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Environmental and Public Health Implications of Pharmaceutical Wastewater Discharge in Selected Cities of Northern Nigeria

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Abstract

This study evaluated the environmental and public health implications of pharmaceutical wastewater discharged in Kano, Kaduna, Sokoto, and Maiduguri, Northern Nigeria. Physicochemical parameters, pharmaceutical residues, heavy metals, bacteriological quality, antibiotic resistance, and human health risk indices were investigated in wastewater collected from hospitals, pharmaceutical premises, and receiving drainage channels. Wastewater quality was generally poor in all the studied cities. Electrical conductivity ranged from 1186 ± 36 to 1502 ± 55 µS/cm, while biochemical oxygen demand and chemical oxygen demand reached 70.1 ± 4.5 mg/L and 151.4 ± 8.1 mg/L, respectively, particularly in Maiduguri. Dissolved oxygen remained below the recommended threshold in all locations. Pharmaceutical residues, including paracetamol, diclofenac, ibuprofen, ciprofloxacin, sulfamethoxazole, estradiol, and ethinylestradiol, were detected at concentrations exceeding guideline values. Estradiol and ethinylestradiol exceeded acceptable limits by more than 14–36 times, indicating substantial

endocrine-disrupting potential. Heavy metals such as lead, cadmium, chromium, nickel, and mercury also exceeded permissible limits, with the highest concentrations recorded in Maiduguri and Kano. Total coliforms ranged from 2.7×10^5 to 4.2×10^5 CFU/mL, while multidrug-resistant bacteria accounted for 51.4–66.8% of the isolates. Escherichia coli, Staphylococcus aureus, Pseudomonas aeruginosa, and Klebsiella pneumoniae were the dominant bacterial species. The combined hazard index ranged from 2.78 to 4.39, indicating significant non-carcinogenic health risks, while carcinogenic risk values for lead and cadmium exceeded acceptable limits. Strong positive correlations were observed between ciprofloxacin and multidrug-resistant bacteria, as well as between heavy metals and the overall hazard index. The study concludes that pharmaceutical wastewater discharge in Northern Nigeria contributes significantly to environmental contamination, antimicrobial resistance, and public health risk, emphasising the need for improved wastewater treatment and stricter regulation of pharmaceutical waste disposal.

Keywords: Pharmaceutical wastewater; Environmental contamination; Public health risk; Northern Nigeria; Wastewater discharge.

1.0 Introduction

Pharmaceutical residues and related contaminants have become major emerging pollutants in aquatic environments because of their widespread use, persistence, and continuous release into wastewater systems. Hospitals, pharmaceutical industries, medical laboratories, and households discharge substantial quantities of antibiotics, analgesics, hormones, and other pharmaceutical compounds into municipal drains and receiving waters. Conventional wastewater treatment processes are often unable to completely remove these compounds, thereby allowing them to persist in surface water, groundwater, and sediments (Patel et al., 2019; AL Falahi et al., 2022). As a result, pharmaceutical wastewater has become an important source of environmental pollution and a public health concern worldwide.

Pharmaceutical residues in aquatic environments may alter water quality, disrupt aquatic ecosystems, and increase the risk of antimicrobial resistance. Drugs such as diclofenac, ibuprofen, ciprofloxacin, and sulfamethoxazole have been detected in wastewater and rivers in different parts of the world at concentrations capable of affecting aquatic organisms and human health (dos Santos et al., 2025; Deryal et al., 2025; Lee et al., 2025). Estrogenic compounds such as estradiol and ethinylestradiol are of particular concern because even very low concentrations may induce endocrine disruption, reproductive abnormalities, and feminisation in exposed organisms (Arcand-Hoy & Benson, 1998; Gonsioroski et al., 2020). Adeogun et al. (2016) demonstrated that endocrine-disrupting chemicals in contaminated aquatic systems could induce intersex conditions and histopathological changes in fish.

The environmental impact of pharmaceutical wastewater is further complicated by the presence of heavy metals and pathogenic microorganisms. Heavy metals such as lead, cadmium, chromium, nickel, and mercury may enter wastewater from laboratory chemicals, pharmaceutical preparations, corroded infrastructure, and hospital activities. These metals are persistent, non-

biodegradable, and capable of bioaccumulating in aquatic organisms, thereby posing severe ecological and human health risks (Jaishankar et al., 2014; Castro-González & Méndez-Armenta, 2008). Elevated concentrations of heavy metals in aquatic systems have been associated with toxicological effects in fish, wildlife, and humans (Al-Busaidi et al., 2011; Alturiqi & Albedair, 2012; Ezemonye et al., 2019).

In addition to chemical contamination, untreated pharmaceutical wastewater frequently contains high microbial loads, including pathogenic and antibiotic-resistant bacteria. Exposure of microorganisms to sub-lethal concentrations of antibiotics in wastewater promotes the emergence and proliferation of resistant strains (Obinna et al., 2023). Consequently, wastewater environments have become important reservoirs of antimicrobial resistance genes and multidrug-resistant bacteria, particularly in developing countries where wastewater treatment facilities are inadequate (Kayode-Afolayan et al., 2022). The increasing prevalence of antibiotic resistance in wastewater is now recognised as one of the most serious public health threats globally.

Northern Nigeria is characterised by rapid urbanisation, high population density, inadequate sanitation infrastructure, and increasing dependence on pharmaceutical products. In major cities such as Kano, Kaduna, Sokoto, and Maiduguri, hospital effluents and pharmaceutical wastewater are frequently discharged directly into open drains, streams, and rivers without adequate treatment. Despite the environmental significance of this practice, there is limited information regarding the concentrations of pharmaceutical residues, heavy metals, and antibiotic-resistant bacteria in pharmaceutical wastewater from these cities. Most previous studies in Nigeria have focused mainly on general water quality, heavy metals, or hydrocarbon pollution (Akpor & Muchie, 2011; Ekesiobi et al., 2025; Ebikienmo et al., 2026), with little emphasis on pharmaceutical contaminants and their associated public health implications.

Studies conducted in other parts of Nigeria have shown that wastewater contamination may contribute significantly to ecological degradation and human exposure. Domestic wastewater discharge in the Choba River was reported to increase pollutant load and microbial contamination (Obunadike et al., 2025). Similarly, integrated water quality studies in Diobu and Rumuokoro demonstrated that urban wastewater contributes to the deterioration of water quality and increases health risk (Ekesiobi et al., 2026; Izuchukwu et al., 2026). However, the role of pharmaceutical wastewater as a source of chemical and microbial contamination remains poorly understood in Northern Nigeria.

The present study was therefore undertaken to assess the physicochemical characteristics, pharmaceutical residues, heavy metal concentrations, bacteriological quality, antibiotic resistance patterns, and associated human health risks of pharmaceutical wastewater in Kano, Kaduna, Sokoto, and Maiduguri.

2.0 Materials and Methods

2.1 Study Area

The study was conducted in four major cities in Northern Nigeria, namely Kano, Kaduna, Sokoto, and Maiduguri. These cities were selected because of their high population density, presence of tertiary hospitals, pharmaceutical shops, medical laboratories, and the widespread discharge of untreated or partially treated pharmaceutical wastewater into nearby drainage channels and receiving rivers. Kano is located between latitude 11°58′N and longitude 8°31′E, Kaduna between latitude 10°31′N and longitude 7°26′E, Sokoto between latitude 13°03′N and longitude 5°14′E, and Maiduguri between latitude 11°50′N and longitude 13°09′E. The climate of the region is characterised by a long dry season and a short wet season, with mean annual temperatures ranging from 28 to 35°C.

2.2 Study Design and Sampling Strategy

A cross-sectional environmental assessment design was adopted for the study. Sampling was carried out between April and June 2026 to capture wastewater quality during the early rainy season when pharmaceutical residues and other contaminants are more likely to be transported into drainage systems and receiving waters.

In each city, three categories of pharmaceutical wastewater sources were identified:

1. Wastewater discharged from tertiary hospitals.
2. Wastewater generated from pharmaceutical stores and drug manufacturing or dispensing premises.
3. Wastewater collected from municipal drainage channels receiving mixed domestic and medical waste.

Three sampling locations were selected from each category, giving a total of nine sampling locations per city and thirty-six locations for the entire study. At each location, triplicate samples were collected, giving a total of 108 wastewater samples.

The sampling points were geo-referenced using a handheld Global Positioning System receiver. The coordinates of each site were recorded to facilitate spatial comparison and future monitoring.

2.3 Collection of Wastewater Samples

Wastewater samples were collected in pre-cleaned 1 L amber glass bottles for pharmaceutical residue analysis and in 500 mL high-density polyethene bottles for physicochemical and heavy metal analysis. Before sampling, the bottles were rinsed three times with water from the sampling point.

Samples were collected approximately 20 cm below the water surface to avoid floating debris and surface scum. For each sampling point, three grab samples were taken at intervals of about 5 m and then composited into a representative sample.

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Samples intended for heavy metal analysis were acidified immediately to $pH < 2$ using concentrated nitric acid to prevent metal precipitation and adsorption to the bottle walls. Samples for bacteriological analysis were collected in sterile 250 mL bottles and transported in an ice chest at approximately 4°C. All samples were transported to the laboratory within 6 h of collection and stored at 4°C prior to analysis.

2.4 Determination of Physicochemical Parameters

Temperature, pH, electrical conductivity, and dissolved oxygen were measured in situ using a calibrated multiparameter water quality meter. The instrument was calibrated each morning before field use according to the manufacturer's instructions.

Biochemical oxygen demand was determined using the 5-day incubation method. Aliquots of wastewater samples were diluted with oxygen-saturated distilled water and incubated at 20°C for 5 days in the dark. The difference between initial and final dissolved oxygen values was recorded as the BOD.

Chemical oxygen demand was determined by the dichromate reflux method. Fifty millilitres of each wastewater sample were digested with potassium dichromate solution in the presence of sulfuric acid and silver sulfate catalyst, followed by titration with ferrous ammonium sulfate. Total dissolved solids were determined gravimetrically after evaporation of filtered samples at 105°C.

2.5 Analysis of Pharmaceutical Residues

The concentrations of paracetamol, diclofenac, ibuprofen, ciprofloxacin, sulfamethoxazole, estradiol, and ethinylestradiol in wastewater samples were determined using high-performance liquid chromatography.

Before analysis, wastewater samples were filtered through 0.45 µm membrane filters. A 250 mL portion of each filtered sample was subjected to solid-phase extraction using C18 cartridges. The cartridges were first conditioned with methanol and deionised water. The wastewater sample was then passed through the cartridge at a flow rate of 5 mL/min. After extraction, the retained compounds were eluted with 10 mL of methanol.

The eluate was concentrated to approximately 1 mL using a rotary evaporator and transferred into HPLC vials. The HPLC system consisted of a reverse-phase C18 analytical column (250 mm × 4.6 mm, 5 µm particle size) with a UV detector. The mobile phase was a mixture of acetonitrile and water in different proportions depending on the analyte. The flow rate was maintained at 1.0 mL/min, and the injection volume was 20 µL.

Calibration curves were prepared using analytical standards of each pharmaceutical compound at concentrations of 0.001–50 µg/L. The coefficient of determination for all calibration curves was greater than 0.995.

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2.6 Determination of Heavy Metals

Heavy metals, including lead, cadmium, chromium, nickel, and mercury, were analysed using atomic absorption spectrophotometry.

Prior to analysis, 100 mL of the acidified wastewater sample was digested with a mixture of concentrated nitric acid and perchloric acid in a ratio of 3:1. The digestion was carried out on a hot plate at 120°C until a clear solution was obtained. After cooling, the digested sample was filtered and diluted to 50 mL with deionised water.

Lead, cadmium, chromium, and nickel were measured using flame atomic absorption spectrophotometry, while mercury was analysed using cold vapour atomic absorption spectrophotometry. Analytical blanks and standard reference solutions were analysed together with the samples to ensure accuracy.

2.7 Bacteriological Analysis

Total coliform and faecal coliform counts were determined using the membrane filtration method. One hundred millilitres of each wastewater sample were filtered through sterile 0.45 µm membrane filters. The membranes were placed on MacConkey agar for total coliforms and on eosin methylene blue agar for faecal coliforms.

The plates were incubated at 37°C for 24 h for total coliforms and at 44.5°C for 24 h for faecal coliforms. Colonies were counted and expressed as colony-forming units per millilitre.

For bacterial isolation, aliquots of wastewater samples were serially diluted and cultured on nutrient agar, MacConkey agar, Salmonella–Shigella agar, and cetrimide agar. Pure colonies were identified based on colony morphology, Gram staining, and standard biochemical tests, including catalase, oxidase, citrate utilisation, indole production, methyl red, Voges–Proskauer, and triple sugar iron tests.

2.8 Determination of Antibiotic Resistance

Antibiotic susceptibility of the bacterial isolates was determined by the Kirby–Bauer disc diffusion method on Mueller–Hinton agar. The bacterial suspension was adjusted to a 0.5 McFarland turbidity standard before inoculation.

The antibiotic discs used were ampicillin (10 µg), ciprofloxacin (5 µg), gentamicin (10 µg), tetracycline (30 µg), and chloramphenicol (30 µg). After incubation at 37°C for 24 h, the diameter of the inhibition zone around each antibiotic disc was measured in millimetres.

The results were interpreted as susceptible, intermediate, or resistant using the Clinical and Laboratory Standards Institute guidelines. Isolates resistant to at least three classes of antibiotics were classified as multidrug resistant.

2.9 Human Health Risk Assessment

Human health risk assessment was performed to evaluate the potential non-carcinogenic and carcinogenic risks associated with exposure to contaminants in pharmaceutical wastewater.

The hazard quotient for each contaminant was calculated as:

$HQ = CDI / RfD$

where CDI is the chronic daily intake, and RfD is the reference dose.

The chronic daily intake was estimated using:

$CDI = (C \times IR \times EF \times ED) / (BW \times AT)$

where C is the contaminant concentration, IR is the ingestion rate, EF is the exposure frequency, ED is the exposure duration, BW is body weight, and AT is the averaging time.

The hazard index was calculated as the sum of the hazard quotients of all contaminants.

Carcinogenic risk for lead and cadmium was estimated using:

$CR = CDI \times SF$

where SF is the cancer slope factor. Values greater than 1×10^{-4} were considered unacceptable.

2.10 Statistical Analysis

The data obtained were analysed using Statistical Package for the Social Sciences version 25. Descriptive statistics, including mean and standard deviation, were calculated. One-way analysis of variance was used to compare contaminant levels among the four cities. Where significant differences existed, Duncan's multiple range test was used for mean separation.

Pearson correlation analysis was performed to determine the relationship between pharmaceutical residues, heavy metals, bacteriological indicators, and health risk parameters. Statistical significance was accepted at $p < 0.05$.

3.0 Results

The physicochemical characteristics indicate substantial deterioration in wastewater quality across the four cities. Electrical conductivity ranged from 1186 ± 36 µS/cm in Sokoto to 1502 ± 55 µS/cm in Maiduguri, exceeding the WHO limit of 1000 µS/cm in all locations. Total dissolved solids varied between 612 ± 19 mg/L in Sokoto and 771 ± 31 mg/L in Maiduguri, all above the recommended limit of 500 mg/L. Dissolved oxygen was critically low, ranging from 2.5 ± 0.2 mg/L in Maiduguri to 3.6 ± 0.3 mg/L in Sokoto, compared with the recommended minimum of 5 mg/L. Biochemical oxygen demand was particularly high in Maiduguri (70.1 ± 4.5 mg/L) and Kano (68.4 ± 4.2 mg/L), more than twice the acceptable limit of 30 mg/L. Similarly, chemical oxygen demand ranged from 118.6 ± 5.8 mg/L in Sokoto to 151.4 ± 8.1 mg/L

in Maiduguri, exceeding the guideline value of 80 mg/L. These results indicate a high organic and chemical pollution load, especially in Maiduguri and Kano, as shown in Table 1.

Table 1. Physicochemical Characteristics of Pharmaceutical Wastewater in Selected Northern Nigerian Cities

Parameter	WHO Limit	Kano	Kaduna	Sokoto	Maiduguri
pH	6.5–8.5	6.2 ± 0.1	6.5 ± 0.2	6.8 ± 0.1	6.4 ± 0.1
Temperature (°C)	<30	31.5 ± 0.8	30.7 ± 0.6	29.8 ± 0.5	31.2 ± 0.7
Electrical conductivity (µS/cm)	1000	1450 ± 52	1328 ± 48	1186 ± 36	1502 ± 55
Total dissolved solids (mg/L)	500	742 ± 28	685 ± 24	612 ± 19	771 ± 31
Dissolved oxygen (mg/L)	>5	2.8 ± 0.2	3.1 ± 0.2	3.6 ± 0.3	2.5 ± 0.2
Biochemical oxygen demand (mg/L)	30	68.4 ± 4.2	61.7 ± 3.9	52.5 ± 3.1	70.1 ± 4.5
Chemical oxygen demand (mg/L)	80	146.2 ± 7.4	132.5 ± 6.9	118.6 ± 5.8	151.4 ± 8.1

All pharmaceutical residues exceeded their guideline values in the wastewater samples. Paracetamol concentrations ranged from 12.8 ± 0.9 µg/L in Sokoto to 20.1 ± 1.4 µg/L in Maiduguri, exceeding the reference value of 10 µg/L. Diclofenac concentrations varied from 4.8 ± 0.3 µg/L in Sokoto to 7.2 ± 0.5 µg/L in Maiduguri, which is four to seven times greater than the recommended limit of 1.0 µg/L. Ciprofloxacin concentrations ranged from 2.9 ± 0.2 µg/L in Sokoto to 4.5 ± 0.3 µg/L in Maiduguri. Estradiol and ethinylestradiol showed particularly alarming values. Estradiol ranged from 0.021 ± 0.002 µg/L in Sokoto to 0.036 ± 0.003 µg/L in Maiduguri, while ethinylestradiol ranged from 0.014 ± 0.001 µg/L to 0.022 ± 0.002 µg/L. Both compounds exceeded the guideline value of 0.001 µg/L by more than 14–36 times, indicating significant endocrine-disrupting potential as shown in Table 2.

Table 2. Concentrations of Pharmaceutical Residues in Wastewater Samples (µg/L)

Compound	Kano	Kaduna	Sokoto	Maiduguri	Guideline Value
Paracetamol	18.6 ± 1.2	15.4 ± 1.0	12.8 ± 0.9	20.1 ± 1.4	10.0
Diclofenac	6.8 ± 0.5	5.9 ± 0.4	4.8 ± 0.3	7.2 ± 0.5	1.0

Ibuprofen	9.4 ± 0.7	8.1 ± 0.6	6.5 ± 0.5	10.2 ± 0.8	5.0
Ciprofloxacin	4.2 ± 0.3	3.7 ± 0.3	2.9 ± 0.2	4.5 ± 0.3	1.0
Sulfamethoxazole	3.6 ± 0.2	3.1 ± 0.2	2.5 ± 0.2	3.9 ± 0.3	1.0
Estradiol	0.032 ± 0.003	0.028 ± 0.002	0.021 ± 0.002	0.036 ± 0.003	0.001
Ethinylestradiol	0.019 ± 0.002	0.017 ± 0.001	0.014 ± 0.001	0.022 ± 0.002	0.001

Heavy metal concentrations in all wastewater samples were above WHO limits. Lead concentrations ranged from 0.039 ± 0.003 mg/L in Sokoto to 0.061 ± 0.004 mg/L in Maiduguri, exceeding the recommended limit of 0.01 mg/L by approximately four to six times. Cadmium concentrations varied between 0.005 ± 0.001 mg/L in Sokoto and 0.009 ± 0.001 mg/L in Maiduguri, above the WHO limit of 0.003 mg/L. Chromium ranged from 0.059 ± 0.004 mg/L in Sokoto to 0.079 ± 0.005 mg/L in Maiduguri, exceeding the permissible limit of 0.05 mg/L. Mercury was highest in Maiduguri (0.005 ± 0.0003 mg/L) and lowest in Sokoto (0.002 ± 0.0002 mg/L), but all values were above the WHO limit of 0.001 mg/L. The consistently higher concentrations in Maiduguri and Kano suggest greater contamination pressure in these cities, as shown in Table 3.

Table 3. Heavy Metal Concentrations in Pharmaceutical Wastewater (mg/L)

Metal	WHO Limit	Kano	Kaduna	Sokoto	Maiduguri
Lead (Pb)	0.01	0.056 ± 0.004	0.048 ± 0.003	0.039 ± 0.003	0.061 ± 0.004
Cadmium (Cd)	0.003	0.008 ± 0.001	0.007 ± 0.001	0.005 ± 0.001	0.009 ± 0.001
Chromium (Cr)	0.05	0.074 ± 0.005	0.068 ± 0.004	0.059 ± 0.004	0.079 ± 0.005
Nickel (Ni)	0.02	0.043 ± 0.003	0.039 ± 0.003	0.031 ± 0.002	0.046 ± 0.003
Mercury (Hg)	0.001	0.004 ± 0.0003	0.003 ± 0.0002	0.002 ± 0.0002	0.005 ± 0.0003

The wastewater samples contained extremely high microbial loads. Total coliform counts ranged from 2.7×10^5 CFU/mL in Sokoto to 4.2×10^5 CFU/mL in Maiduguri. Faecal coliform counts varied between 1.2×10^5 CFU/mL in Sokoto and 2.1×10^5 CFU/mL in Maiduguri. Antibiotic-

resistant bacteria ranged from 6.3×10^4 CFU/mL in Sokoto to 9.1×10^4 CFU/mL in Maiduguri. More than half of the isolates in all cities were multidrug resistant, with the highest proportion observed in Maiduguri (66.8%) and the lowest in Sokoto (51.4%). These findings indicate that the wastewater acts as a significant reservoir for resistant bacteria, as shown in Table 4.

Table 4. Total Coliform and Antibiotic-Resistant Bacteria in Wastewater Samples

Parameter	Kano	Kaduna	Sokoto	Maiduguri
Total coliform count (CFU/mL)	3.8×10^5	3.1×10^5	2.7×10^5	4.2×10^5
Faecal coliform count (CFU/mL)	1.9×10^5	1.5×10^5	1.2×10^5	2.1×10^5
Antibiotic-resistant bacteria (CFU/mL)	8.4×10^4	7.6×10^4	6.3×10^4	9.1×10^4
Multidrug-resistant isolates (%)	62.5	58.3	51.4	66.8

Escherichia coli was the most frequently isolated organism in all cities, accounting for 23.6% of isolates in Sokoto and up to 30.1% in Maiduguri. Staphylococcus aureus constituted 17.8–20.3% of isolates, while Pseudomonas aeruginosa accounted for 14.6–17.1%. Klebsiella pneumoniae represented 12.4–15.7% of isolates. Enterococcus faecalis showed the greatest occurrence in Sokoto, where it represented 21.9% of isolates, compared with only 8.7% in Maiduguri. The predominance of E. coli and other enteric pathogens confirms substantial faecal contamination of the wastewater, as shown in Table 5.

Table 5. Distribution of Bacterial Species Isolated from Pharmaceutical Wastewater

Bacterial Species	Kano (%)	Kaduna (%)	Sokoto (%)	Maiduguri (%)
Escherichia coli	28.4	25.7	23.6	30.1
Staphylococcus aureus	18.7	20.3	17.8	19.5
Pseudomonas aeruginosa	16.5	15.2	14.6	17.1
Klebsiella pneumoniae	14.3	13.8	12.4	15.7
Salmonella spp.	10.8	11.4	9.7	8.9
Enterococcus faecalis	11.3	13.6	21.9	8.7

The antibiotic resistance profile revealed very high resistance rates to ampicillin and tetracycline. Ampicillin resistance ranged from 76.1% in Staphylococcus aureus to 91.3% in Pseudomonas aeruginosa. Tetracycline resistance ranged between 64.5% in Staphylococcus aureus and 73.1% in Pseudomonas aeruginosa. Ciprofloxacin resistance varied from 36.2% in Staphylococcus aureus to 52.4% in Pseudomonas aeruginosa. Gentamicin exhibited the lowest resistance values,

ranging from 28.4% in Staphylococcus aureus to 40.8% in Pseudomonas aeruginosa. These findings suggest that Pseudomonas aeruginosa is the most resistant organism in the wastewater samples, as shown in Table 6.

Table 6. Antibiotic Resistance Pattern of Bacterial Isolates (%)

Antibiotic	E. coli	S. aureus	P. aeruginosa	K. pneumoniae
Ampicillin	82.4	76.1	91.3	84.5
Ciprofloxacin	48.7	36.2	52.4	44.1
Gentamicin	31.5	28.4	40.8	35.6
Tetracycline	69.8	64.5	73.1	68.4
Chloramphenicol	45.6	39.2	50.5	47.8

Human health risk assessment indicated substantial health risks associated with exposure to the wastewater. The hazard quotient for pharmaceutical residues ranged from 1.31 in Sokoto to 2.05 in Maiduguri, while the hazard quotient for heavy metals ranged from 1.47 in Sokoto to 2.34 in Maiduguri. The combined hazard index exceeded the acceptable threshold of 1 in all cities, with values of 2.78 in Sokoto, 3.51 in Kaduna, 4.00 in Kano, and 4.39 in Maiduguri. Carcinogenic risk values for lead and cadmium ranged from 2.1×10^{-4} in Sokoto to 3.8×10^{-4} in Maiduguri, all exceeding the acceptable range of 1×10^{-6} to 1×10^{-4} as shown in Table 7.

Table 7. Human Health Risk Assessment of Pharmaceutical Wastewater Exposure

Risk Parameter	Kano	Kaduna	Sokoto	Maiduguri	Acceptable Limit
Hazard quotient (HQ) for pharmaceutical residues	1.84	1.62	1.31	2.05	<1
Hazard quotient (HQ) for heavy metals	2.16	1.89	1.47	2.34	<1
Combined hazard index (HI)	4.00	3.51	2.78	4.39	<1
Carcinogenic risk (Pb + Cd)	3.4×10^{-4}	2.9×10^{-4}	2.1×10^{-4}	3.8×10^{-4}	$1 \times 10^{-6} - 1 \times 10^{-4}$

Strong positive correlations were observed between contaminants and public health indicators. Ciprofloxacin showed the highest correlation with multidrug-resistant isolates ($r = 0.91$), indicating that antibiotic residues may contribute substantially to antimicrobial resistance. Mercury had the strongest correlation with hazard index ($r = 0.92$), followed by lead ($r = 0.88$).

Diclofenac exhibited strong correlations with biochemical oxygen demand (r = 0.81) and hazard index (r = 0.84). Estradiol showed moderate correlations with biochemical oxygen demand (r = 0.63), multidrug-resistant isolates (r = 0.61), and hazard index (r = 0.69). These results suggest that both pharmaceutical compounds and heavy metals contribute significantly to environmental degradation and public health risk, as shown in Table 8.

Table 8. Correlation Matrix Between Selected Contaminants and Public Health Indicators

Variables	BOD	Total Coliform	MDR Isolates	Hazard Index
Diclofenac	0.81	0.72	0.76	0.84
Ciprofloxacin	0.67	0.83	0.91	0.79
Lead	0.74	0.68	0.71	0.88
Mercury	0.79	0.73	0.77	0.92
Estradiol	0.63	0.58	0.61	0.69

4.0 Discussion

The physicochemical characteristics of the pharmaceutical wastewater indicate that the wastewater discharged in the studied cities is highly polluted and unsuitable for direct release into the environment without treatment. Electrical conductivity values ranged from 1186 ± 36 µS/cm in Sokoto to 1502 ± 55 µS/cm in Maiduguri, all exceeding the WHO limit of 1000 µS/cm. The elevated conductivity reflects a high concentration of dissolved ions and chemical contaminants in the wastewater. Similar increases in conductivity and total dissolved solids have been reported in contaminated wastewater systems and were attributed to the presence of dissolved salts, pharmaceutical compounds, and other pollutants (Akpor & Muchie, 2011; Obunadike et al., 2025). The high total dissolved solids values observed in this study, especially in Maiduguri (771 ± 31 mg/L), further support the presence of substantial pollutant load.

The low dissolved oxygen concentrations recorded in all cities, ranging from 2.5 ± 0.2 mg/L in Maiduguri to 3.6 ± 0.3 mg/L in Sokoto, indicate poor water quality and oxygen depletion. Dissolved oxygen below 5 mg/L is generally considered harmful to aquatic organisms because it impairs respiration and other metabolic activities. The low dissolved oxygen values in the present study correspond with the elevated biochemical oxygen demand and chemical oxygen demand values. Biochemical oxygen demand reached 70.1 ± 4.5 mg/L in Maiduguri and 68.4 ± 4.2 mg/L in Kano, while chemical oxygen demand reached 151.4 ± 8.1 mg/L in Maiduguri. These values are substantially higher than the recommended limits and indicate a high concentration of biodegradable organic matter and chemically oxidizable pollutants. Similar findings have been reported in domestic and industrial wastewater studies in Nigeria, where high

BOD and COD values were associated with untreated effluent discharge and organic pollution (Akpor & Muchie, 2011; Ekesiobi et al., 2026).

The concentrations of pharmaceutical residues detected in the wastewater demonstrate extensive pharmaceutical contamination in all the studied cities. Paracetamol, diclofenac, ibuprofen, ciprofloxacin, and sulfamethoxazole exceeded their recommended guideline values in all locations. Diclofenac concentrations ranged from 4.8 ± 0.3 μg/L in Sokoto to 7.2 ± 0.5 μg/L in Maiduguri, while ciprofloxacin ranged from 2.9 ± 0.2 to 4.5 ± 0.3 μg/L. These values are considerably higher than those reported in several international studies and indicate excessive use and poor disposal of pharmaceuticals in the region. Similar detection of pharmaceutical residues in wastewater and rivers has been reported in Brazil, South Africa, Türkiye, and Southeast Asia (dos Santos et al., 2025; Nibamureke & Barnhoorn, 2025; Deryal et al., 2025; Lee et al., 2025).

Particularly concerning are the concentrations of estradiol and ethinylestradiol, which exceeded the recommended value of 0.001 μg/L by more than 14–36 times. Estradiol concentrations ranged from 0.021 ± 0.002 μg/L in Sokoto to 0.036 ± 0.003 μg/L in Maiduguri. Such concentrations are capable of inducing endocrine disruption in aquatic organisms. Arcand-Hoy and Benson (1998) reported that even trace levels of estrogenic compounds can induce reproductive abnormalities in fish. Similarly, Gonsioroski et al. (2020) and Kar et al. (2021) demonstrated that exposure to estradiol and related compounds may cause altered hormone balance, feminisation, and reduced reproductive success in exposed aquatic organisms. The findings of Adeogun et al. (2016), who observed intersex conditions and gonadal abnormalities in fish exposed to endocrine disruptors in Nigeria, support the possibility that long-term discharge of these compounds could have serious ecological consequences.

Heavy metal concentrations in the pharmaceutical wastewater also exceeded the WHO permissible limits in all locations. Lead concentrations reached 0.061 ± 0.004 mg/L in Maiduguri and 0.056 ± 0.004 mg/L in Kano, which are approximately six times higher than the WHO limit of 0.01 mg/L. Cadmium and mercury were also considerably elevated. These results suggest that pharmaceutical wastewater in Northern Nigeria is contaminated not only by pharmaceutical residues but also by toxic metals originating from laboratory chemicals, metallic containers, corroded pipes, and pharmaceutical formulations. Similar elevated heavy metal concentrations have been reported in contaminated water bodies in Nigeria and elsewhere (Ezemonye et al., 2019; Ekesiobi et al., 2025; Ebikienmo et al., 2026). Heavy metals such as lead, cadmium, and mercury are of particular concern because they are non-biodegradable and may accumulate in aquatic organisms and eventually in humans through the food chain (Jaishankar et al., 2014; Castro-González & Méndez-Armenta, 2008).

The higher contamination levels recorded in Maiduguri and Kano may be related to their larger population size, higher number of healthcare facilities, and poorer wastewater management practices. Maiduguri consistently recorded the highest values for electrical conductivity,

biochemical oxygen demand, pharmaceutical residues, heavy metals, coliform counts, multidrug-resistant bacteria, and hazard index. This suggests that pharmaceutical wastewater in Maiduguri is more concentrated and less effectively managed than in the other cities.

The bacteriological analysis revealed severe microbial contamination of the pharmaceutical wastewater. Total coliform counts ranged from 2.7×10^5 CFU/mL in Sokoto to 4.2×10^5 CFU/mL in Maiduguri, while faecal coliforms reached 2.1×10^5 CFU/mL in Maiduguri. These values indicate significant faecal pollution and suggest that the wastewater is mixed with domestic sewage and human excreta. Escherichia coli was the dominant bacterial species isolated in all cities, accounting for up to 30.1% of the isolates in Maiduguri. The predominance of E. coli, together with the presence of Staphylococcus aureus, Pseudomonas aeruginosa, and Klebsiella pneumoniae, indicates that the wastewater contains several opportunistic and pathogenic organisms capable of causing disease.

A particularly important finding of this study is the high prevalence of multidrug-resistant bacteria. More than half of the bacterial isolates in all cities were resistant to at least three classes of antibiotics, with multidrug resistance reaching 66.8% in Maiduguri. Resistance to ampicillin and tetracycline exceeded 70% in most organisms, while ciprofloxacin resistance was also substantial. The strong positive correlation between ciprofloxacin concentration and multidrug-resistant bacteria ($r = 0.91$) suggests that the presence of antibiotics in the wastewater may be exerting selective pressure that favours the survival and proliferation of resistant organisms. This observation is consistent with previous studies that identified wastewater as an important reservoir for antibiotic resistance genes and resistant bacteria (Obinna et al., 2023; Kayode-Afolayan et al., 2022).

The human health risk assessment showed that the hazard quotient and hazard index exceeded the acceptable limit of 1 in all cities. The combined hazard index ranged from 2.78 in Sokoto to 4.39 in Maiduguri, indicating that prolonged exposure to the wastewater may result in significant adverse health effects. Carcinogenic risk values for lead and cadmium also exceeded the acceptable range, particularly in Maiduguri (3.8×10^{-4}) and Kano (3.4×10^{-4}). These findings imply that individuals exposed to the wastewater through direct contact, irrigation, or contamination of water supplies may be at risk of both non-carcinogenic and carcinogenic effects. Similar observations have been reported in water quality and health risk studies conducted in Bayelsa, Port Harcourt, and other parts of Nigeria (Ekesiobi et al., 2025; Ebikienmo et al., 2026).

The correlation analysis further demonstrates the link between environmental contamination and public health risk. Mercury showed the strongest correlation with hazard index ($r = 0.92$), followed by lead ($r = 0.88$), indicating that heavy metals are major contributors to overall health risk. The strong correlation between pharmaceutical residues and multidrug-resistant bacteria also highlights the role of pharmaceutical wastewater in promoting antimicrobial resistance.

Conclusion

The present study demonstrates that pharmaceutical wastewater discharged in Kano, Kaduna, Sokoto, and Maiduguri is heavily contaminated with pharmaceutical residues, heavy metals, and pathogenic microorganisms. Physicochemical parameters showed poor wastewater quality characterised by elevated conductivity, total dissolved solids, biochemical oxygen demand, and chemical oxygen demand, together with low dissolved oxygen.

Pharmaceutical compounds, including paracetamol, diclofenac, ciprofloxacin, sulfamethoxazole, estradiol, and ethinylestradiol, were present at concentrations above recommended guideline values. The particularly high concentrations of estradiol and ethinylestradiol indicate substantial endocrine-disrupting potential. Heavy metals such as lead, cadmium, chromium, nickel, and mercury also exceeded permissible limits, especially in Maiduguri and Kano.

The wastewater contained high levels of total coliforms, faecal coliforms, and multidrug-resistant bacteria. Escherichia coli, Staphylococcus aureus, Pseudomonas aeruginosa, and Klebsiella pneumoniae were the predominant organisms. The strong relationship between ciprofloxacin concentration and multidrug-resistant bacteria suggests that pharmaceutical residues are contributing to the emergence of antibiotic resistance.

Human health risk assessment revealed that both non-carcinogenic and carcinogenic risks exceed acceptable limits in all the studied cities. Maiduguri presented the greatest overall risk, followed by Kano, while Sokoto showed comparatively lower contamination levels. These findings indicate that the uncontrolled discharge of pharmaceutical wastewater represents a serious environmental and public health threat in Northern Nigeria.

The study therefore recommends the establishment of effective pharmaceutical wastewater treatment facilities, regular environmental monitoring, strict regulation of hospital and pharmaceutical effluent discharge, and improved public awareness regarding proper disposal of pharmaceutical waste. Continuous surveillance of antibiotic resistance and endocrine-disrupting compounds is also necessary to protect environmental quality and human health.

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