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Comparative Evaluation of Emerging Contaminants in Wastewater from Makurdi and Gwer West Local Government Areas, Benue State, Nigeria

Godsday Idanegbe Usiabulu[1], Osagioduwa N. Olotu[2], Awajiiroijana U. Okpoji[3]*, Ejikeme E. Onuchukwu[4], Joy C. Obunadike[5], Emeka C. Izuchukwu[6], Eze L. Osuagwu[7], Nsima A. Akpan[8], Chisom A. Amadi[9], Muhammed H. Garuba[10], John E. Ekpe[11], Franklin K. Ugbechie[12], Sandra U Ekesiobi[13], Gertrude U. Nwafor[14]

[1] World Bank Africa Centre of Excellence, Centre for Oilfield Chemicals Research, University of Port Harcourt, Port Harcourt, Nigeria
[2] Department of Public Health and Community Medicine, University of Benin Teaching Hospital, Benin City, Nigeria
[3] Department of Pure and Industrial Chemistry, University of Port Harcourt, Choba, Nigeria
[4] Department of Geological Sciences, Nnamdi Azikiwe University, Awka, Nigeria
[5] Department of Agricultural and Vocational Education, Michael Okpara University of Agriculture, Umudike, Nigeria
[6] Department of Chemical Pathology, Nnamdi Azikiwe University, Nnewi, Nigeria
[7] Department of Fisheries and Marine Technology, Imo State Polytechnic, Omuma, Nigeria
[8] Department of Chemical Sciences, Ritman University, Ikot Ekpene, Nigeria
[9] Department of Chemistry, Ignatius Ajuru University of Education, Port Harcourt, Nigeria
[10] Department of Chemistry and Industrial Chemistry, Kwara State University, Malete, Nigeria
[11] Department of Physics, Alex Ekwueme Federal University, Ndufu-Alike, Nigeria
[12] Department of Chemistry/Biochemistry, Federal Polytechnic Nekede, Nigeria
[13] School of Public Health, University of Port Harcourt, Choba, Nigeria
[14] Department of Pure and Industrial Chemistry, Nnamdi Azikiwe University, Awka, Nigeria

ABSTRACT

Emerging contaminants in wastewater have become major environmental and public health concerns due to their persistence, toxicity, and ecological effects in aquatic environments. This study comparatively evaluated the occurrence and distribution of emerging contaminants in wastewater from Makurdi and Gwer West Local Government Areas of Benue State, Nigeria. A comparative cross-sectional environmental study was conducted using 40 wastewater samples collected from selected drainage systems and wastewater discharge points. Physicochemical parameters, heavy metals, microbial contaminants, and selected emerging contaminants were analysed using standard analytical procedures. Results revealed that wastewater samples from Makurdi recorded higher physicochemical pollution levels compared to Gwer West. Electrical conductivity was 812.4 ± 24.6 µS/cm in Makurdi and 524.7 ± 18.3 µS/cm in Gwer West, while biochemical oxygen demand values were 38.6 ± 3.4 mg/L and 24.1 ± 2.6 mg/L respectively. Caffeine recorded the highest concentration among emerging contaminants with values of 18.42 ± 2.11 µg/L in Makurdi and 9.26 ± 1.34 µg/L in Gwer West. Lead concentrations exceeded WHO permissible limits in both locations, with values of 0.18 ± 0.03 mg/L in Makurdi and 0.07 ± 0.01 mg/L in Gwer West. Microbial analysis showed high total coliform counts of 5.8×10^4 CFU/mL in Makurdi and 2.9×10^4 CFU/mL in Gwer West, alongside the presence of Escherichia coli and Salmonella species. Statistical analysis revealed significant differences in contaminant burden between both locations ($p < 0.05$). The study demonstrated substantial

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wastewater contamination, particularly within urban environments, highlighting the need for improved wastewater treatment, environmental monitoring, and pollution control measures.

KEY WORDS: Emerging contaminants, wastewater pollution, heavy metals, microbial contamination, urban wastewater, Benue State.

Corresponding Author:
Sandra U Ekesiobi
ORCID: 0009-0002-1713-1210

1.0 INTRODUCTION

Environmental pollution associated with wastewater discharge has become a major ecological and public health concern globally, particularly in developing countries where wastewater management systems remain inadequate [7]. Wastewater generated from domestic, industrial, agricultural, and healthcare activities contains complex mixtures of contaminants including heavy metals, pharmaceuticals, endocrine-disrupting compounds, pathogenic microorganisms, hydrocarbons, and other emerging pollutants [8,46]. The indiscriminate discharge of untreated or poorly treated wastewater into aquatic environments contributes significantly to ecosystem degradation, biodiversity loss, and increased public health risks [7].

Emerging contaminants are synthetic or naturally occurring chemicals that are not routinely monitored in environmental systems but possess the potential to cause adverse ecological and human health effects [29,46]. These contaminants include pharmaceuticals, personal care products, detergents, plasticisers, hormones, and industrial chemicals [8]. Their continuous release into aquatic systems has become an increasing environmental concern because many conventional wastewater treatment systems are unable to effectively remove them [8,50]. Consequently, these compounds persist within surface waters, sediments, aquatic organisms, and groundwater systems where they may accumulate and exert toxicological effects [46].

Urban wastewater systems are particularly vulnerable to contamination due to high population density, industrialisation, healthcare activities, poor waste disposal practices, and increasing anthropogenic pressure [27]. Rural wastewater systems may also become contaminated through agricultural runoff, domestic waste discharge, and poor sanitation infrastructure [47]. Comparative studies between urban and rural wastewater environments are therefore important for understanding contaminant distribution patterns associated with human activities and environmental management practices.

Several studies have reported the occurrence of pharmaceuticals and endocrine-disrupting compounds within aquatic ecosystems globally [8,17,18,48]. AL Falahi et al. [8] observed widespread occurrence of pharmaceuticals and personal care products in domestic wastewater and highlighted the limitations of conventional wastewater treatment technologies in removing these contaminants. Deryal et al. [17] reported the occurrence of fluoxetine and serotonin hormone in aquatic environments, while dos Santos et al. [18] documented seasonal variations in pharmaceutical contamination in Brazilian urban rivers. In South Africa, Nibamureke and Barnhoorn [48] also reported the presence of pharmaceutical residues in surface waters exposed to anthropogenic activities.

Endocrine-disrupting compounds in wastewater environments have attracted significant attention because of their ability to interfere with hormonal regulation and reproductive processes in aquatic organisms [2,10,32]. Adeogun et al. [2] reported endocrine-disruptor responses, occurrence of intersex conditions, and gonado-histopathological alterations in fish exposed to contaminated freshwater systems in Nigeria. Arcand-Hoy and Benson [10] further identified fish reproductive impairment as an ecologically relevant indicator of endocrine disruption in aquatic ecosystems. Gonsioroski et al. [32] emphasised that endocrine disruptors in water environments may adversely affect reproductive health and developmental processes in both aquatic organisms and humans.

Heavy metal contamination in wastewater systems also remains a major environmental concern because of the persistence, bioaccumulation potential, and toxicity of these pollutants [14,33]. Heavy metals such as lead, cadmium, chromium, and mercury may accumulate in aquatic organisms and subsequently enter the human food chain [14]. Castro-González and Méndez-Armenta [14] reported that exposure to heavy metals through contaminated aquatic systems may result in neurological disorders, kidney dysfunction, carcinogenicity, and reproductive toxicity. Similarly, Jaishankar et al. [33] highlighted the severe toxicological and health effects associated with chronic heavy metal exposure.

Wastewater environments also serve as reservoirs for pathogenic microorganisms and antimicrobial-resistant bacteria [3,7,34]. Studies conducted in Nigeria and other developing countries have reported the occurrence of multidrug-resistant bacteria and antibiotic resistance genes in wastewater systems [3,5,20,21]. Adesoji et al. [3] identified multidrug-resistant Pseudomonas species in Nigerian water distribution systems, while Igbinosa et al. [34] reported the potential transmission of antibiotic resistance through wastewater effluents. The occurrence of antimicrobial-resistant microorganisms in aquatic environments therefore poses significant public health challenges.

Several environmental studies conducted in Nigeria have demonstrated increasing contamination of aquatic environments with hydrocarbons, heavy metals, pharmaceuticals, and microbial pollutants [4,9,24,27,37]. Obunadike et al. [27] reported the effects of domestic wastewater discharge on water quality and public health in the Choba River, Rivers State, Nigeria. Similarly, Aghanwa et al. [4] documented atmospheric deposition of soot and heavy metals into surface waters in the Niger Delta region. However, despite increasing concern regarding emerging contaminants in wastewater systems, limited comparative information exists regarding contaminant occurrence and distribution within urban and rural wastewater environments in Benue State, Nigeria. Therefore, this study comparatively evaluated the occurrence and distribution of emerging contaminants in wastewater from Makurdi and Gwer West Local Government Areas of Benue State, Nigeria,

2.0 MATERIALS AND METHODS

2.1 Study Area

The study was conducted in Makurdi and Gwer West Local Government Areas of Benue State, Nigeria. Makurdi is the capital city of Benue State and represents an urban environment characterised by high population density, commercial activities, healthcare facilities, urban drainage systems, and increased anthropogenic activities. Gwer West Local Government Area is predominantly rural, characterised by agricultural settlements, lower population density, and limited industrial activities. The two locations were selected to provide comparative information on urban and rural wastewater contamination patterns.

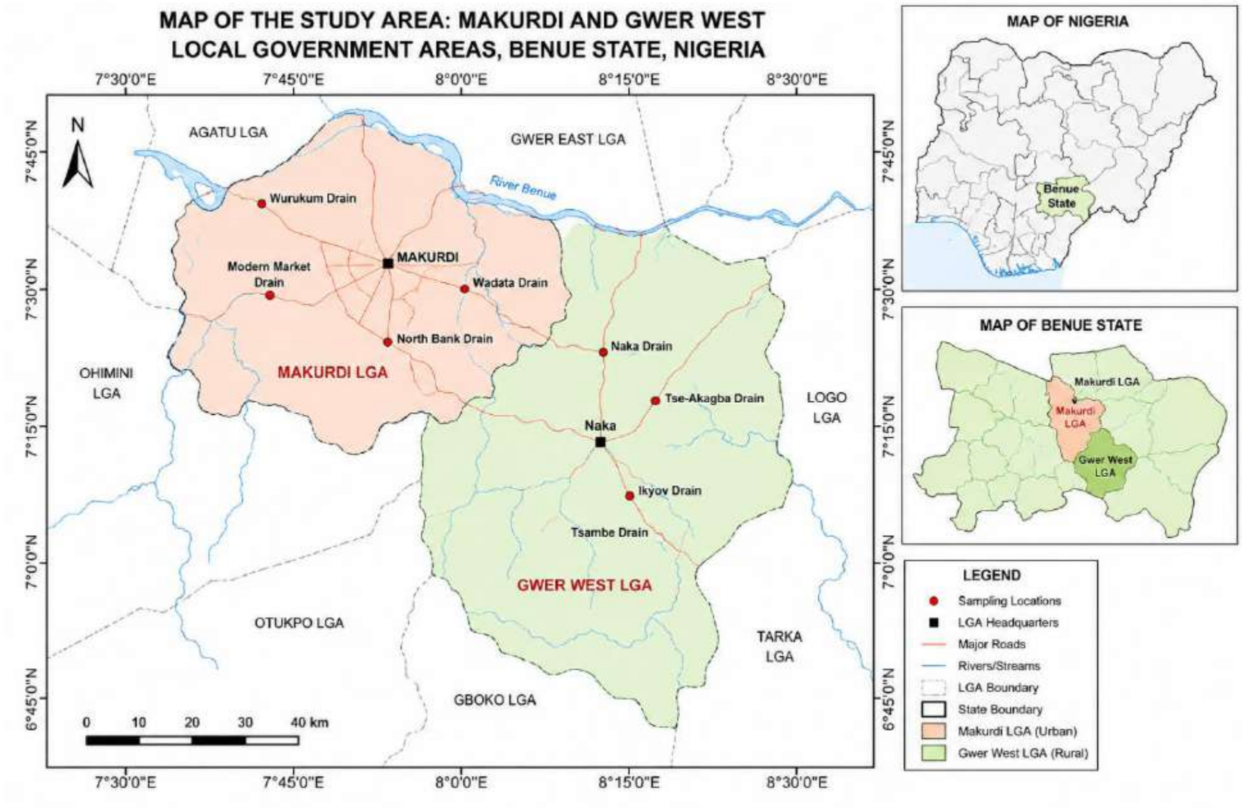

Figure 1: Map of the Study Area Showing Makurdi and Gwer West Local Government Areas, Benue State, Nigeria

2.2 Study Design

This study employed a comparative cross-sectional environmental study design to evaluate the occurrence and distribution of emerging contaminants in wastewater samples collected from urban and rural communities in Benue State, Nigeria.

2.3 Sample Collection

Wastewater samples were collected from selected drainage channels, domestic wastewater discharge points, and wastewater receiving environments within Makurdi and Gwer West Local Government Areas. Sampling locations were selected based on population density, wastewater discharge intensity, accessibility, and proximity to residential areas.

A total of 40 wastewater samples were collected, comprising 20 samples from Makurdi and 20 samples from Gwer West. Samples were collected during the morning hours between 7:00 am and 10:00 am using pre-cleaned sterile polyethylene bottles. The bottles were rinsed with sample water before final collection to minimise contamination.

Samples for heavy metal analysis were acidified immediately with concentrated nitric acid to pH < 2, while samples for microbial analysis were stored in sterile containers without preservatives. All samples were labelled appropriately and transported in ice-packed coolers to the laboratory for analysis within 24 hours of collection.

2.4 Determination of Physicochemical Parameters

Physicochemical parameters including pH, temperature, electrical conductivity, turbidity, dissolved oxygen, biochemical oxygen demand (BOD), and chemical oxygen demand (COD) were determined using standard analytical procedures recommended by the American Public Health Association (APHA).

The pH and electrical conductivity were measured in situ using a calibrated digital multiparameter meter. Turbidity was determined using a turbidimeter, while dissolved oxygen was analysed using the Winkler titration method. Biochemical oxygen demand was determined after five days of incubation at 20°C, whereas chemical oxygen demand was analysed using the dichromate reflux method.

2.5 Analysis of Emerging Contaminants

Selected emerging contaminants including caffeine, bisphenol-A, triclosan, phthalates, and nonylphenol were analysed using High Performance Liquid Chromatography (HPLC).

Wastewater samples were first filtered using 0.45 µm membrane filters to remove suspended particles. Solid-phase extraction was subsequently carried out to concentrate the contaminants before instrumental analysis. Quantification of the contaminants was achieved by comparing sample peak areas with calibration standards prepared from analytical-grade reference compounds.

2.6 Heavy Metal Analysis

Heavy metals including lead (Pb), cadmium (Cd), chromium (Cr), iron (Fe), and zinc (Zn) were analysed using Atomic Absorption Spectrophotometry (AAS).

Prior to analysis, wastewater samples were digested using nitric acid and perchloric acid digestion methods. The digested samples were filtered and diluted appropriately before analysis using an Atomic Absorption Spectrophotometer. Calibration standards and reagent blanks were used for quality assurance during analysis.

2.7 Microbial Analysis

Microbial analyses were carried out to determine total coliform count, total heterotrophic bacterial count, and the presence of Escherichia coli and Salmonella species.

Serial dilution techniques were employed, and samples were cultured using appropriate microbiological media. Total coliforms were determined using MacConkey agar, while nutrient agar was used for total heterotrophic bacterial count. Identification of bacterial isolates was carried out using standard biochemical tests and colony morphology characteristics.

2.8 Quality Assurance and Quality Control

All laboratory analyses were carried out using analytical-grade reagents and calibrated instruments. Glassware and sampling containers were thoroughly washed and sterilised prior to use. Duplicate analyses, reagent blanks, and standard reference materials were used to ensure analytical accuracy and reliability of results.

2.9 Data Analysis

Data obtained from laboratory analyses were entered into Microsoft Excel and analysed using the Statistical Package for Social Sciences (SPSS) version 25. Descriptive statistics including mean and standard deviation were used to summarise the data.

Independent sample t-test was used to compare contaminant concentrations between Makurdi and Gwer West Local Government Areas. Statistical significance was set at $p < 0.05$.

2.10 Ethical and Environmental Consideration

Permission for sample collection was obtained from relevant community authorities and environmental management agencies within the study areas. All laboratory procedures and wastewater handling were conducted in accordance with standard environmental safety and laboratory biosafety guidelines to minimise contamination and environmental hazards.

3.0 RESULTS

3.1 Physicochemical Characteristics of Wastewater Samples

As shown in Table 1, the physicochemical characteristics of wastewater samples varied between Makurdi and Gwer West Local Government Areas. Wastewater samples from Makurdi recorded higher mean values of electrical conductivity (812.4 ± 24.6 µS/cm), biochemical oxygen demand (BOD) (38.6 ± 3.4 mg/L), and chemical oxygen demand (COD) (74.2 ± 5.1 mg/L) compared to Gwer West, which recorded conductivity of 524.7 ± 18.3 µS/cm, BOD of 24.1 ± 2.6 mg/L, and COD of 46.5 ± 4.3 mg/L. The pH values of both locations were within slightly acidic to neutral ranges. Turbidity levels were also significantly higher in Makurdi wastewater samples (28.7 ± 4.1 NTU) compared to Gwer West (16.9 ± 2.7 NTU), suggesting increased anthropogenic and domestic pollution within the urban environment.

Table 1: Physicochemical Characteristics of Wastewater Samples from Makurdi and Gwer West LGAs

Parameter	Makurdi (Mean ± SD)	Gwer West (Mean ± SD)	WHO Limit
pH	6.8 ± 0.3	6.5 ± 0.2	6.5–8.5
Temperature (°C)	29.4 ± 1.2	28.1 ± 1.0	-
Electrical Conductivity (µS/cm)	812.4 ± 24.6	524.7 ± 18.3	1000
Turbidity (NTU)	28.7 ± 4.1	16.9 ± 2.7	5
Dissolved Oxygen (mg/L)	3.2 ± 0.4	4.6 ± 0.5	>5
Biochemical Oxygen Demand (mg/L)	38.6 ± 3.4	24.1 ± 2.6	30
Chemical Oxygen Demand (mg/L)	74.2 ± 5.1	46.5 ± 4.3	50

3.2 Concentration of Emerging Contaminants in Wastewater Samples

As shown in Table 2, emerging contaminants were detected in wastewater samples from both Makurdi and Gwer West LGAs, although concentrations were generally higher in Makurdi samples. Caffeine recorded the highest mean concentration in Makurdi (18.42 ± 2.11 µg/L), followed by triclosan (11.36 ± 1.48 µg/L) and bisphenol-A (9.84 ± 1.25 µg/L). In Gwer West, caffeine also recorded the highest concentration (9.26 ± 1.34 µg/L). The significantly higher contaminant concentrations observed in Makurdi may be attributed to increased urban activities, hospital discharge, domestic waste disposal, and higher population density.

Table 2: Concentration of Emerging Contaminants in Wastewater Samples

Contaminant	Makurdi (µg/L) Mean ± SD	Gwer West (µg/L) Mean ± SD	p-value
Caffeine	18.42 ± 2.11	9.26 ± 1.34	<0.001
Bisphenol-A	9.84 ± 1.25	4.73 ± 0.88	0.002
Triclosan	11.36 ± 1.48	5.12 ± 0.71	<0.001
Phthalates	7.43 ± 0.94	3.66 ± 0.52	0.004
Nonylphenol	5.88 ± 0.81	2.94 ± 0.47	0.008

3.3 Heavy Metal Concentrations in Wastewater Samples

As shown in Table 3, heavy metals were detected in wastewater samples from both study locations. Lead concentration was highest in Makurdi wastewater samples (0.18 ± 0.03 mg/L), exceeding the WHO permissible limit of 0.01 mg/L. Cadmium and chromium concentrations were also higher in Makurdi than in Gwer West. Iron concentrations were elevated in both locations, although values remained comparatively higher in Makurdi. These findings indicate increased environmental contamination associated with urban wastewater discharge.

Table 3: Heavy Metal Concentrations in Wastewater Samples

Heavy Metal	Makurdi (mg/L) Mean ± SD	Gwer West (mg/L) Mean ± SD	WHO Limit (mg/L)
Lead (Pb)	0.18 ± 0.03	0.07 ± 0.01	0.01
Cadmium (Cd)	0.06 ± 0.01	0.02 ± 0.01	0.003
Chromium (Cr)	0.14 ± 0.02	0.05 ± 0.01	0.05
Iron (Fe)	1.26 ± 0.14	0.74 ± 0.10	0.30
Zinc (Zn)	0.92 ± 0.11	0.51 ± 0.08	3.00

3.4 Microbial Analysis of Wastewater Samples

As shown in Table 4, microbial contamination levels were significantly higher in Makurdi wastewater samples compared to Gwer West. Total coliform count in Makurdi was 5.8 × 10^4 CFU/mL, while Gwer West recorded 2.9 × 10^4 CFU/mL. Escherichia coli and Salmonella spp. were detected in samples from both locations, indicating faecal contamination and poor wastewater management practices. The higher microbial loads in Makurdi may be associated with increased population density, urban sewage discharge, and poor sanitation infrastructure.

Table 4: Microbial Characteristics of Wastewater Samples

Parameter	Makurdi	Gwer West	WHO Standard
Total Coliform Count (CFU/mL)	5.8 × 10^4	2.9 × 10^4	0
Escherichia coli	Present	Present	Absent
Salmonella spp.	Present	Present	Absent
Total Heterotrophic Bacteria (CFU/mL)	7.4 × 10^4	3.8 × 10^4	-

3.5 Comparative Analysis of Contaminant Burden Between Urban and Rural Wastewater

As shown in Table 5, wastewater samples from Makurdi demonstrated significantly higher overall contaminant burden compared to Gwer West across physicochemical, microbial, and emerging contaminant parameters. Independent t-test analysis revealed statistically significant differences between the two locations for most measured variables ($p < 0.05$). The findings suggest that urban wastewater systems contribute substantially to environmental contamination compared to rural wastewater systems.

Table 5: Comparative Statistical Analysis of Wastewater Contamination Between Makurdi and Gwer West LGAs

Variable Category	Mean Rank (Makurdi)	Mean Rank (Gwer West)	p-value
Physicochemical Pollution Index	18.6	10.2	0.001
Emerging Contaminant Load	21.4	9.8	<0.001
Heavy Metal Burden	19.2	11.5	0.003
Microbial Contamination Index			

4.0 DISCUSSION

This study comparatively evaluated the occurrence and distribution of emerging contaminants in wastewater from Makurdi and Gwer West Local Government Areas of Benue State, Nigeria. The findings demonstrated significant differences in contaminant concentrations between the urban and rural wastewater systems, with Makurdi consistently recording higher pollutant loads across physicochemical, microbial, heavy metal, and emerging contaminant parameters.

The elevated biochemical oxygen demand (38.6 ± 3.4 mg/L) and chemical oxygen demand (74.2 ± 5.1 mg/L) observed in Makurdi wastewater samples indicate substantial organic pollution and increased anthropogenic influence within the urban environment. Similar findings were reported by Akpor and Muchie [7], who observed that untreated wastewater systems in developing countries often contain high organic loads capable of depleting dissolved oxygen and altering aquatic ecosystem balance. The lower dissolved oxygen levels recorded in Makurdi further support increased microbial decomposition and oxygen depletion associated with urban wastewater discharge.

Emerging contaminants including caffeine, bisphenol-A, triclosan, phthalates, and nonylphenol were detected in wastewater samples from both study locations, although concentrations were significantly higher in Makurdi. Caffeine recorded the highest concentration with values of 18.42 ± 2.11 µg/L in Makurdi and 9.26 ± 1.34 µg/L in Gwer West. These findings agree with previous studies reporting widespread occurrence of pharmaceuticals and personal care products in aquatic systems [8,29]. AL Falahi et al. [8] noted that pharmaceuticals and personal care products are frequently detected in domestic wastewater due to increasing consumption and inefficient removal during wastewater treatment processes. Similarly, Patel et al. [46] reported that pharmaceuticals of emerging concern persist in aquatic systems and may exert toxicological effects on aquatic organisms even at low concentrations.

The presence of endocrine-disrupting compounds such as bisphenol-A and nonylphenol in wastewater samples raises serious ecological concerns. Adeogun et al. [2] reported endocrine disruption, intersex occurrence, and gonado-histopathological changes in fish exposed to contaminated freshwater environments in Nigeria. Arcand-Hoy and Benson [10] also observed that endocrine disruptors may interfere with fish reproductive processes and ecological stability. Gonsioroski et al. [32] further emphasised that endocrine-disrupting compounds in aquatic systems may negatively affect reproductive health and developmental processes in both wildlife and humans.

Heavy metal analysis revealed elevated concentrations of lead, cadmium, chromium, and iron in wastewater samples, particularly within Makurdi. Lead concentration reached 0.18 ± 0.03 mg/L in Makurdi, exceeding recommended WHO permissible limits. Similar observations have been reported in surface waters and aquatic organisms from different parts of Nigeria [4,9,24,37]. Heavy metals are environmentally persistent and capable of bioaccumulating within aquatic organisms and food chains [14]. Castro-González and Méndez-Armenta [14] highlighted the potential health implications associated with heavy metal exposure through contaminated aquatic systems, including neurological disorders, renal damage, carcinogenicity, and reproductive toxicity.

Jaishankar et al. [33] similarly reported that chronic exposure to heavy metals may result in severe human health complications due to their cumulative toxic effects.

Microbial analysis revealed high total coliform counts alongside the presence of Escherichia coli and Salmonella species in wastewater samples from both locations. These findings indicate faecal contamination and poor wastewater management practices within the study areas. Similar results were reported by Adebowale et al. [1], who isolated bacterial zoonotic pathogens from abattoir wastewater and receiving surface waters in Nigeria. Ateba and Mbewe [11] also reported the occurrence of pathogenic Escherichia coli strains in contaminated water sources, emphasising the public health risks associated with wastewater pollution.

The occurrence of multidrug-resistant microorganisms in wastewater systems represents an additional environmental health concern. Previous studies conducted in Nigeria have reported the presence of multidrug-resistant Pseudomonas aeruginosa and AmpC beta-lactamase-producing Enterobacteriaceae in contaminated aquatic environments [3,5,20,21]. Breidenstein et al. [13] noted that Pseudomonas aeruginosa possesses multiple resistance mechanisms which contribute to increasing antimicrobial resistance globally. Wastewater systems may therefore serve as environmental reservoirs for antimicrobial resistance dissemination [34].

The significantly higher contaminant burden observed in Makurdi compared to Gwer West may be attributed to increased urbanisation, population density, healthcare activities, domestic sewage discharge, and poor waste management infrastructure associated with urban environments. Similar urban-rural differences in contaminant occurrence have been reported in previous environmental studies [17,18,48]. Deryal et al. [17] observed significant pharmaceutical contamination in urban aquatic systems, while Nibamureke and Barnhoorn [48] reported the occurrence of pharmaceutical residues in surface waters of South Africa associated with anthropogenic activities.

CONCLUSION

This study demonstrated the occurrence of significant physicochemical, microbial, heavy metal, and emerging contaminant pollution in wastewater systems from Makurdi and Gwer West Local Government Areas of Benue State, Nigeria. Urban wastewater samples from Makurdi consistently recorded higher contaminant concentrations compared to rural wastewater samples from Gwer West, indicating increased anthropogenic influence associated with urbanisation and poor wastewater management practices.

The detection of endocrine-disrupting compounds, pharmaceuticals, pathogenic microorganisms, and heavy metals in wastewater samples poses serious ecological and public health concerns. Elevated concentrations of lead, cadmium, chromium, and microbial contaminants further suggest potential risks to aquatic ecosystems and human populations exposed to contaminated water resources.

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