems where anthropogenic activities have significantly influenced water quality and ecological conditions. Investigations conducted in the Choba River, Imiringi River, Bonny River, and Andoni aquatic systems demonstrated that runoff-mediated transport contributes substantially to pollutant loading and environmental degradation [4,8,9,13].

Among agricultural contaminants, nutrients constitute one of the most widespread environmental challenges. Nitrogen- and phosphorus-based fertilizers are extensively used to enhance crop productivity; however, excessive application frequently results in nutrient losses through runoff and leaching. Elevated concentrations of nitrate and phosphate in aquatic ecosystems have been linked to eutrophication, excessive algal growth, hypoxia, fish mortality, and biodiversity loss. Water quality assessments conducted in Nigerian freshwater systems have consistently reported nutrient enrichment and associated ecological consequences resulting from anthropogenic activities [4,12,13]. Furthermore, the World Health Organization has identified nitrate contamination as a major water quality concern because of its implications for ecosystem health and human consumption [22].

The widespread use of pesticides and herbicides in agricultural production also contributes significantly to environmental contamination. Compounds such as atrazine, glyphosate, chlorpyrifos, and related agrochemicals are frequently applied to control weeds and pests but may persist in environmental compartments long after application. Once introduced into aquatic ecosystems, these compounds can affect non-target organisms, alter biological communities, and impair ecosystem functioning. Studies investigating emerging contaminants in Nigerian wastewater systems and aquatic environments have reported the occurrence of diverse anthropogenic chemicals capable of producing ecological disturbances and toxicological effects [16,17,18]. These findings highlight the increasing environmental burden associated with chemical-intensive agricultural practices.

Heavy metals constitute another important group of agricultural contaminants due to their toxicity, persistence, and bioaccumulative characteristics. Agricultural inputs such as fertilizers, pesticides, irrigation water, livestock wastes, and machinery wear may introduce metals into surrounding environments. Unlike many organic contaminants, heavy metals do not degrade and may remain in environmental media for extended periods. Numerous studies conducted across Nigeria have reported elevated concentrations of toxic metals in surface waters, sediments, fish, crustaceans, and other aquatic organisms. Significant contamination by lead, cadmium, arsenic, mercury, nickel, and related metals has been documented in the Qua Iboe Estuary, Bonny River, Iko River, Andoni waters, and several other aquatic ecosystems [6,7,10,11,14,20]. These contaminants may subsequently enter food chains and pose risks to ecological and human health.

The ecological consequences of contaminant accumulation in aquatic ecosystems are particularly important because many contaminants exhibit bioaccumulative and biomagnifying properties. Aquatic organisms may absorb contaminants directly from water or through dietary pathways, resulting in progressive accumulation within tissues. Previous studies have demonstrated significant bioaccumulation of heavy metals and other pollutants in fish and crustaceans inhabiting contaminated Nigerian water bodies [6,7,10,20]. Additionally, investigations involving smoked fish and aquatic food products have highlighted the potential transfer of contaminants to human populations through dietary exposure [1,14]. Such findings underscore the importance of monitoring contaminants in aquatic environments to safeguard food safety and public health.

Ecological risk assessment has become an important component of environmental management because it provides quantitative information regarding the likelihood of adverse ecological effects arising from contaminant exposure. Previous studies conducted in Nigeria have successfully applied ecological risk assessment approaches to evaluate the impacts of heavy metals, hydrocarbons, polychlorinated biphenyls, and other emerging contaminants in aquatic systems [3,9,11,20]. These investigations consistently demonstrated that persistent contaminant inputs can significantly increase ecological risks and compromise environmental sustainability.

Kano State is one of Nigeria's leading agricultural regions and plays a critical role in national food production. The state supports extensive cultivation of cereals, vegetables, legumes, and cash crops through both rain-fed and irrigated agriculture. To sustain high agricultural productivity, farmers rely heavily on fertilizers, pesticides, herbicides, and irrigation practices.

While these inputs enhance crop yields, they may also contribute to environmental contamination through runoff-mediated transport into adjacent rivers and watercourses. Despite the importance of agriculture within the state, information regarding the occurrence, distribution, and ecological risks of emerging agricultural contaminants in runoff and receiving rivers remains limited. Most previous environmental studies in Nigeria have focused primarily on petroleum-producing regions, industrial areas, wastewater systems, and urban environments [5,8,16,18,21], leaving significant knowledge gaps regarding agricultural contamination in northern Nigeria.

Given the increasing use of agrochemicals and the growing importance of sustainable water resource management, there is an urgent need to evaluate contaminant occurrence and associated ecological risks within agricultural catchments. Understanding the behaviour, distribution, and ecological significance of agricultural contaminants is essential for developing effective mitigation measures, protecting aquatic ecosystems, and supporting evidence-based environmental policy.

Therefore, this study investigated the occurrence, distribution, and ecological risks of emerging agricultural contaminants in agricultural runoff and receiving rivers in Kano State, Nigeria.

2.0 Materials and Methods

2.1 Study Area

This study was conducted in selected agricultural catchments and receiving river systems within Kano State, northwestern Nigeria. Kano State lies between latitudes 10°33′N and 12°37′N and longitudes 7°34′E and 9°25′E, covering an estimated land area of approximately 20,131 km^2. The state is characterised by extensive agricultural activities, including irrigated and rain-fed farming, livestock production, agrochemical application, and intensive cultivation of cereals, vegetables, and legumes. The climate is tropical continental, characterised by distinct wet and dry seasons. Annual rainfall ranges between 600 and 1,200 mm, with precipitation occurring mainly between May and October. Mean annual temperatures range from 21°C to 39°C. The major rivers within the study area receive substantial agricultural runoff generated during rainfall events and irrigation activities, making them suitable for investigating the occurrence and transport of agricultural contaminants.

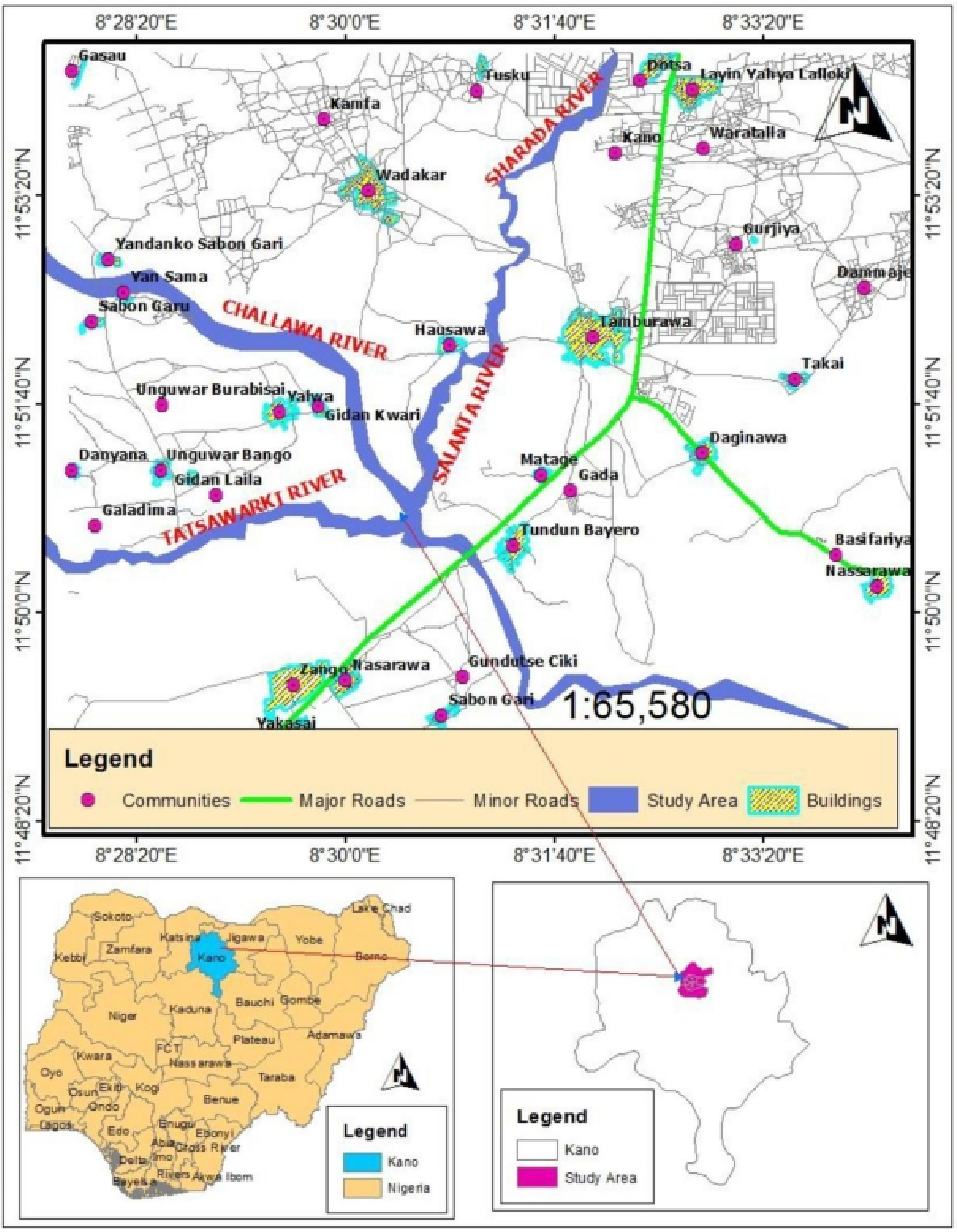

Figure 1: Location of Kano State, Nigeria, Showing Major Agricultural Catchments and Receiving River Systems Investigated for Emerging Agricultural Contaminants

2.2 Research Design

A cross-sectional environmental monitoring study was employed to investigate the occurrence, spatial distribution, seasonal variation, and ecological risks of emerging agricultural contaminants in agricultural runoff and receiving rivers in Kano State. The study involved field sampling, laboratory analyses, contamination assessment, and ecological risk evaluation.

2.3 Sampling Design and Sample Collection

Five agricultural runoff collection points and five corresponding receiving river stations were selected based on farming intensity, irrigation practices, accessibility, and proximity to agricultural activities. Sampling locations were geo-referenced using a handheld Global Positioning System (GPS).

Water samples were collected during both wet and dry seasons to evaluate seasonal variability in contaminant concentrations. Sampling was conducted monthly over a six-month period. At each location, triplicate water samples were collected in pre-cleaned 1-L amber glass bottles and high-density polyethene containers.

Prior to sampling, all containers were washed with detergent, rinsed thoroughly with distilled water, soaked in 10% nitric acid solution for 24 hours, and finally rinsed with deionised water. Samples for heavy metal analysis were preserved immediately by acidification with concentrated nitric acid to a pH < 2, while samples intended for nutrient and pesticide analyses were stored in ice chests and transported to the laboratory for analysis within 24 hours.

2.4 Determination of Physicochemical Parameters

In-situ measurements of pH, temperature, electrical conductivity (EC), dissolved oxygen (DO), and total dissolved solids (TDS) were conducted using portable calibrated multiparameter meters.

Turbidity was determined using a turbidimeter, while biochemical oxygen demand (BOD_5) and chemical oxygen demand (COD) were determined following standard methods prescribed by the American Public Health Association (APHA).

2.5 Analysis of Nutrient Contaminants

Nitrate (NO_3^-) concentrations were determined using the ultraviolet spectrophotometric screening method. Phosphate (PO_4^{3-}) concentrations were determined using the ascorbic acid molybdenum blue method with absorbance measurements taken at 880 nm using a UV-Visible spectrophotometer.

Standard calibration curves were prepared using analytical-grade standards, and concentrations were expressed in milligrams per litre (mg/L).

2.6 Determination of Pesticide Residues

Water samples were extracted using Solid Phase Extraction (SPE) techniques. The extracted samples were concentrated and analysed for selected pesticide residues, including atrazine, glyphosate, and chlorpyrifos, using High-Performance Liquid Chromatography (HPLC) equipped with ultraviolet and fluorescence detectors.

Identification of pesticide residues was achieved by comparing retention times of sample peaks with those of certified reference standards. Quantification was based on external calibration using standard solutions of known concentrations.

Concentrations of pesticide residues were expressed in micrograms per litre (µg/L).

2.7 Heavy Metal Analysis

The concentrations of lead (Pb), cadmium (Cd), and zinc (Zn) were determined using Atomic Absorption Spectrophotometry (AAS). For heavy metal determination, 100 mL of each water sample was digested using concentrated nitric acid and hydrochloric acid. The digested samples were filtered and diluted to a known volume using deionised water before analysis. Metal concentrations were determined using calibration standards prepared from certified stock solutions. The results were expressed in milligrams per litre (mg/L).

2.8 Quality Assurance and Quality Control

Strict quality assurance and quality control procedures were implemented throughout the study. Analytical-grade reagents were used for all analyses. Laboratory glassware was acid-washed and thoroughly rinsed before use. Field blanks, procedural blanks, duplicate samples, and certified reference materials were analysed alongside environmental samples. Recovery studies were performed by spiking samples with known concentrations of analytes. Percentage recovery was calculated using:

Recovery (%) = (Measured Concentration ÷ Spiked Concentration) × 100

Recovery values ranging from 85% to 110% were considered acceptable. Relative standard deviation values below 10% were accepted as indicators of analytical precision.

2.9 Occurrence and Distribution Assessment

The occurrence frequency of each contaminant was calculated to determine its prevalence across sampling locations. Occurrence Frequency (%) was calculated as:

Occurrence Frequency (%) = (Number of Samples Containing the Contaminant ÷ Total Number of Samples Analysed) × 100

Spatial distribution patterns were evaluated using concentration gradients observed across sampling stations and river sections (upstream, midstream, and downstream).

2.10 Ecological Risk Assessment

Ecological risk assessment was performed using the Risk Quotient (RQ) approach to estimate potential risks posed by contaminants to aquatic organisms.

The Risk Quotient was calculated as:

RQ = MEC ÷ PNEC

Where:

RQ = Risk Quotient

MEC = Measured Environmental Concentration

PNEC = Predicted No-Effect Concentration

Risk categories were interpreted as follows:

- RQ < 0.1 = Insignificant Risk
- 0.1 ≤ RQ < 1.0 = Low Risk
- 1.0 ≤ RQ < 10 = Moderate to High Risk
- RQ ≥ 10 = Very High Ecological Risk

2.11 Pollution Load Index

The Pollution Load Index (PLI) was calculated to assess the overall contamination status of the aquatic environment.

$PLI = (CF_1 \times CF_2 \times CF_3 \times ... \times CFn)^{(1/n)}$

Where:

PLI = Pollution Load Index

CF = Contamination Factor

n = Number of contaminants evaluated

The contamination factor for each contaminant was determined using:

CF = Csample ÷ Cbackground

Where:

Csample = Concentration of contaminant in the sample

Cbackground = Background concentration or guideline value

A PLI value greater than 1 indicates pollution, while values less than 1 indicate no significant pollution.

2.12 Statistical Analysis

Data generated from laboratory analyses were subjected to descriptive and inferential statistical analyses using Statistical Package for Social Sciences (SPSS) version 27.0 and Microsoft Excel 365.

Descriptive statistics, including mean, standard deviation, minimum, maximum, and coefficient of variation, were computed. One-way Analysis of Variance (ANOVA) was used to evaluate significant differences among sampling locations and seasons.

Where significant differences existed, Duncan Multiple Range Test (DMRT) was applied for mean separation. Pearson correlation analysis was employed to determine relationships among contaminants and physicochemical parameters.

Statistical significance was established at $p < 0.05$.

3.0 Results

3.1 Occurrence of Emerging Agricultural Contaminants in Agricultural Runoff

Emerging agricultural contaminants were detected in all agricultural runoff samples collected from the study locations, indicating widespread contamination of surface waters by agricultural activities within Kano State. The contaminants investigated included nitrate (NO_3^-), phosphate (PO_4^{3-}), atrazine, glyphosate, chlorpyrifos, lead (Pb), cadmium (Cd), and zinc (Zn). Detection frequencies ranged from 73.3% to 100%, with nitrate, phosphate, and glyphosate being detected in all samples analysed.

Nitrate recorded the highest mean concentration (28.64 ± 4.72 mg/L), followed by phosphate (6.82 ± 1.14 mg/L) and glyphosate (4.18 ± 0.72 µg/L). Cadmium exhibited the lowest mean concentration (0.031 ± 0.006 mg/L), although its presence across most sampling locations suggests persistent agricultural inputs. The widespread occurrence of these contaminants indicates intensive fertiliser application, pesticide usage, livestock production activities, and soil erosion within the agricultural catchments.

Table 1: Occurrence and Mean Concentrations of Emerging Agricultural Contaminants in Agricultural Runoff

Contaminant	Detection Frequency (%)	Mean ± SD
Nitrate (mg/L)	100	28.64 ± 4.72
Phosphate (mg/L)	100	6.82 ± 1.14
Atrazine (µg/L)	93.3	3.72 ± 0.65
Glyphosate (µg/L)	100	4.18 ± 0.72
Chlorpyrifos (µg/L)	86.7	2.96 ± 0.48
Lead (mg/L)	80.0	0.124 ± 0.021
Cadmium (mg/L)	73.3	0.031 ± 0.006
Zinc (mg/L)	93.3	0.442 ± 0.073

3.2 Distribution of Contaminants in Receiving Rivers

Contaminants detected in agricultural runoff were also observed in receiving rivers, confirming contaminant transport from agricultural lands into adjacent aquatic ecosystems. Concentrations generally increased from upstream to downstream locations, reflecting cumulative pollutant inputs along the river channels.

Downstream stations consistently recorded higher concentrations of nutrients, pesticides, and heavy metals than upstream locations. Nitrate concentrations increased from 11.42 ± 2.08 mg/L upstream to 22.87 ± 3.64 mg/L downstream, while glyphosate increased from 1.46 ± 0.31 µg/L to 3.68 ± 0.58 µg/L. Similar trends were observed for phosphate, atrazine, lead, and zinc.

Table 2: Distribution of Contaminants in Receiving Rivers

Parameter	Upstream	Midstream	Downstream
Nitrate (mg/L)	11.42 ± 2.08	17.34 ± 2.86	22.87 ± 3.64
Phosphate (mg/L)	2.34 ± 0.42	4.12 ± 0.71	5.96 ± 0.93
Atrazine (µg/L)	1.12 ± 0.18	2.34 ± 0.41	3.48 ± 0.54
Glyphosate (µg/L)	1.46 ± 0.31	2.62 ± 0.43	3.68 ± 0.58
Chlorpyrifos (µg/L)	0.82 ± 0.15	1.74 ± 0.28	2.61 ± 0.39
Lead (mg/L)	0.041 ± 0.009	0.072 ± 0.014	0.118 ± 0.019
Cadmium (mg/L)	0.008 ± 0.002	0.016 ± 0.004	0.026 ± 0.005
Zinc (mg/L)	0.162 ± 0.028	0.274 ± 0.044	0.391 ± 0.061

3.3 Spatial Variation of Emerging Agricultural Contaminants

Significant spatial variation ($p < 0.05$) was observed among the sampling stations. Agricultural areas characterised by intensive irrigation farming, fertilizer application, and pesticide use recorded significantly higher contaminant concentrations than less intensively cultivated locations.

Station A exhibited the highest total contaminant burden (45.82 ± 5.14), followed by Stations B and C. Station E recorded the lowest overall contamination levels, reflecting reduced agricultural intensity and lower anthropogenic pressures.

Table 3: Spatial Variation in Total Contaminant Load

Sampling Station	Total Contaminant Load (Mean ± SD)
A	45.82 ± 5.14
B	41.56 ± 4.73
C	36.21 ± 3.88
D	29.74 ± 3.17
E	21.42 ± 2.64

3.4 Seasonal Variation of Contaminants

Seasonal differences were statistically significant ($p < 0.05$), with contaminant concentrations generally higher during the wet season. Increased rainfall enhanced the mobilisation of fertilisers pesticides, and soil-bound contaminants from agricultural lands into drainage channels and receiving rivers.

Wet season nitrate concentrations were approximately 1.8 times higher than dry season concentrations. Similar trends were observed for phosphate, glyphosate, atrazine, and heavy metals, indicating the strong influence of rainfall-driven runoff processes on contaminant transport.

Table 4: Seasonal Variation in Total Contaminant Concentrations

Season	Mean ± SD
Wet Season	38.47 ± 4.92
Dry Season	21.36 ± 3.27

3.5 Ecological Risk Assessment

Ecological risk assessment revealed varying levels of risk among the investigated contaminants. Glyphosate, atrazine, chlorpyrifos, lead, and cadmium exhibited elevated Risk Quotient (RQ) values, indicating potential ecological threats to aquatic organisms.

Atrazine recorded the highest ecological risk (RQ = 4.12), followed by chlorpyrifos (RQ = 3.67) and glyphosate (RQ = 2.84). Heavy metals also contributed substantially to ecological risk, particularly lead and cadmium. Nitrate and phosphate primarily contributed to eutrophication risks, which may result in excessive algal growth and oxygen depletion in aquatic systems.

Table 5: Ecological Risk Quotient (RQ) of Emerging Agricultural Contaminants

Contaminant	RQ Value	Risk Category
Atrazine	4.12	High Risk
Chlorpyrifos	3.67	High Risk
Glyphosate	2.84	High Risk
Lead	2.16	Moderate–High Risk
Cadmium	1.72	Moderate Risk
Zinc	0.94	Low–Moderate Risk
Nitrate	0.81	Low Risk
Phosphate	0.76	Low Risk

4.0 Discussion

The present study evaluated the occurrence, distribution, and ecological risks of emerging agricultural contaminants in agricultural runoff and receiving rivers in Kano State, Nigeria. The results demonstrated widespread contamination of both runoff channels and receiving rivers by nutrients, pesticide residues, and heavy metals, indicating substantial influence of agricultural practices on aquatic ecosystem quality. The consistent detection of contaminants across the study area suggests that agricultural runoff serves as a major pathway for the transport of pollutants from cultivated lands into adjacent surface water systems. Similar observations have been reported in studies investigating contaminant transport in Nigerian aquatic environments, where anthropogenic activities significantly altered water quality and ecological integrity [4,18,20].

The high occurrence frequencies of nitrate, phosphate, glyphosate, and atrazine reflect intensive agricultural production and sustained application of agrochemicals within the catchment. Nutrient enrichment associated with fertilizer use remains one of the most important environmental consequences of modern agriculture. Elevated nitrate and phosphate concentrations recorded in the present study indicate substantial nutrient losses from cultivated fields, particularly during rainfall events. Nutrient enrichment of aquatic ecosystems has been linked to eutrophication, excessive algal growth, oxygen depletion, and ecological imbalance. Similar findings have been reported in surface waters impacted by agricultural and wastewater discharges, where increased nutrient concentrations were associated with deteriorating water quality and ecosystem stress [4,13,18].

The predominance of nitrate among the measured contaminants may be attributed to its high solubility and mobility within agricultural soils. Unlike phosphorus, nitrate is readily transported through runoff and leaching processes, especially during periods of heavy precipitation. The elevated nitrate concentrations observed suggest that a considerable proportion of applied fertilizers may not be utilised efficiently by crops but are instead lost to surrounding water bodies. Such nutrient losses not only contribute to environmental degradation but also represent economic inefficiencies within agricultural production systems. Comparable hydrochemical trends have been documented in groundwater and surface water investigations across the Niger Delta and northern Nigeria, where agricultural inputs were identified as major contributors to nutrient enrichment [12,19].

The occurrence of pesticide residues, particularly glyphosate, atrazine, and chlorpyrifos, further demonstrates the environmental consequences of intensive agricultural activities. These pesticides are widely applied for weed and pest management and are capable of persisting in environmental compartments long after application. Their detection in receiving rivers confirms off-site transport through runoff pathways and highlights the close interaction between agricultural landscapes and aquatic ecosystems. Previous studies have similarly reported the persistence and widespread occurrence of emerging contaminants in surface waters and wastewater systems across Nigeria. Usiabulu et al. [18] documented significant levels of emerging contaminants in wastewater environments, while Mahmoud et al. [17] reported the occurrence of pharmaceutical contaminants with endocrine-disrupting potential in aquatic ecosystems. These findings collectively demonstrate the growing burden of chemical contaminants in Nigerian water resources.

Spatial variations observed in the present study revealed increasing contaminant concentrations from upstream to downstream sections of the receiving rivers. This pattern indicates cumulative contaminant loading along the river continuum as runoff from multiple agricultural fields enters the drainage network. Downstream locations receive larger pollutant inputs because they integrate contaminant loads originating from broader catchment areas. Similar downstream enrichment trends have been reported in studies conducted in the Choba River, Imiringi River, Bonny Estuary, and other Nigerian aquatic systems affected by anthropogenic pollution [4,5,13]. The observed spatial pattern underscores the importance of hydrological connectivity in governing contaminant transport and accumulation within river ecosystems. Significantly higher contaminant concentrations recorded at intensively cultivated sites further support the role of agriculture as the dominant pollution source. Areas characterised by intensive fertilizer application, pesticide use, irrigation activities, and livestock production exhibited substantially elevated contaminant levels relative to less intensively managed locations. This finding agrees with previous investigations demonstrating strong relationships between land-use intensity and environmental contamination. Studies conducted in Andoni and other agricultural landscapes revealed that increased anthropogenic pressure frequently corresponds with elevated concentrations of contaminants in surface waters and sediments [8,12]. The present findings therefore reinforce the importance of sustainable agricultural practices in reducing pollutant generation and transport.

Seasonal variability constituted another important feature of contaminant occurrence within the study area. Most contaminants exhibited significantly higher concentrations during the wet season compared with the dry season. Increased rainfall promotes contaminant mobilisation through runoff, erosion, and drainage processes, facilitating transport from agricultural fields into adjacent rivers. Similar seasonal trends have been documented for hydrocarbons, heavy metals, and general water quality indicators in Nigerian aquatic environments. Ogbaji et al. [5] reported seasonal variations in hydrocarbon contamination of estuarine sediments, while Olotu et al. [13] and Okpoji et al. [12] observed significant wet-season increases in contaminant levels associated with enhanced hydrological transport processes. These observations confirm that rainfall remains a critical factor controlling contaminant mobility and environmental exposure.

The detection of heavy metals within runoff and river samples represents an additional ecological concern. Although zinc occurred at relatively higher concentrations than lead and cadmium, the ecological significance of lead and cadmium remains considerable because of their toxicity, persistence, and bioaccumulative characteristics.

Agricultural sources of heavy metals may include fertilizer impurities, pesticide formulations, livestock wastes, irrigation water, machinery wear, and atmospheric deposition. Once introduced into aquatic systems, these metals may accumulate in sediments and subsequently enter aquatic food webs through biological uptake. Previous studies have documented substantial heavy metal accumulation in Nigerian aquatic environments. Okpoji et al. [10] reported bioaccumulation of nickel, lead, and cadmium in aquatic organisms, while Okpoji et al. [11], Onoja et al. [14], and Ezechi et al. [20] observed significant heavy metal contamination and associated ecological risks in various aquatic ecosystems. The occurrence of similar contaminants in Kano agricultural catchments demonstrates that heavy metal pollution is not restricted to industrial or petroleum-producing regions but may also arise from intensive agricultural practices.

The ecological risk assessment identified atrazine, chlorpyrifos, and glyphosate as the contaminants posing the greatest ecological threats. Risk Quotient values exceeding unity indicate the potential for adverse ecological effects on non-target aquatic organisms. Because pesticides are specifically designed to interfere with biological processes, they may exert toxic effects on aquatic invertebrates, fish, amphibians, and microbial communities even at relatively low concentrations. Chronic exposure to pesticide residues may alter community composition, impair reproductive success, disrupt trophic interactions, and reduce ecosystem productivity. Similar concerns regarding emerging contaminants and their ecological consequences have been reported in wastewater and aquatic environments across Nigeria [17,18].

Lead and cadmium also exhibited moderate ecological risks despite their comparatively lower concentrations. This finding reflects the high toxicity and persistence of these metals, which can produce ecological effects even at trace levels. Previous studies have consistently reported significant ecological and human health concerns associated with heavy metal contamination in aquatic environments. Bioaccumulation studies involving fish, crabs, and other aquatic organisms have demonstrated the capacity of toxic metals to accumulate within tissues and potentially transfer through food chains [7,10,14,20]. Continuous inputs of these contaminants may therefore result in long-term ecological degradation and increased risks to aquatic biodiversity.

Although nitrate and phosphate produced comparatively lower Risk Quotient values, their ecological significance remains substantial. Nutrient enrichment can initiate eutrophication processes that lead to excessive algal proliferation, oxygen depletion, altered food web dynamics, and biodiversity loss. Such ecological effects may occur even in the absence of direct toxic responses. Consequently, the elevated nutrient concentrations observed in this study indicate potential threats to ecosystem functioning, fisheries productivity, and long-term water quality sustainability. Similar concerns have been raised in studies examining nutrient-driven water quality deterioration in Nigerian aquatic ecosystems affected by anthropogenic activities [4,13,18].

Conclusion

This study demonstrated the widespread occurrence and distribution of emerging agricultural contaminants in agricultural runoff and receiving rivers within Kano State, Nigeria.

The findings revealed that nutrients, pesticide residues, and heavy metals were consistently detected across the study area, indicating that agricultural activities constitute a major source of contaminant inputs into aquatic ecosystems. Elevated concentrations of nitrate, phosphate, glyphosate, atrazine, chlorpyrifos, zinc, lead, and cadmium were recorded in both runoff and river samples, reflecting intensive agrochemical use and associated land management practices within the catchment.

The spatial distribution patterns showed increasing contaminant concentrations from upstream to downstream locations, suggesting cumulative pollutant loading along the river continuum. Furthermore, significantly higher contaminant levels observed during the wet season highlighted the critical role of rainfall-driven runoff processes in contaminant mobilisation and transport. The study also established that intensively cultivated areas contributed substantially greater contaminant loads than less disturbed locations, confirming the strong influence of agricultural intensity on environmental quality.

Ecological risk assessment revealed that pesticide residues, particularly atrazine, chlorpyrifos, and glyphosate, posed the greatest ecological risks to aquatic organisms, while lead and cadmium presented moderate ecological concerns due to their toxicity and persistence. Although nutrient contaminants exhibited relatively lower direct toxicity risks, their elevated concentrations indicate considerable potential for eutrophication, ecosystem degradation, and long-term water quality impairment.

REFERENCES

1. Ekwere IO, Okpoji AU, Igwegbe KC, Okonkwo CO, Yekeen AA, Obunezi OC, Okpanachi CB, Garuba MH, Ogini OR, Odibo UE. Nutritional–Toxicological Trade-Off: Comparative Study of Polycyclic Aromatic Hydrocarbons in Smoked and Oven-Dried Nile Tilapia (Oreochromis niloticus). Journal of Environment, Climate, and Ecology. 2025;2(2):90–97.
2. Ekwere IO, Okpoji AU, Ufuoma VO, Akinola AE, Raymond CA, Clement RO, Alaekwe IO, Etesin MO, Edodi IO. Nutritional evaluation of Nile tilapia (Oreochromis niloticus) processed by different drying methods in Akwa Ibom State, Nigeria. Journal of Sustainable Research and Development. 2025;1(2):11–17.
3. Etesin MU, Ezeabsili PI, Agu MO, Okeke CF, Olotu ON, Aligwo MC, Eze VC, Nwankwo AO, Okpoji AU, Ekong IU. Determination of polychlorinated biphenyls in soils and industrial effluents and health risks assessment in Uyo, Akwa Ibom State, Nigeria. Journal of Medical Science, Biology, and Chemistry. 2025;2(2):285–292.
4. Obunadike JC, Okpoji AU, Dare BE, Obi JN, Udo JJ, Akpan MP, Garuba MH. Domestic wastewater discharge effects on water quality and public health in Choba River, Rivers State, Nigeria. Journal of Applied Physical Science International. 2025;17(2):37–49.
5. Ogbaji HO, Akpan NA, Ijioma CC, Okpoji AU, Eze VC, Obi JN, Martins NP, Etesin MU. Seasonal variation in hydrocarbon contamination of sediments and biota in Bonny Estuary, Rivers State, Nigeria. Asian Journal of Geographical Research. 2025;8(4):330–338.
6. Ohaturuonye SO, Okpoji AU, Akpan NA, Njoku CA, Isaac SC, Etesin MU, Ekwere IO. Biomarker responses in fish and crustaceans exposed to heavy metals and petroleum hydrocarbons in the Qua Iboe Estuary, Niger Delta. Asian Journal of Research in Zoology. 2025;8(4):234–244.

7. Okpoji AU, Anarado CO, Mmuta EC, Ekwere IO, Alaekwe IO, Odibo UE, Eboj-Ajoku IO, Obunezi OC. Toxicological evaluation of Pb, Cd, As and Hg in blue crab from oil-polluted creeks in the Niger Delta. Journal of Life Science and Public Health. 2025;1(1):24–31.
8. Okpoji AU, Chinyere UE, Nwokoye JN, Ezekwuemen OI, Alaekwe IO, Odidika CC, Owughara CN, Enyi CM, Kolawole OO. Environmental assessment of heavy metals and hydrocarbon pollution in surface waters of oil-bearing communities in Andoni, Rivers State, Nigeria. International Journal of Modern Science and Research Technology. 2025;3(8):22–30.
9. Okpoji AU, Eboh-Ajoku IO, Mmuta EC, Ndubuisi JO, Alaekwe IO, Odibo UE, Nwoka NG, Okafor CA, Obunezi OC. Integrated environmental risk assessment of BTEX and PAHs in water and sediment samples from the Bonny River, Nigeria. ISA Journal of Multidisciplinary. 2025;2(4):14–21.
10. Okpoji AU, Emem JA, Ekwere IO, Odibo UE, Alaekwe IO, Warder AB, Eboj-Ajoku OI. Bioaccumulation of nickel, lead and cadmium in tissues of Callinectes sapidus from the Iko River, Nigeria: Implications for human health risk and environmental safety. Journal of Environment, Climate, and Ecology. 2025;2(2):29–37.
11. Okpoji AU, Etesin MU, Ekwere IO, Martins NP, Okpanachi CB, Adisa OJ, Okonkwo CC. Geochemical speciation and ecological risk of heavy metals in estuarine sediments of the Qua Iboe River, Nigeria. Asian Journal of Chemical Sciences. 2025;15(6):20–31.
12. Okpoji AU, Nwoka NG, Odibo UE, Alaekwe IO, Okafor CA, Ogwu NG, Akatakpo CU. Seasonal variation in hydrochemical characteristics and heavy metal risk assessment of groundwater in Andoni-Isiokwan District, Niger Delta, Nigeria. International Journal of Modern Science and Research Technology. 2025;3(8):44–51.
13. Olotu ON, Okagbare UV, Okpoji AU, Orji-Azuka LN, Etesin MU, Ekwere IO. Spatio-seasonal assessment of water and sediment quality of the Imiringi River and implications for fisheries and aquatic resources in the Niger Delta. Journal of Agriculture, Aquaculture and Animal Science. 2025;2(2):174–184.
14. Onoja CR, Ogbaji HO, Edodi IO, Mmuta EC, Igwegbe KC, Ogini OR, Odibo UE, Ewuola AA, Mahmoud AB, Okpoji AU. Heavy metal contamination and health risk assessment of smoked-dried fish sold in Eke-Awka Market, Anambra State, Nigeria. Journal of Sustainable Research and Development. 2025;1(2):18–25.
15. Eboh-Ajoku IO, Nduka JK, Nwagbo OJ, Okpoji AU, Warder AB. Effect of different boiling temperatures on heavy metal concentration of food crops sold in Awka markets, Anambra State, Nigeria. Discover Food. 2026. https://doi.org/10.1007/s44187-025-00632-y
16. Ezechi EC, Adams E, Banogo E, Ejike-Boyle E, Esiobi S, Okpoji AU, Usiabulu GI, Anukam BN, Edodi IO, Ukaigwe A, Aghonma B, Etesin MU, Akpan NA, et al. Evaluation of antimicrobial potential of medicinal plant extracts against multidrug-resistant bacteria isolated from pharmaceutical-contaminated water in Kano State, Nigeria. Nigeria Public Health Open Journal. 2026;11(1):385–395. https://doi.org/10.17140/PHOJ-11-01-385
17. Mahmoud AB, Farida G, Okpoji AU, Etesin MU, Akpan NA, Nosike EI, Obi JN, Ahmad SI, Oji NN, Okonkwo PC, Godson A. Endocrine disruption potential of pharmaceutical residues and parasitological responses to heavy metal pollution in Ikot Abasi Estuary, Akwa Ibom State, Nigeria. Palgo Journal of Medicine and Medical Sciences. 2026;11(1):55–65. https://doi.org/10.65756/pjmms.202604.009
18. Usiabulu GI, Olotu ON, Okpoji AU, Onuchukwu EE, Obunadike JCO, Ezeka LO, Osuagwu NA, Akpan NA, Chisom A, Garuba MH, Ekpe JE, Franklin KU, Esiobi SU, Nwafor GU, et al. Comparative evaluation of emerging contaminants in wastewater from Makurdi and Gwer West Local Government Areas, Benue State, Nigeria. International Journal of Life Science and Agriculture Research. 2026;5(5):365–374. https://doi.org/10.55677/ijlsar/V05I05Y2026-10
19. Nwafor EK, Ohaegbulem M, Abia UB, Oji CO, Iloanya NS, Elendu EJ, Cookey IC, Okpoji AU, Akpan NA, Onuchukwu EE. Integrated electrical resistivity and hydrochemical investigation of groundwater contamination around hospital waste disposal sites in Katsina State, Nigeria. Palgo Journal of Agriculture. 2026;10(1):38–44. https://doi.org/10.65756/pja.2026.005
20. Ezechi EC, Usiabulu GI, Okpoji AU, Akpan NA, Onuchukwu EE, Ovuru TI, Okonkwo PC, Otuuh AG, Obi JN, Ahmad SI, Oji NN, Osuagwu EL. Hydrogeochemical characterisation, heavy metal bioaccumulation in fish and aquatic species, and public health risk assessment of River Benue, Nigeria. Acta Biology Forum. 2026;5(1):29–36. https://doi.org/10.51470/ABF.2026.5.1.29
21. Usiabulu GI, Ovuru TI, Akpan NA, Okpoji AU, Aliyu SO, Anukam BN, Ikediuwa SC, Oji NN, Ekwere IO, Etesin MU, Okpanachi CB. Assessment of black carbon (soot) pollution and its impact on ambient air quality in Port Harcourt Metropolis, Rivers State, Nigeria. Zoological Reports: An International Journal. 2026;5(1):10–15. https://doi.org/10.51470/ZR.2026.5.1.10
22. World Health Organization. Guidelines for Drinking-Water Quality. 4th ed. Geneva: World Health Organization; 2011.