Water Quality, Sanitation Practices, and Public Health Outcomes in Major Urban Areas of Nigeria (A Comparative Analysis)

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ABSTRACT

With rapid urbanization, major urban centres in developing countries face complex challenges related to water quality, sanitation practices, and public health outcomes. This review paper investigates the relationship between water quality, sanitation practices, and public health outcomes in major urban areas of Lagos, Kano, Ibadan, and Enugu, Nigeria. The study comprehensively analyses water quality indicators (pH, dissolved oxygen, total dissolved solids, lead, coliform bacteria, etc.). It examines sanitation practices, including access to sanitation facilities and waste management. The review synthesizes data from multiple studies conducted between 2022 and 2023. Findings indicate significant pollution levels with many water quality parameters exceeding standards, including WHO and FEPA. Inadequate sanitation facilities and poor waste management practices are prevalent, leading to high incidences of waterborne diseases such as diarrhoea, typhoid fever, and cholera. The study underscores the need for improved water management, enhanced sanitation infrastructure, and comprehensive public health interventions. Recommendations include regular monitoring, public-private partnerships, and policy reforms to address the root causes of waterborne diseases and promote sustainable urban development.

Keywords: Water Quality, Sanitation Practices, Public Health Outcomes, Waterborne Diseases, Environmental Health

INTRODUCTION

In Nigeria, a country experiencing rapid urbanization, major urban centers face complex challenges related to water quality, sanitation practices, and public health outcomes. These cities serve as microcosms of broader issues affecting urban areas in developing nations, where factors such as improper waste disposal, urban sprawl, and population growth strain existing infrastructure and exacerbate environmental hazards [1]. Access to safe drinking water is a fundamental human right for maintaining public health and fostering sustainable development. However, in urban areas with high population density and strained infrastructure, ensuring clean water and proper sanitation becomes even more critical [2]

In populated cities, inadequate water and sanitation infrastructure significantly contribute to public health risks. Residents often lack access to clean water sources, increasing the prevalence of waterborne diseases like dysentery and cholera (3). Similar challenges are observed in other urban areas, where human activities such as mining and waste disposal further degrade water quality (4). One billion people globally lack access to any sanitation facility and practice open defecation, which is associated with numerous adverse health impacts (5).

Water, sanitation, and hygiene (WASH) remain among the foremost issues in developing countries. The scarcity of basic sanitation and personal hygiene facilities in private homes and public places has imposed an inestimable toll on the health of the most vulnerable members of society. Infants and schoolchildren are

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usually exposed to far less than ideal environmental conditions. Proper sanitation practices are crucial in reducing contamination and pathogen exposure from human waste (6).

Despite efforts to improve these conditions, major Nigerian cities continue to experience high incidences of waterborne diseases such as diarrhoea, typhoid fever, dysentery, and cholera. The interplay between water quality, sanitation practices, and public health outcomes remains poorly understood, making it difficult to design effective interventions. The existing literature provides fragmented insights into these issues, often focusing on isolated water quality or sanitation without a comprehensive comparative analysis.

The findings of this study will provide information for comparison with established standards to enhance effective interventions and policies to address public health challenges in these urban areas.

Research Questions

This systematic review intends to answer the following questions. How does water quality vary among major urban cities, and how do these variations compare to standards? What are the common sanitation practices in these cities, and how do they align with guidelines? What public health outcomes are associated with these cities' water quality and sanitation practices? How do these public health outcomes compare among the four cities and with guidelines?

METHODOLOGY

This study employs a comparative analysis approach to examine the interplay between water quality, sanitation practices, and public health outcomes in four major urban areas in Nigeria: Lagos, Kano, Ibadan, and Enugu.

The data for this study were collected through a comprehensive desktop review of the literature. The articles and reports were sourced from several academic and research databases, including JSTOR, Google Scholar, PubMed, Springer Open, Frontiers, Academia, and Research Gate. The search queries used to identify relevant studies included terms such as “water quality in Lagos metropolis,” “water quality in Ibadan metropolis,” “water quality in Kano,” “water quality in Enugu,” “WASH practices in each state,” “waterborne diseases,” “surface water quality,” “groundwater quality,” “physicochemical characteristics” “water quality index” “population density” “sanitation infrastructure” “socio-economic factors” and “water sources”.

Screening and Selection Criteria

The systematic review followed PRISMA guidelines to enhance transparency in data collection and synthesis. The screening process involved:

A total of 150 articles were identified through the search queries. After applying the criteria, 50 articles were included in the review, and 28 were used directly in the results section. The inclusion and exclusion criteria employed include:

Table 1: Inclusion and Exclusion Criteria

Criterion	Inclusion	Exclusion
Geographic Focus	Nigerian urban areas (Lagos, Kano, Ibadan, Enugu)	Rural areas or non-Nigerian cities
Publication Date	2022–2023	Pre-2022 publications
Study Type	Peer-reviewed articles, technical reports	Unverified sources, editorials, or commentaries
Focus Area	Water quality, sanitation, public health	Studies not addressing the research

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		objectives
Data Availability	Studies reporting measurable outcomes	Studies lacking specific data

Description of the Study Areas

This study focuses on four major urban cities in Nigeria: Kano, Lagos, Enugu, and Ibadan. These cities were selected due to their significant population sizes, economic activities, and known challenges with water quality, sanitation practices, and public health outcomes. Each city presents unique characteristics and challenges, making them ideal for a comparative analysis.

Kano: Kano, the capital of Kano State in northern Nigeria, is a major commercial and industrial centre. Kano City is situated at approximately 12.0022°N latitude and 8.591956°E longitude. However, it faces severe sanitation issues, with most residents lacking access to hygienic toilets and untreated faecal waste being discharged into the environment (7). Groundwater is the primary reliable source of fresh water due to inadequate surface water (8). Figure 1 shows Kano with its urban areas

Lagos: Lagos, Nigeria's most populous city and economic hub, experiences significant sanitation and water supply challenges. The city lies at approximately 6.5244°N latitude and 3.3792°E longitude. Rapid population growth has led to a water crisis, with many residents relying on non-public water sources such as boreholes and wells. The city's current water production capacity falls short of demand, exacerbating sanitation issues (9). Figure 2 shows Lagos with its urban areas

Enugu: Enugu, known for its coal mining history, has a growing urban population and struggles with water supply and sanitation infrastructure. The city is approximately 6.4483°N latitude and 7.5137°E longitude. Limited access to public water forces most residents to depend on boreholes, wells, and water vendors. The city's deficient sanitation facilities pose health risks (10). Figure 3 shows Enugu with its urban areas

Ibadan: Ibadan, one of Nigeria's oldest and largest cities, is an important commercial centre. It is around 7.3775°N latitude and 3.9054°E longitude. However, it faces severe sanitation challenges, with poorly managed solid waste, inadequate public utilities, and limited access to public water supply. Major rivers drain the city, but the yield from well sources is low during the dry season (11) (12). Figure 4 shows Ibadan with its urban areas

Criteria for Analysis

The analysis of the collected data was guided by specific criteria designed to provide a comprehensive understanding of the interplay between water quality, sanitation practices, and public health outcomes in the selected urban areas.

- **Water Quality Indicators**: The analysis focused on key water quality indicators, including pH levels, dissolved oxygen, TDS, heavy metals, and coliform counts. These indicators were compared against the standards (WHO and FEPA) to assess the adequacy of water quality in each city.
- **Sanitation Practices**: The evaluation of sanitation practices considered factors such as access to sanitation facilities, effectiveness of waste management practices, prevalence of open defecation, and hygiene practices. The analysis aimed to identify the strengths and weaknesses of the sanitation infrastructure in each urban area.
- **Public Health Outcomes**: The impact of water quality and sanitation practices on public health was assessed by examining the incidence rates of waterborne diseases and respiratory infections. The analysis sought to establish correlations between poor water quality, inadequate sanitation, and adverse health outcomes.

Data from the selected studies were synthesized and presented in comparative tables to facilitate a clear and concise comparison across the different urban areas. The results were then analyzed to identify patterns, trends,

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and significant deviations from standards, providing a basis for discussing the implications and recommendations for improving water quality, sanitation practices, and public health outcomes in these urban areas.

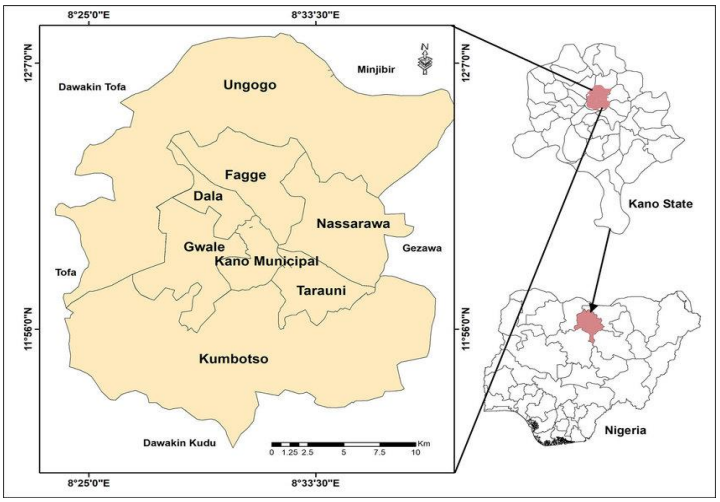

Figure 1: Kano and its urban areas. (*13)*

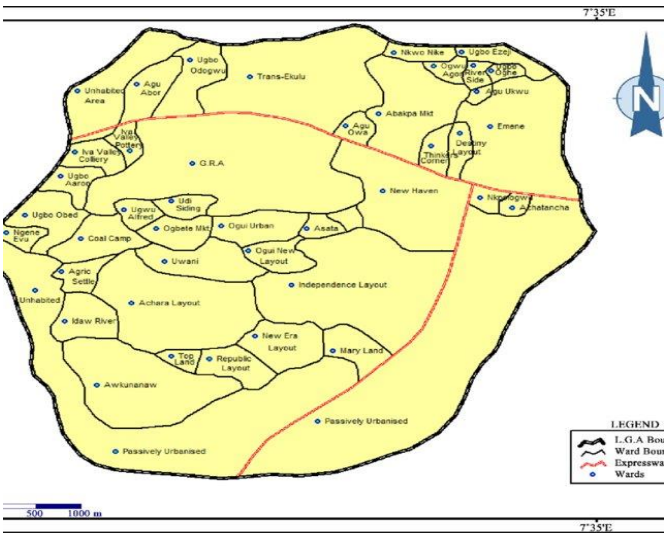

Figure 2: Lagos and its main urban areas. (14)

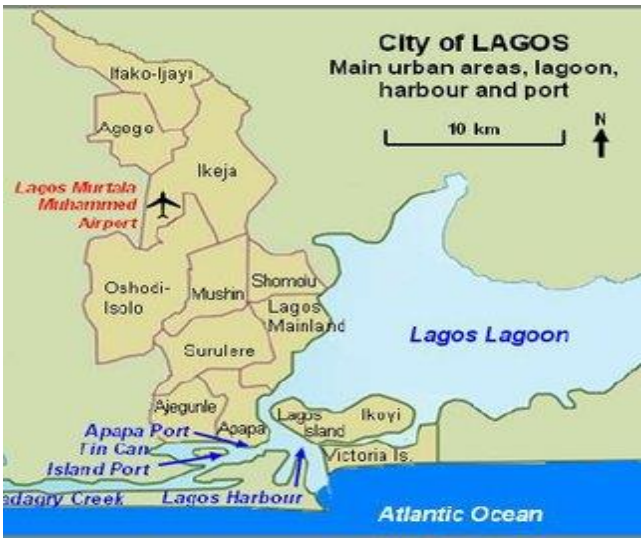

Figure 3: Enugu and its urban areas. (15)

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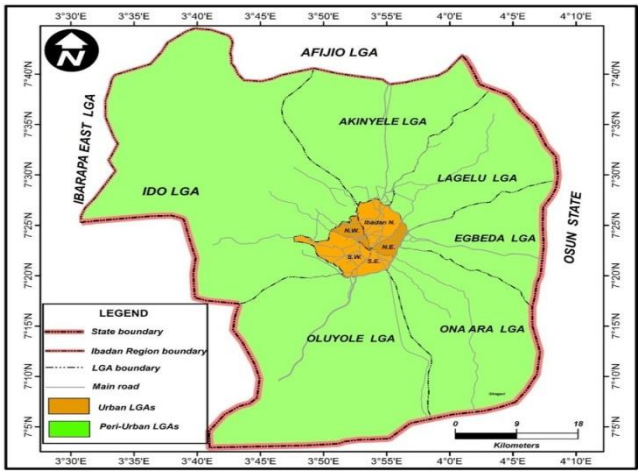

Figure 4: Ibadan and its urban areas. (*16*)

RESULTS AND DISCUSSION

The results of this study are presented in three main sections: water quality analysis, sanitation practices analysis, and public health outcomes analysis. Each section includes tabular data and a narrative discussion of the key findings.

Water Quality Analysis

Water quality is a critical determinant of public health. The analysis focused on key indicators such as pH levels, dissolved oxygen, total dissolved solids (TDS), hardness, alkalinity, heavy metals, and coliform counts. The tables 2 & 3 below summarize the water quality indicators for surface water and groundwater across the four cities. **Table 2** compares the water quality parameters for groundwater for each city. **Table 3** compares water quality parameters for surface water for each city.

Sanitation Practices

Table 4 compares sanitation practices across the four cities, focusing on key indicators such as access to sanitation facilities, waste management practices, awareness and education, hygiene and personal hygiene practices, open defecation, and access to water.

Permissible Standards

Each reviewed study compared their results with different standard limits, including WHO, FEPA, NSDWQ, and NESREA. **Table 5** shows the limits of each agency for each indicator.

Table 2: DO = Dissolved Oxygen, TDS = Total Dissolved Solids, TH = Total Hardness, TA = Total Alkalinity, EC = Electrical Conductivity, C.C = Coliform Count, BH = Borehole Water, WE = Well Water.

Table 1: Groundwater Quality Comparison

State		Lagos				Kano				Ibadan			Enugu			
Criteria	Permissible Limits	Oyebode et al., (2023)	Ferreira et al., (2023)	Eze & Obong, (2023)		Abubakar & Said (2022)	Matazu et al., (2023)	Simon		Rabiu et al., (2022)		Isibor et al., (2023)	Nnaemeka & Okeke, (2024)		Obuka et al., (2023)	Ezike & Okonkwo, (2023)
				BH	WE			Wet	Dry	Wet	Dry		Wet	Dry		
pH	6.5 – 8.5	6.26	6.35	5.84	6.23	6.95	6.1	7.25	7.96	6.74	6.65	7.01	5.2	6.2	6.45	5.05
DO (mg/l)	≤5	5.85							3.65						5.56	
TDS	≤500	79.95	76	205	340		400	410	497.9	506	505	215	111.65	210	200.1	64
TH	≤100	67.95	69	326	542	330.4			88.95			240	66.95	120	70	
TA	≤	-				348.71						234.5	33.7	34.57	12.31	
EC (µs/cm)	≤1000	114.6	139	415	685	1425	398	254.5	820.75	1008	1010	315	162.7		336.6	114.5
C.C (cfu/ml)	1×10^2	-													13.29	
TURBIDITY (NTU)	≤5	Clear		5.45	5.87	74.7	13	5.8	6.4			0.03			0.92	
PHOSPHATE	≤5	0.76	0.77			0.99							29.75	26.73	0.613	
IRON	≤3.0	0.79	1.8	0.38	0.29								1.651	0.81	0.08	0.01
ZINC	≤3.0	0.14	0.13										1.71	1.51	0.63	
NITRATE	≤50	2.47	2.44	0.06	0.06	11.62	0.98	1.38	66.85	80.83	172.5				15.2	
Lead	0.01	0.04	0.04							0.95	0.83		0.001	0	0.004	

These data were collected from 2022 – 2024

Table 3: DO = Dissolved Oxygen, TDS = Total Dissolved Solids, TH = Total Hardness, TA = Total Alkalinity, EC = Electrical Conductivity, C.C = Coliform Count

Table 2: Surface Water Quality Comparison

State		Lagos							Kano			Ibadan				Enugu					
Criteria	Permissible Limits	Okunade et al., (2023)				Lawal et al., (2022)	Ogunbawo (2022)		Alkali et al., (2022)	Abdulsalam et al., (2023)	Hussaini et al., (2023)	Olagbemide & Olayinka, 2017			Fashae (2023)	Okoye et al., (2023)		Ezike & Okonkwo (2023)	Alum et al., (2023)		
		Ologe		Badagry																	
		WET	DRY	WET	Dry		Offin	Bayeiku				SITE A	SITE B	SITE C		WET	DRY		EARLY WET	LATE WET	DRY
pH	6.5 – 8.5	6.31	6.53	6.65	6.51	6.93	7.74	7.45	7.5	5.36	1.86	7	7	7.2	5.7	7.55	7.79	5.55	6.8	6.5	6.8
DO (mg/l)	≤5	4.91	4.81	4.66	4.75	8.38	6.12	5.49	3.83			2.2	2.53	2.77				34.01	3.02	3.21	2.9
TDS	≤500	77.17	80.31	96	87.89	91.82				323.5	5632	321.67	258.33	421.67	582.5	191.35	356	52.5	600	558	507.5
TH	≤100	87.46	87.92	100.33	94.78	45.5	8518					65.23	70.5	69.23	19.65	155	134		172.5	173.5	147.75
TA	≤					41.6						1.23	1	0.73	2.8	30	21.49		53.1	42	61.16
EC (µs/cm)	≤1000	155.82	162.94	192.89	175.18	117.75	336.01	917	622.5	539.5	10240	319.67	601.67	306.67	427.9	144.5	207.1		1288.75	1261.25	1267
C.C (cfu/ml)	1×10^2					110															
TURBIDITY (NTU)	≤5	16.1	17.96	24.85	23.82	6.2			143.5			5.5	2.1	2.13							
PHOSPHATE	≤5					4.95			1.08			2.13	1.47	1.13	0.2	2.31	0.82				
IRON	≤3.0	0.69	0.65	0.52	0.55	8.56				8.17											
ZINC	≤3.0	1.15	1.03	0.5	0.53	0.235				0.019	2.34										
NITRATE	≤50					<0.05			1.97			1.3	1.03	0.87	0.91	9	1.74		49	42	45.5
Lead	0.01	0.26	0.25	0.34	0.39	<0.01					0.569										

[1]These data were collected from 2022 – 2024

Table 4: Sanitation Practices Comparison

State	Lagos		Kano	Ibadan		Enugu	
CRITERIA	**[39]**	**[40]**	**[41]**	**[42]**	**[43]**	**[44]**	**[45]**
Access to Sanitation Facilities	Inadequate	No sanitation facilities	Inadequate	Inadequate	Adequate	Inadequate	Inadequate
Waste Management Practices	Improper waste disposal	Open – Burning	Wastewater flows freely	Waste disposed into river		Open Dumping	
Open Defecation	High	High; both home and schools		Defecation In Bushes			Improper Faeces Disposal
Hygiene Practices	Poor Hygienic Practices			Fair Practices	Poor Hygiene	Fair	Poor Hygiene
Awareness & Education		Fair Knowledge of WASH			Good Knowledge of Waterborne Diseases	Fair Knowledge of Personal Hygiene	

[1]Permissible limits were based on WHO and FEPA guidelines for water quality. Observed seasonal variations are likely due to increased surface runoff during the wet season, which introduces pollutants, and reduced dilution during the dry season

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Access to Water		Limited Water Services		Adequate Borehole and Well			

Each criteria evaluation is solely based on the results from the studies

Data was collected from 2022 – 2024

Table 5: Summary of the Standards for the Water Quality Indicators

Criteria	WHO	FEPA	NSDWQ	NESREA
pH	6.5 - 8.5	6.5 - 8.5	6.5 – 8.5	6.5 – 8.5
DO (mg/l)	≥ 5.0	≥ 5.0	-	4.0 – 6.0
TDS	≤ 1000	≤ 500	≤ 500	-
TH	≤ 500	≤ 150	≤300	≤ 500
TA	-	-	≤ 200	-
EC (µs/cm)	≤ 1400	≤ 1000	≤ 750	-
C.C (cfu/ml)	0	0	≤ 0	1×10^2
TURBIDITY (NTU)	≤ 5.0	≤ 5.0	≤ 0	≤ 10
PHOSPHATE	≤ 5.0	≤ 5.0	≤ 5	≤3.5
IRON	≤ 0.3	≤ 0.3	≤ 0.5	≤ 0.5
ZINC	≤ 3.0	≤ 5.0	≤ 0.3	≤ 0.2
NITRATE	≤ 50	≤ 10	≤ 50	≤ 40
LEAD	≤ 0.01	≤ 0.01	≤ 10	≤ 0.1

Water Quality Indicators in the Cities

pH

pH measures the hydrogen ion concentration in water, indicating its acidity or alkalinity on a scale of 0 to 14, with 7 being neutral. Values below 7 are acidic, and above 7 are alkaline. In Lagos, surface water pH ranges from 6.31 to 6.65, slightly acidic, according to Okunade et al. [28]. Conversely, Ogunbawo [30] reported a higher range of 7.45 to 7.74, and Lawal & Afolabi [29] found a pH of 6.93. Groundwater in Lagos also shows acidity, with Eze & Obong [27] finding values from 5.84 to 6.23, Ferreira et al. [18] reporting 6.35, and Oyebode et al. [17] showing 6.26.

In Ibadan, surface water pH ranges from 5.70 [35] to 7.00 [34], generally within acceptable limits but indicating slight acidity. Groundwater pH ranges from 6.65 - 6.74 [23] to 7.01 [24], indicating a similar pattern of slight acidity. In Enugu, surface water pH values range from 5.55 [27] to 7.79 [36], varying from acidic to slightly alkaline. Groundwater pH ranges from 5.05 [27] to 6.45 [26], showing a similar acidic trend. Kano's surface water pH ranges from 1.86 [33] to 7.50 [31], with a wide variation possibly due to industrial activity

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and seasonal changes. Groundwater pH ranges from 6.10 - 7.96 [21][22], indicating variation from acidic to alkaline conditions.

The slightly acidic to neutral pH in surface waters across Lagos and Ibadan highlights the influence of landfills and dumpsites on groundwater quality. The variation in pH levels in Enugu and Kano is consistent with seasonal studies showing changes in pH during wet and dry seasons.

Dissolved Oxygen (DO):

Dissolved Oxygen is the amount of oxygen dissolved in water, essential for the survival of aquatic organisms. Dissolved Oxygen (DO) is a crucial indicator of water quality, representing the amount of oxygen available for aquatic organisms. Typically, DO levels above 5 mg/L support aquatic life, while lower levels can indicate pollution and poor water quality.

In Lagos, DO levels in surface water range from 4.66 to 4.91 mg/L, according to Okunade et al. [28], which are below the acceptable limit, indicating potential pollution issues. Lawal and Afolabi [29] reported slightly higher values of 8.38 mg/L, suggesting better conditions in some areas. Ogunbawo's [30] findings range from 5.49 to 6.12 mg/L. Eze & Obong [27] recorded DO levels ranging from 5.84 to 6.23 mg/L, which are adequate and suggest good groundwater quality. Ferreira et al. [18] reported a DO level of 6.35 mg/L, also within acceptable standards.

In Ibadan, Fashae [35] reported DO levels between 2.20 and 2.77 mg/L, significantly below the acceptable standard, indicating poor water quality and potential risks to aquatic life. While groundwater DO levels weren't included, this indicates that future research is needed to address this gap.

In Enugu, Okoye et al. [36] found DO levels ranging from 2.90 to 3.21 mg/L below acceptable limits, indicating potential organic pollution. Ezike and Okonkwo [27] reported an unusually high DO level of 34.01 mg/L, which may indicate measurement anomalies or specific local conditions; such elevated levels are atypical and warrant further investigation. Groundwater DO levels also show an optimal range supportive of aquatic life, with 5.56 mg/L recorded by Obuka et al. [26].

In Kano, Alkali et al. [31] reported a DO level of 3.83 mg/L, which is below the standard, suggesting polluted conditions potentially due to industrial or agricultural runoff. Groundwater DO levels in Kano vary from 3.56 to 3.65 mg/L [22], indicating poor water quality and possible contamination. The variation in DO levels across these cities reflects the influence of pollution, land use, and seasonal changes, suggesting that improved wastewater treatment and pollution control could enhance water quality.

Total Dissolved Solids (TDS):

TDS is the total concentration of dissolved substances in water, including minerals, salts, and organic matter. High TDS can affect water taste because of scaling in pipes and harms aquatic life; however, low TDS is generally not harmful but can affect water taste.

In Lagos, groundwater TDS levels recorded by Eze & Obong [27] range between 205 to 304 mg/L, indicating good water quality, while Ferreira et al. [18] recorded 76 mg/L showing excellent quality, and Oyebode et al. [17] recorded 79.95 mg/L, showing excellent quality as well. However, TDS levels in surface water range from 77.17 to 96 mg/L, indicating excellent water quality as demonstrated by Okunade et al. [28], while Lawal & Afolabi [29] recorded 91.82 mg/L, which is also within excellent standards.

In Ibadan, groundwater TDS levels reported by Rabiu et al. [23] range between 505 and 506 mg/L, indicating acceptable but approaching upper limits. Isibor et al. [24] reported 215 mg/L, reflecting good quality. Surface water TDS levels varied from 65.23 to 70.50 mg/L, indicating excellent quality, as shown by Olagbemide [34], and 19.65 mg/L as shown by Fashae [35].

In Enugu, surface water levels range from 191.35 to 356 mg/L, as shown by Okoye et al. [36], while Ezike and Okonkwo [27] recorded 52.5 mg/L, showing excellent quality. Alum et al. [38] recorded 507.5 to 600 mg/L at

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the upper acceptable limit. For groundwater levels, Ezike & Okonkwo [27] recorded 64 mg/L, while Nnaemeka & Okeke [25] recorded 111.65 to 210 mg/L, and Obuka et al. [26] recorded 200.1 mg/L reflecting good quality.

In Kano, groundwater TDS levels range from 400 to 410 mg/L [21], within acceptable limits, and 439.1 to 497.9 mg/L, as Simon [22] recorded, which are adequate but higher than desirable. Surface water TDS levels in Kano varied, recording 323.5 mg/L shown by Abdulsalam [32], and a high TDS of 563.2 mg/L by Hussaini et al. [33], which is near the upper limit but still acceptable. High TDS levels in groundwater in Ibadan and Kano highlight the seasonal and pollution impacts on groundwater quality. Natural and anthropogenic factors influence the variability in TDS levels across different cities

Total Hardness:

Total Hardness is the concentration of calcium and magnesium ions in water, affecting its suitability for domestic and industrial use. High Hardness can cause scaling in pipes and appliances and affect water taste; however, generally, low hardness is not harmful but can affect water taste.

In Lagos, Groundwater hardness ranges from 67.95 to 69 mg/L [17][18], indicating moderate hardness. Eze & Obong [27] reported significantly higher groundwater hardness values ranging from 326 to 542 mg/L, indicating very hard water. Surface water hardness ranges from 87.46 to 100.33 mg/L [28], with Lawal & Afolabi [29] reporting lower values at 45.5 mg/L. Ogunbawo [30] reported an unusually high average value of 8518 mg/L, which seems anomalous.

In Ibadan, Groundwater hardness was recorded at 240 mg/L by Isibor et al. [24], indicating moderately hard water. Surface water hardness ranges from 65.23 to 70.50 mg/L [34], with Fashae [35] reporting a significantly lower average of 19.65 mg/L.

Enugu's groundwater total hardness ranges from 66.95 to 120 mg/L [25], indicating moderately hard water, while Obuka et al. [26] recorded 70.0 mg/L. Surface water hardness ranges from 134 to 155 mg/L [36], with Alum et al. [38] reporting values between 147.75 and 173.5 mg/L, indicating hard water.

In Kano, Groundwater hardness ranges from 330.40 mg/L [22] to 88.95-153.3 mg/L [20], indicating hard water. The high hardness values in groundwater in Lagos and Kano indicate the influence of geological formations and anthropogenic activities. These findings suggest the need for water-softening treatments in areas with high hardness levels.

Electrical Conductivity (EC):

Electrical Conductivity measures the water's ability to conduct electric current, indicating the concentration of dissolved ions. An increase in EC indicates high levels of dissolved ions, potentially harmful to aquatic life and unsuitable for drinking. In contrast, a low EC, generally not harmful, indicates low mineral content.

In Lagos, Groundwater EC levels range from 415 to 685 µs/cm [17][18], within acceptable limits. Surface water EC levels range from 155.82 to 192.89 µs/cm [28], with Lawal & Afolabi [29] reporting 117.75 µs/cm and Ogunbawo [30] reporting higher values between 336.01 to 917.00 µs/cm.

In Ibadan, the EC levels in groundwater range from 1008 to 1010 µs/cm [22], while Isibor et al. recorded 315 µs/cm [24]. Surface water EC levels range from 306.67 to 601.67 µs/cm [34], with Fashae [35] reporting 427.9 µs/cm.

In Enugu, Ezike & Okonkwo [27], Nnaemeka & Okeke [25], and Obuka et al. [26] recorded 114.5 µs/cm, 162.7 µs/cm, and 336.6 µs/cm, respectively. The EC levels in surface water range from 144.5 to 207.10 µs/cm [36] and 1261.25 to 1288.75 µs/cm [38].

In Kano, the EC levels in groundwater range from 254.5 µs/cm to 398 µs/cm [21], while Simon [22] reported 504.2 to 820.7 µs/cm, which was within acceptable limits. On the contrary, Abubakar & Said [20] recorded

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1425 µs/cm. The highest level of EC was reported by Hussaini [33] at 10240 µs/cm, while 539.5 µs/cm was reported by Abdulsalam et al. [32], and 622.5 µs/cm was recorded by Alkali et al. [31]. The high EC values in groundwater in Ibadan and Kano highlight the influence of seasonal variations and anthropogenic activities on water quality. These findings emphasize the need for regular monitoring and management of water resources.

Coliform Count:

Coliform Count is a measure of the presence of coliform bacteria, indicating potential contamination by pathogens. A high Coliform Count indicates potential contamination by harmful pathogens, posing health risks, while a low Coliform Count indicates low contamination and is generally safe for drinking.

In Lagos, surface water coliform levels were reported at an average of 110 cfu/ml by Lawal & Afolabi [29], indicating potential contamination. In Ibadan, no data were reported, indicating a need for further research. In Enugu, groundwater coliform counts were high, with an average of 13.29 cfu/ml recorded, suggesting contamination [26]. No data were reported in Kano, indicating a need for further research. High coliform counts in Lagos and Enugu suggest contamination from domestic and industrial sources. These findings highlight the need for improved sanitation and water treatment practices.

Turbidity:

Turbidity measures the cloudiness or haziness of water caused by suspended particles. High Turbidity can interfere with disinfection, indicate contamination, and affect water taste; however, Low Turbidity generally indicates clean water.

In Lagos, Groundwater turbidity was generally low, with Oyebode et al. [17] recording clear water and Eze & Obong [27] reporting slightly higher levels of 5.45 to 5.87 NTU. Surface water turbidity ranged from 16.10 to 24.85 NTU [28], with Lawal & Afolabi [29] reporting 6.20 NTU.

In Ibadan, the turbidity level in groundwater recorded by Isibor et al. [24] was rather low, with an average value of 0.03. The turbidity level in surface water ranges from 2.10 to 5.50 NTU [34][35].

In Enugu, the turbidity level in groundwater recorded by Obuka et al. [26] was low, similar to the findings of Isibor et al. [24], with an average value of 0.92 NTU.

In Kano, Groundwater turbidity ranged from 5.8 to 13 NTU [22], with Abubakar & Said [20] reporting 74.7 NTU. Surface water turbidity was very high, with Alkali et al. [31] recording 143.5 NTU. The high turbidity levels in surface water in Lagos and Kano indicate the impact of pollution from activities along riverbanks and industrial effluents. These findings emphasize the need for improved water treatment and pollution control measures.

Phosphate:

Phosphate is a nutrient that can cause eutrophication in water bodies if present in high concentrations. If high, this can lead to algal blooms, deplete oxygen, and harm aquatic life. Meanwhile, low phosphate is generally not harmful but can limit aquatic plant growth.

In Lagos, Oyebode et al. [17] reported phosphate levels in groundwater ranging from 0.76 to 0.77 mg/L, slightly above the recommended limits. While the surface water level of phosphate was recorded at an average level of 4.95 mg/L [29].

In Ibadan, Groundwater phosphate levels were not recorded, which highlights a gap in the data. In surface water, Olagbemide [34] reported phosphate levels ranging from 1.13 to 2.13 mg/L, and Fashae [35] recorded 1.13 mg/L, all of which are within the permissible limits but suggest a potential for eutrophication.

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In Enugu, phosphate levels in groundwater were significantly high, ranging from 26.73 to 29.75 mg/L [25], while Obuka et al. [26] recorded 0.613 mg/L. The phosphate level in surface water ranges from 0.82 to 2.31 mg/L, according to Okoye et al. [36], indicating variable conditions.

In Kano, Abubakar & Said [20] recorded phosphate levels of 0.99 mg/L in groundwater, within the acceptable range. In surface water, Alkali et al. [31] found levels at 1.08 mg/L, suggesting a need for monitoring to prevent eutrophication. The phosphate levels in groundwater in Enugu indicate the influence of land use and seasonal patterns on water quality. These findings suggest the need for regular monitoring and managing nutrient levels in water bodies.

Iron

Iron is a naturally occurring element in water, but high concentrations can affect water taste, stain laundry, and fixtures. High levels of Iron can cause staining, affect water taste, and pose health risks at very high levels. At the same time, low iron is generally not harmful.

In Lagos, Groundwater iron levels were acceptable, with Oyebode et al. [17] recording 0.79 mg/L, slightly above the WHO limit, and Ferreira et al. [18] reporting 1.80 mg/L, which is significantly high. Surface water iron levels ranged from 0.52 to 0.69 mg/L as per Okunade et al. [28], but Lawal and Afolabi [29] found an average of 8.56 mg/L, indicating a serious iron contamination issue. In Ibadan, no data were provided for groundwater and surface water iron levels, indicating a gap in the study. In Enugu, Groundwater iron levels ranged from 0.81 to 1.651 mg/L, according to Nnaemeka & Okeke [25], exceeding the recommended limits, while Obuka et al. [26] and Ezike & Okonkwo [27] recorded 0.08 mg/L and 0.01 mg/L, respectively. In Kano, Iron levels were not reported for groundwater. However, Surface water iron levels were high, with Abdulsalam et al. [32] recording an average of 8.17 mg/L, indicating significant contamination. The high iron levels in surface waters in Lagos and Kano are concerning, particularly because they exceed the WHO standards. This suggests the influence of landfills, dumpsites, and other anthropogenic activities, as high iron levels are often associated with industrial activities and poorly managed landfills, as noted by Oyebode et al. (2023) and Abdulsalam et al. (2023). However, while specific studies that links the contamination to landfills in Lagos and Kano exist, there is a need for further research to establish the level of causality.

Zinc

Zinc is an essential nutrient, but high concentrations can affect water taste and pose health risks; if present highly, it can cause a metallic taste and pose health risks at very high levels.

In Lagos, Groundwater zinc levels were low, ranging from 0.13 to 0.14 mg/L, indicating minimal contamination. Surface water levels ranged from 0.50 to 1.15 mg/L according to Okunade et al. [28], while Lawal & Afolabi [29] recorded 0.235 mg/L. These are within the acceptable limits. In Ibadan, no data were provided for both groundwater and surface water zinc levels, highlighting a study gap. In Enugu, Groundwater zinc levels ranged from 1.51 to 1.71 mg/L [25], while 0.63 mg/L was recorded by Obuka et al. [26], which is within acceptable limits. In Kano, Surface water levels ranged from 0.019 to 2.34 mg/L, as reported by Abdulsalam et al. [32] and Hussaini et al. [33], within acceptable limits. Zinc levels across all cities are generally within the acceptable range, suggesting that no significant contamination from industrial or domestic sources exists.

Nitrate

Nitrate is a nutrient that can cause health issues, particularly for infants, if present in high concentrations. This can cause methemoglobinemia (blue baby syndrome) in infants and affect aquatic life if high.

In Lagos, Groundwater nitrate levels ranged from 0.06 mg/L as per Eze & Obong [27] to 2.47 mg/L, reported by Oyebode et al. [17], which are well within the acceptable limits. Surface water nitrate levels were recorded below 0.05 mg/L by Lawal & Afolabi [29], indicating minimal contamination.

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In Ibadan, Groundwater nitrate levels were much higher, ranging from 80.83 to 172.4 mg/L, according to Rabiu et al. [23], exceeding WHO limits and indicating potential contamination. Surface water levels ranged from 0.87 to 1.30 mg/L, as reported by Olagbemide [34] and Fashae [35], which are within acceptable limits. In Enugu, groundwater nitrate levels were recorded at 15.2 mg/L by Obuka et al. [26], within acceptable limits. In contrast, Surface water nitrate levels ranged from 1.74 to 49.0 mg/L, according to Okoye et al. [36] and Alum et al. [38], with some values approaching or exceeding WHO limits.

In Kano, Groundwater nitrate levels ranged from 46.25 to 66.85 mg/L, according to Simon [22], with some values exceeding WHO limits. Surface water levels were generally low, with Alkali et al. [31] recording 1.97 mg/L. High nitrate levels in Ibadan and Kano's groundwater pose significant health risks and suggest contamination from agricultural runoff or improper waste disposal.

Lead

Lead is a toxic metal that can cause various health problems, particularly in children. High levels can cause neurological damage, developmental delays, and other health issues. Lead in surface water and groundwater in Lagos and Ibadan is above the standards.

In Lagos, Groundwater lead levels were found to be high, with both Oyebode et al. [17] and Ferreira et al. [18] recording 0.04 mg/L, which exceeds the WHO guideline. Surface water lead levels ranged from 0.25 to 0.39 mg/L, as reported by Okunade et al. [28], significantly above the acceptable limits, indicating serious contamination risks. Lawal & Afolabi [29] recorded <0.01 mg/L, within safe limits.

In Ibadan, Rabiu et al. [23] reported high lead levels in groundwater, ranging from 0.83 to 0.95 mg/L, well above the recommended limits, indicating potential health risks. However, no data was provided for the lead levels in surface water, indicating a gap. In Enugu, Groundwater lead levels were recorded at 0.001 to 0 mg/L by Nnaemeka & Okeke [25], with an average value of 0.004 mg/L recorded by Obuka et al. [26], which is within safe limits.

In Kano, Surface water lead levels were recorded at 0.569 mg/L by Hussaini et al. [33], which is significantly above the acceptable limits, indicating a high risk of contamination. However, no data was provided for the lead levels in groundwater, indicating a gap. High lead levels in surface water in Lagos, Kano, and groundwater in Ibadan are alarming, as they exceed WHO safety standards and pose significant public health risks.

Sanitation Practices in the Cities

Access to Sanitation Facilities

Sanitation facilities refer to toilets, latrines, and other systems used to dispose of human waste. High access to sanitation facilities reduces the incidence of waterborne diseases, improves hygiene, and enhances quality of life. Due to data availability, different authors were referenced for each variable. Inadequate access to sanitation facilities leads to practices like open defecation, increasing disease risks and environmental contamination. In Lagos, Wada et al. [40] showed that Public schools provided no sanitation service, and 40% had no toilet facilities. Private schools had limited sanitation services. Sanitation practices vary significantly across cities in Nigeria, reflecting disparities in access and maintenance. In Enugu, sanitation facilities are generally accessible, with 95% of schools equipped with improved toilets, such as pit latrines, flush toilets, and pour-flush toilets [44]. Conversely, in Ibadan, public sanitation infrastructure is poorly maintained, particularly in motor parks, leading to widespread user dissatisfaction [43]. These differences underscore the varying levels of sanitation services across urban areas. The high population and lack of central sewerage led to indiscriminate wastewater discharge in Kano, according to the findings of Mshelia [41].

The lack of adequate sanitation facilities in Lagos and Kano aligns with the findings of Wada et al. [40] and Mshelia [41], indicating significant disparities in access to sanitation. In Ibadan, the poor sanitation facilities in motor parks, as noted by Adedayo et al. [43], highlight the need for improved infrastructure. Enugu shows

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better access to sanitation facilities in schools, as per Nnaji [44], but still faces challenges in maintaining hygiene standards.

Waste Management Practices

Waste management practices refer to the methods used to collect, treat, and dispose of waste. Good Practices help minimize environmental pollution, reduce disease vectors, and promote public health, while Poor Practices lead to open dumping, increased disease risk, and environmental degradation.

The prevalence of open burning and poor waste management practices in Lagos, as noted by Wada et al. [40], reflects the significant gaps in waste management infrastructure. The indiscriminate wastewater discharge in Kano, highlighted by Mshelia [41], underscores the need for centralized wastewater treatment facilities. In Ibadan, the poor sanitation in motor parks, as documented by Adedayo et al. [43], indicates the necessity for regular maintenance and improved waste management practices. Enugu shows a mix of self-help water supply sources and varying waste management practices, according to Nnaji's findings [44].

Hygiene Practices

Hygiene practices refer to behaviours that promote cleanliness and prevent the spread of diseases, such as handwashing and safe food handling. Good Practices reduce the incidence of infectious diseases, promote overall health, and improve quality of life. At the same time, poor practices increase the risk of infectious diseases, lead to poor health outcomes, and reduce quality of life.

The low levels of handwashing and poor hygiene practices in Lagos, as observed by Wada et al. [40], highlight significant gaps in hygiene education and infrastructure. The adverse health outcomes in Kano, linked to poor drainage and wastewater management by Mshelia [41], indicate the need for improved hygiene practices. In Ibadan, the high prevalence of diarrhoea among children and poor handwashing practices, as noted by Aleru et al. [42], highlights the need for better hygiene education. Enugu's negative hygiene practices, highlighted by Nnaji [44] and Nweke and Ani [45], point to the need for comprehensive hygiene interventions.

Public Health Outcomes

Incidence of Waterborne Diseases

Waterborne diseases are illnesses caused by microorganisms in contaminated water, leading to diarrhoea, cholera, typhoid fever, and dysentery. High Incidence indicates poor water quality, inadequate sanitation, and poor hygiene practices, leading to increased morbidity and mortality. Aminu & Udeze [39] reported a high incidence of diarrhoea (71.8%), typhoid fever (67.5%), dysentery (45.3%), and cholera (32.5%) in Lagos. Msheila [41] also reported that wastewater affects residents' health, causing various diseases in Kano. Meanwhile, Aleru et al. [42] revealed a high prevalence of diarrhoea (48.5%) among children in Ibadan, and Nnaji [44] found a significant correlation between poor hygiene practices and waterborne diseases in schools. The high incidence of waterborne diseases in Lagos aligns with the findings of Aminu & Udeze [39], who noted that poor water quality, inadequate sanitation, and poor hygiene practices contribute to the prevalence of these diseases. In Kano, the impact of wastewater on health, as observed by Msheila [41], underscores the need for proper wastewater management. In Ibadan, the high prevalence of diarrhoea among children, as noted by Aleru et al. [42], highlights the need for improved hygiene practices. Enugu shows a significant correlation between poor hygiene practices and waterborne diseases, according to Nnaji [44].

Treatment Practice

Treatment practices refer to the methods individuals use to treat waterborne diseases, including seeking medical care, using traditional remedies, or self-medication. Poor Practices lead to ineffective treatment, increased morbidity, and potential complications. In Aminu & Udeze's [39] study, most respondents seek treatment at chemists or drug vendors in Lagos. The reliance on chemists and drug vendors for treatment in Lagos, as observed by Aminu & Udeze [39], reflects a gap in access to proper healthcare services. In Kano, the lack of proper wastewater management, as highlighted by Mshelia [41], poses challenges for effective

treatment. In Ibadan, the poor sanitation conditions in motor parks, as noted by Adedayo et al. [43], contribute to the spread of diseases and treatment difficulties. As Nweke & Ani [45] documented, Enugu's negative hygiene practices affect treatment outcomes and highlight the need for better hygiene education.

Environmental Impact

Environmental impact refers to the effects of poor sanitation and water management practices on the environment, including pollution and habitat degradation. Wada et al. [40] revealed that open burning and poor waste management contribute to environmental pollution. Also, indiscriminate wastewater discharge affects land use and domestic activities [41]. The environmental pollution in Lagos due to open burning, as observed by Wada et al. [40], calls for improved waste management practices. In Kano, the indiscriminate wastewater discharge, as noted by Msheila [41], affects land use and domestic activities, underscoring the need for centralized wastewater management. In Ibadan, the poor sanitation conditions in motor parks, as highlighted by Adedayo et al. [43], contribute to environmental degradation. Enugu's mixed waste management practices, documented by Nnaji [44], indicate a need for better infrastructure.

Incidence of Related Diseases

These are illnesses indirectly associated with water quality and sanitation, such as malaria and respiratory infections. A high incidence of such illnesses indicates poor environmental conditions and inadequate sanitation, increasing the disease burden. High disease incidence is evident in Lagos, where 71.8% of respondents reported diarrhea and 67.5% typhoid fever (39). Similar patterns are observed in Kano, with 92.5% of respondents linking wastewater exposure to health issues (41). These findings highlight the need for comprehensive public health interventions to address the root causes of these diseases and improve overall health outcomes in the studied urban areas.

CONCLUSION AND RECOMMENDATION

This study highlights significant disparities in water quality, sanitation practices, and public health outcomes across Lagos, Kano, Ibadan, and Enugu. The findings underscore critical issues, including that many water quality indicators, such as pH, dissolved oxygen, total dissolved solids, and lead, exceed WHO, FEPA, NSDWQ, and NESREA standards, indicating significant pollution. Inadequate sanitation facilities and poor waste management are prevalent, particularly in Lagos' public schools and Ibadan's motor parks, leading to poor hygiene and high disease incidence. Moreover, high incidences of waterborne diseases like diarrhoea, typhoid fever, and cholera are linked to poor water quality and sanitation practices, highlighting gaps in healthcare access and environmental management. It is crucial to improve water management by monitoring the quality of water to address contamination issues. There should also be substantial investment in sanitation infrastructure. Developing centralized wastewater treatment plants in cities like Kano will also help manage indiscriminate wastewater discharge and protect the environment from further contamination. Public health interventions like implementing hygiene education programs and improving access to healthcare services are also necessary to address the root causes of waterborne diseases. Most importantly, regulatory frameworks to enforce water quality and sanitation standards are vital. These actions will improve public health outcomes and a more sustainable future for the country's urban populations. While this study focuses on Nigerian urban areas, the findings highlight challenges such as inadequate sanitation, water pollution, and public health risks that are common across rapidly urbanizing cities in Africa. we believe future research could validate these findings in other African cities with similar socio-economic and environmental contexts, enhancing external validity

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