

Physicochemical Quality and Heavy-Metal Concentrations of Water Used in Selected Maternity Centres in Rivers State, Nigeria

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ABSTRACT

Water used in maternity centres may contribute to environmental exposure through bathing, hand washing, cleaning and handling of reusable materials. This study assessed the physicochemical quality, including heavy-metal concentrations, of water used in selected maternity centres in Rivers State, Nigeria. Water samples were collected monthly for twelve (12) months from six maternity centres, comprising two centres in each of the Rivers East/Central, Rivers South East and Rivers West senatorial districts of Rivers State. Physicochemical parameters, heavy metals, seasonal and quarterly patterns, t-test comparisons and Pearson correlations were evaluated. Seasonal mean pH increased from 5.082 in the dry season to 5.780 in the wet season, while dissolved oxygen decreased from 1.857 to 1.306 mg/L. Electrical conductivity had similar seasonal means, 93.084 and 93.236 microS/cm, but a wider wet-season range. Nitrate increased from 0.424 to 0.442 mg/L, phosphate from 0.0049 to 0.0056 mg/L and total organic carbon from 0.052% to 0.054%. Out of 44 physicochemical ANOVA comparisons, 42 were significant at $p < 0.05$. Cadmium, chromium, arsenic and mercury were reported at 0.001 mg/L in the seasonal summaries, while iron and lead showed variation. Iron decreased from a dry-season mean of 0.0261 mg/L to 0.0253 mg/L in the wet season, and lead decreased from 0.0042 to 0.0034 mg/L. The highest monthly senatorial-district mean iron concentration occurred in Rivers South East in April (0.0835 mg/L), while the highest corresponding lead concentration occurred there in February (0.0155 mg/L), exceeding the WHO provisional guideline value of 0.01 mg/L. Heavy-metal ANOVA results were significant in 12 of 14 comparisons. Quarterly summaries showed that pH and nitrate were highest in Q3, electrical conductivity and total organic carbon in Q2, dissolved oxygen in Q1, and iron and lead in Q1. Significant t-test results were observed for iron, electrical conductivity and pH. Pearson correlation showed moderate positive relationships between electrical conductivity and total organic carbon ($r = 0.554, p < 0.001$), iron and lead ($r = 0.533, p < 0.001$), and dissolved oxygen and iron ($r = 0.509, p < 0.001$), while dissolved oxygen and electrical conductivity were negatively correlated ($r = -0.398, p < 0.001$). Rivers East/Central had the most favourable maximum monthly district-mean lead concentration (0.0070 mg/L), below the WHO benchmark, whereas Rivers West (0.0125 mg/L) and Rivers South East (0.0155 mg/L) exceeded it, with the greatest departure in Rivers South East. The water therefore did not consistently meet the lead benchmark, despite seasonal means below that value. Acidic water and episodic lead elevation support facility-specific monitoring and investigation of water supplies and plumbing; chemical results alone do not establish suitability for all maternity-care uses.

Keywords: Maternity Centres, Water Quality, Heavy Metals, Arsenic, Mercury, Physicochemical Parameters.

Introduction

Safe water is a basic requirement for maternity care because water is used for hand washing, bathing, cleaning of delivery areas, washing of materials and other activities that bring it into contact with mothers, newborns, attendants and delivery equipment. In healthcare facilities, water safety cannot be judged only by availability. Water, sanitation and hygiene (WASH), waste management and environmental cleaning are among the minimum environmental requirements for safe healthcare delivery (World Health Organization [WHO] and United Nations Children's Fund [UNICEF], 2023).

The 2024 JMP update further emphasizes that quality, reliability and management of water services are important in healthcare facilities (UNICEF and WHO, 2024). Evidence on the Water and Sanitation for Health Facility Improvement Tool (WASH FIT) also shows that facility WASH improvement requires practical monitoring rather than one-time assessment (Lineberger et al., 2025; WHO and UNICEF, 2025).

Where maternity centres depend on boreholes, stored water or poorly protected sources, water may contribute to environmental exposure even when it appears clear.

This is relevant to maternal safety because poor environmental hygiene and weak infection-prevention systems can increase exposure around childbirth (WHO, 2016; Collins, 2008; Bonet et al., 2017; Abubakar et al., 2022). It is also relevant to newborn safety because Nigerian and international evidence continues to identify neonatal sepsis and resistant Gram-negative infections as important concerns in low-resource settings (Medugu et al., 2018; Onubogu et al., 2024; Simonsen et al., 2014; Wen et al., 2021).

Physicochemical characteristics provide useful information on the condition of water used in care settings. Parameters such as pH, electrical conductivity, nitrate, phosphate, dissolved oxygen and total organic carbon help to describe acidity, ionic content, nutrient input, organic load and general water condition. These parameters are relevant because they may influence bacterial survival, corrosion, metal mobility and the suitability of water for repeated domestic or healthcare-related use. Bacteriological and physicochemical assessment have been used together in evaluating Nigerian borehole water, showing that water quality is better interpreted through combined indicators than through a single measurement (Adogo et al., 2016). Nigerian WASH evidence also shows that water and sanitation weaknesses remain part of the wider service environment (Federal Ministry of Water Resources, National Bureau of Statistics, World Bank and UNICEF, 2022). Heavy-metal contamination adds another dimension to water-quality assessment. Cadmium, chromium, iron, arsenic, lead and mercury may enter water through geological sources, corrosion, industrial activity, waste disposal, runoff or local environmental contamination. In maternity-centre environments, such metals are relevant because water may be repeatedly used for washing, bathing, cleaning and handling of reusable materials.

The Rivers State environment makes water-quality assessment particularly relevant. The Niger Delta contains dense urban settlements, industrial activity, petroleum-related land use, heavy rainfall periods and drainage challenges. Previous work from the Port Harcourt area has reported acidic water conditions and variable metal concentrations in surface and groundwater sources (Kumpel et al., 2017; Offodile et al., 2023). Seasonal change may further affect water quality through rainfall, runoff, flooding, groundwater recharge, storage duration and dry-season water scarcity. A single sampling period may miss relevant variation in physicochemical and heavy-metal results. Maternity-centre water should be assessed in relation to actual care activities.

Water used for bathing mothers or newborns, washing hands, cleaning delivery rooms and handling reusable materials may create repeated contact with mothers, newborns, attendants, surfaces and equipment. Traditional birth homes and maternity units may also face WASH and infection-prevention limitations that affect how water is stored, handled and used (Arowosegbe et al., 2021; Arowosegbe et al., 2023; Trivedi et al., 2020; Kalpana et al., 2022). These challenges may be more complex where traditional birth-attendant care remains part of maternal service delivery (Lane and Garrod, 2016). This study investigated physicochemical parameters and heavy-metal concentrations in water used in selected maternity centres in Rivers State, Nigeria, with attention to seasonal and quarterly variation and statistical relationships among selected water-quality parameters.

Material and Methods

Study setting

The investigation was conducted in Rivers State, Nigeria, across six maternity centres distributed within the three senatorial districts. Rivers East/Central was represented by Rumukwurusi Model Primary Health Centre and a Traditional Birth Attendant home in Rumukwurusi. Rivers South East was represented by Oyigbo Model Primary Health Centre and a Traditional Birth Attendant home in Oyigbo. Rivers West was represented by Saint Peter's Clinic, Bonny, and a Traditional Birth Attendant home in Bonny.

Study design, sampling locations and water-sample collection

A cross-sectional observational design with repeated monthly sampling was used. Water samples were collected monthly for twelve months from the selected maternity centres. The locations were grouped by senatorial district and facility type so that water-quality results could be interpreted across formal maternity facilities and Traditional Birth Attendant (TBA-linked) settings. Borehole water use was reported at all six maternity centres, while monopump use was also reported at the Oyigbo TBA facility. Samples were aseptically collected from water available for maternity-care activities within each facility using sterile bottles. The bottles were labelled according to location and sampling period, placed in a cooler with ice packs and transported to the laboratory for analysis.

Table 1: Sampled maternity centres and water-sample grouping

District	Sampled maternity centre	Facility type	Water-sample grouping
Rivers East/Central	Rumukwurusi Model Primary Health Centre	Formal facility	RE formal facility
Rivers East/Central	Rumukwurusi Traditional Birth Attendant home	TBA facility	RE TBA facility
Rivers South East	Oyigbo Model Primary Health Centre	Formal facility	RSE formal facility
Rivers South East	Oyigbo Traditional Birth Attendant home	TBA facility	RSE TBA facility
Rivers West	Saint Peter's Clinic, Bonny	Formal facility	RW formal facility
Rivers West	Bonny Traditional Birth Attendant home	TBA facility	RW TBA facility

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Physicochemical analysis

Physicochemical water-quality analysis covered pH, electrical conductivity, nitrate, phosphate, dissolved oxygen and total organic carbon. These parameters were selected to describe acidity, ionic content, nutrient input, oxygen condition and organic load in water used within the maternity-care environment.

The pH of each water sample was measured on arrival at the laboratory using a pH meter calibrated with standard buffer solutions of pH 4, 7 and 10. The electrode was rinsed with distilled water between measurements.

Electrical conductivity was measured using a conductivity cell checked against a potassium chloride standard with a nominal conductivity of 1413 microS/cm.

Dissolved oxygen was determined by immersing the probe of a DO meter in the water sample and recording the initial oxygen concentration in mg/L (APHA, 2005).

Nitrate was determined by the phenol disulphonic acid colourimetric procedure. A 50 ml aliquot of the water sample was evaporated to dryness on a water bath, and the residue was dissolved in 2 ml of phenol disulphonic acid. Ammonium hydroxide and distilled water were added to produce an alkaline solution.

The solution was filtered into a Nessler tube and made up to 50 ml with distilled water. Absorbance was measured at 410 nm, and nitrate concentration was determined from a standard calibration curve (APHA, 2005).

Phosphate was determined by the ammonium molybdate-stannous chloride colourimetric method. A 2 ml aliquot of the water sample was transferred into a 25 ml volumetric flask, followed by one drop of phenolphthalein indicator, 2 ml of ammonium molybdate and 1 ml of freshly diluted stannous chloride solution.

The mixture was diluted to 25 ml with distilled water and mixed. After 5-6 minutes of colour development, absorbance was measured at 660 nm using an OPTIMA SP 300 spectrophotometer (APHA, 1998).

Total organic carbon was determined by high-temperature combustion following Standard Methods 5310 B.

An aliquot of the homogenized sample was introduced into a heated reaction chamber, where carbon was converted to carbon dioxide and measured using a non-dispersive infrared detector.

Inorganic carbon was determined separately and subtracted from total carbon to obtain total organic carbon (APHA, 2005).

Heavy-metal analysis

The water samples were analyzed for cadmium, chromium, iron, arsenic, lead and mercury. Lead and iron were determined by atomic absorption spectrophotometry at wavelengths of 283.3 nm and 248.3 nm, respectively. Lead calibration standards were prepared from lead nitrate, while iron standards were prepared from an iron stock solution. Concentrations were determined by comparison with the corresponding calibration curves and reported in mg/L (APHA, 2005).

Cadmium, chromium and arsenic were determined by stabilized-temperature graphite furnace atomic absorption spectrometry following EPA Method 200.9, Revision 2.2. Unfiltered aliquots were prepared for total recoverable analysis by nitric acid-hydrochloric acid digestion. The prepared solutions were analyzed against element-specific calibration standards at 228.8 nm for cadmium, 357.9 nm for chromium and 193.7 nm for arsenic. Concentrations were calculated from the calibration response, corrected for dilution and expressed in mg/L (United States Environmental Protection Agency [USEPA], 1994b).

Total mercury was determined by cold-vapour atomic absorption spectrometry following EPA Method 245.1, Revision 3.0. Water aliquots were oxidized with potassium permanganate and potassium persulphate in an acid medium. After removal of excess oxidant, mercury was reduced to its elemental form using stannous chloride. The released vapour was transferred to the absorption cell and measured against mercury calibration standards. Concentrations were calculated after accounting for aliquot volume and dilution and expressed in mg/L (USEPA, 1994a).

Heavy-metal results were reported by sampled location, senatorial district, season and quarter. The results were interpreted in relation to water used in maternity-centre activities; ingestion and dermal exposure doses were not estimated in this study.

Seasonal and quarterly grouping

The monthly results were grouped into dry and wet seasons and into four quarters. November to February was treated as dry season, while March to October was treated as wet season. Seasonal patterns were considered alongside the 2025 Seasonal Climate Prediction for the sampled local government areas (Nigerian Meteorological Agency, 2025). The quarters comprised January to March (Q1), April to June (Q2), July to September (Q3) and October to December

(Q4). Quarterly summaries were used to show changes that might not be visible from the dry-wet grouping alone.

Statistical analysis

Data were analyzed using descriptive statistics, analysis of variance, independent-samples t-test and Pearson correlation. Analysis of variance was used to compare measured parameters across sampling locations. Independent-samples t-test was used for selected district and facility-type comparisons where sufficient observations were available. Pearson correlation assessed the strength and direction of association between selected quantitative water-quality parameters. Statistical significance was interpreted at $p < 0.05$.

Comparison with water-quality guidance

Concentrations were compared with the WHO (2022) drinking-water guideline values as chemical water-quality benchmarks. Nitrate was compared on a nitrate-ion basis, chromium with the total-chromium value, and mercury with the inorganic-mercury value as a screening comparison rather than a species-specific assessment. Parameters without an established WHO health-based guideline value were interpreted separately as operational or descriptive indicators. These comparisons do not constitute an exposure-dose assessment or establish suitability for all maternity-care activities.

Results

The physicochemical characteristics of water varied across sampled locations, seasons and quarters. Seasonal mean pH increased from 5.082 in the dry season to 5.780 in the wet season (Table 2).

Electrical conductivity showed almost identical seasonal means, with 93.084 microS/cm in the dry season and 93.236 microS/cm in the wet season, although the wet-season range was wider and extended to 265.000 microS/cm.

Nitrate increased slightly from 0.424 mg/L in the dry season to 0.442 mg/L in the wet season, phosphate increased from 0.0049 mg/L to 0.0056 mg/L, and total organic carbon increased from 0.052% to 0.054%.

Dissolved oxygen moved in the opposite direction, decreasing from 1.857 mg/L in the dry season to 1.306 mg/L in the wet season.

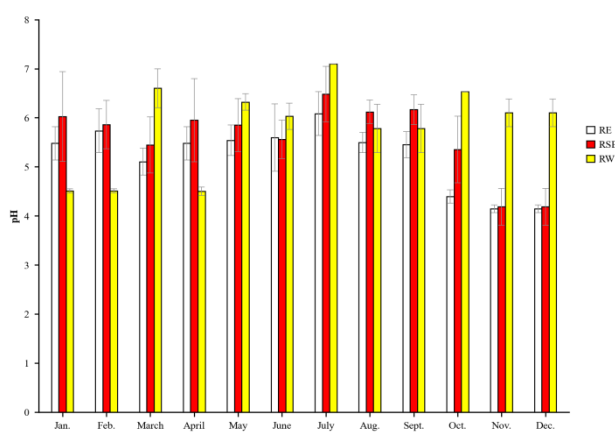
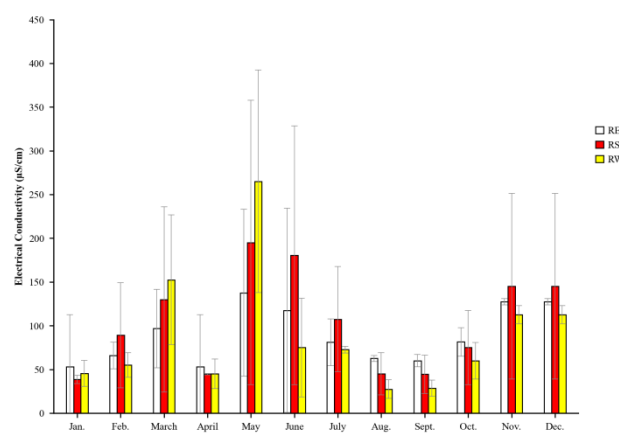
Table 2: Seasonal summary of physicochemical water parameters

Parameter	Unit	Dry season mean	Dry season range	Wet season mean	Wet season range	WHO allowable limit
pH	pH unit	5.082	4.145 to 6.100	5.780	4.395 to 7.100	No health-based value
Electrical conductivity	microS/cm	93.084	38.500 to 145.000	93.236	27.500 to 265.000	No health-based value
Nitrate	mg/L	0.424	0.238 to 0.710	0.442	0.170 to 0.756	50, as nitrate ion
Phosphate	mg/L	0.0049	0.0035 to 0.0080	0.0056	0.0015 to 0.0175	No health-based value
Dissolved oxygen	mg/L	1.857	1.500 to 2.450	1.306	0.500 to 2.400	No health-based value
Total organic carbon	%	0.052	0.030 to 0.0925	0.054	0.010 to 0.200	No health-based value

The monthly physicochemical profiles showed that water quality did not follow one uniform seasonal direction. The pH values ranged from 3.92 at the TBA facility in Oyigbo in November to 7.10 at Saint Peter's Clinic, Bonny, in July. Electrical conductivity ranged from 11.00 microS/cm at the Rumukwursi TBA-linked facility in January to 355.00 microS/cm at TBA Bonny in May. Nitrate ranged from 0.158 mg/L at Saint Peter's Clinic, Bonny, in October to 0.918 mg/L at TBA Bonny in July, while phosphate ranged from 0.001 mg/L at TBA Bonny in June to 0.028 mg/L at Rumukwursi Model Primary Health Centre in March. Dissolved oxygen ranged from 0.50 mg/L at Saint Peter's Clinic, Bonny, in May to 2.60 mg/L at TBA Oyigbo in April. Total organic carbon ranged from 0.01% at Saint Peter's Clinic, Bonny, in August to 0.21% at TBA Oyigbo in May.

These ranges show why seasonal averages alone are insufficient for evaluating water used in maternity settings.

The monthly figures show the parameter-specific nature of the variation. The pH plot shows acidic values in several months, with the highest value recorded in July (Fig. 1). Electrical conductivity was more variable than the seasonal means suggest, with a clear high value in May at TBA Bonny (Fig. 2). Nitrate and phosphate had separate peak months and did not behave as a single nutrient pattern (Figs. 3 and 4). Dissolved oxygen was generally low and showed its highest monthly value in April (Fig. 5), while total organic carbon had a localized May peak at TBA Oyigbo (Figure 6).

**Figure 1: pH of sampled water across the different locations.****Figure 2: Electrical conductivity of sampled water across the different locations.**

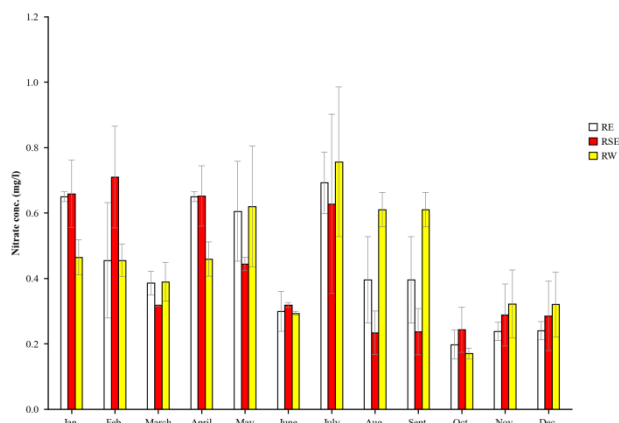


Figure 3: Nitrate concentration in sampled water across the different locations.

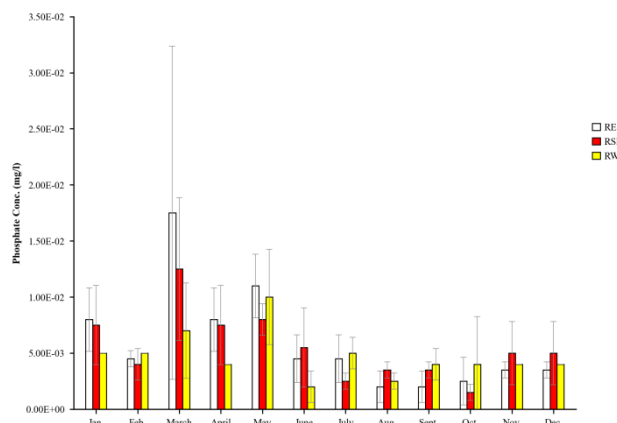


Figure 4: Phosphate concentration in sampled water across the different locations.

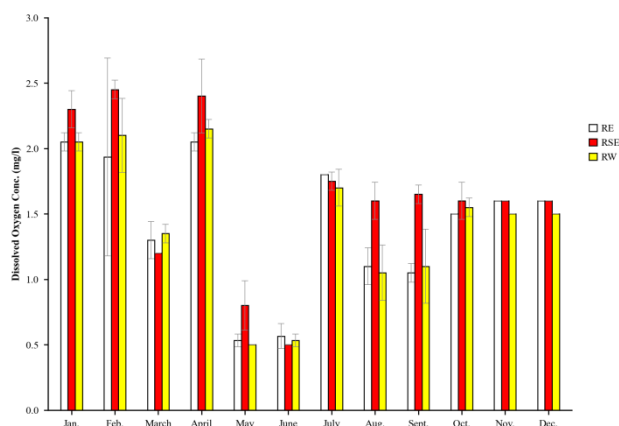


Figure 5: Dissolved oxygen concentration in sampled water across the different locations.

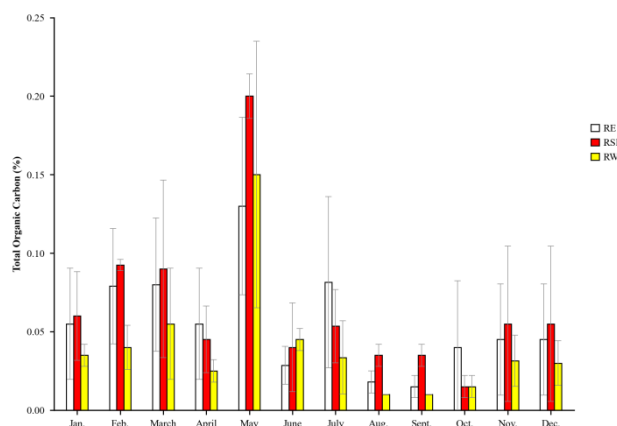


Figure 6: Total organic carbon in sampled water across the different locations.

Out of 44 physicochemical ANOVA comparisons, 42 were significant at $p < 0.05$. All nitrate, dissolved oxygen and electrical-conductivity comparisons were significant, while pH had eight significant and two non-significant comparisons.

Heavy-metal analysis covered cadmium, chromium, iron, arsenic, lead and mercury (Table 3). Cadmium, chromium, arsenic and mercury were reported at 0.001 mg/L across the seasonal summaries. Iron and lead varied across locations, seasons and quarters.

Iron had a dry-season mean of 0.0261 mg/L and a wet-season mean of 0.0253 mg/L, while lead had a dry-season mean of 0.0042 mg/L and a wet-season mean of 0.0034 mg/L. The highest monthly senatorial-district mean iron concentration was recorded in Rivers South East in April at 0.0835 mg/L, while the highest corresponding lead concentration was recorded there in February at 0.0155 mg/L. The maximum lead values in both seasonal summaries exceeded the WHO provisional guideline value of 0.01 mg/L, although both seasonal means were below it.

Table 3: Seasonal summary of heavy-metal concentrations in water

Metal	Dry season mean (mg/L)	Dry season range (mg/L)	Wet season mean (mg/L)	Wet season range (mg/L)	WHO allowable limit
Cadmium	0.0010	0.0010 to 0.0010	0.0010	0.0010 to 0.0010	0.003
Chromium	0.0010	0.0010 to 0.0010	0.0010	0.0010 to 0.0010	0.05, total chromium
Iron	0.0261	0.0070 to 0.0565	0.0253	0.0010 to 0.0835	No health-based value
Arsenic	0.0010	0.0010 to 0.0010	0.0010	0.0010 to 0.0010	0.01, provisional
Lead	0.0042	0.0020 to 0.0155	0.0034	0.0020 to 0.0125	0.01, provisional
Mercury	0.0010	0.0010 to 0.0010	0.0010	0.0010 to 0.0010	0.006, inorganic mercury

Source of comparison values: WHO (2022). The ranges describe monthly senatorial-district means. Numerical guideline values are expressed in mg/L. The arsenic and lead values are provisional; the chromium value applies to total chromium and the mercury value to inorganic mercury. Mercury results represent total mercury.

The senatorial-district heavy-metal profiles showed variation mainly in iron and lead. Rivers East/Central had a maximum monthly district-mean lead concentration of 0.0070 mg/L in February, below the WHO provisional guideline value of 0.01 mg/L (Fig. 7; Table 3). The corresponding maximum was 0.0155 mg/L in February in Rivers South East (Fig. 8) and 0.0125 mg/L in April in Rivers West (Fig. 9), both above the guideline value. Maximum monthly district-mean iron concentrations were 0.0405 mg/L in Rivers East/Central in March, 0.0835 mg/L in Rivers South East in April and 0.0545 mg/L in Rivers West in March. At facility level, Oyigbo Model Primary Health Centre, the Rumukwurusi TBA facility and the Bonny TBA facility recorded no exceedances of the numerical WHO guideline values for cadmium, chromium, arsenic and lead during the twelve-month sampling period. Saint Peter's Clinic, Bonny recorded lead concentrations of 0.015 mg/L in February and 0.022 mg/L in both March and April. Rumukwurusi Model Primary Health Centre recorded 0.012 mg/L in February, while the Oyigbo TBA facility recorded 0.023 mg/L in February; each exceeded the provisional lead value of 0.01 mg/L.

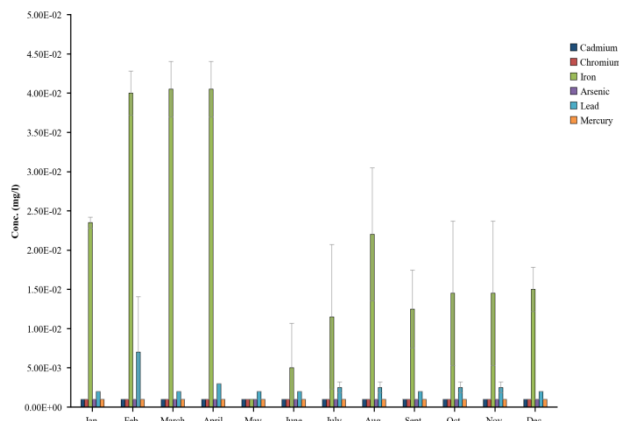


Figure 7: Concentrations of assessed heavy metals in water within the sampled locations in Rivers East/Central Senatorial District.

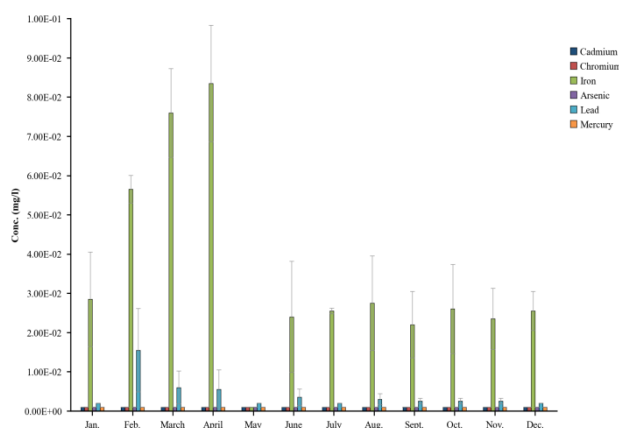


Figure 8: Concentrations of assessed heavy metals in water within the sampled locations in Rivers South East Senatorial District.

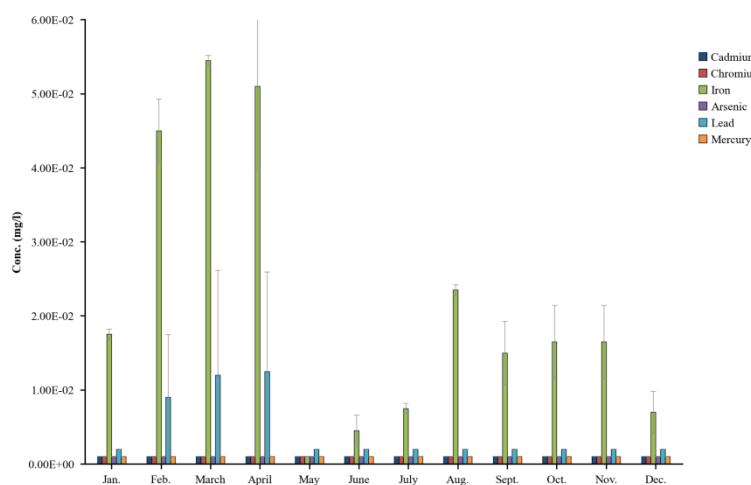


Figure 9: Concentrations of assessed heavy metals in water within the sampled locations in Rivers West Senatorial District.

Quarterly summaries showed that physicochemical and heavy-metal parameters varied by time period (Table 4). The highest quarterly pH and nitrate means occurred in Q3, while electrical conductivity and total organic carbon had their highest means in

Q2. Dissolved oxygen had its highest mean in Q1. Iron decreased from 0.0424 mg/L in Q1 to 0.0177 mg/L in Q4, while lead decreased from 0.0064 mg/L to 0.0022 mg/L over the same period.

Table 4: Quarterly summary of physicochemical parameters, iron and lead

Parameter	Unit	Q1	Q2	Q3	Q4
pH	pH unit	5.474	5.647	6.051	5.016
Electrical conductivity	microS/cm	80.686	123.667	58.796	109.593
Nitrate	mg/L	0.498	0.482	0.506	0.256
Phosphate	mg/L	0.0079	0.0067	0.0033	0.0037
Dissolved oxygen	mg/L	1.859	1.115	1.422	1.561
Total organic carbon	%	0.065	0.080	0.032	0.037
Iron	mg/L	0.0424	0.0235	0.0186	0.0177
Lead	mg/L	0.0064	0.0038	0.0023	0.0022

Significant t-test results were recorded for iron, electrical conductivity and pH (Table 5). Among TBA locations, iron differed significantly between Rivers East/Central and Rivers South East ($t = -2.585$, $p = 0.0184$) and between Rivers South East and Rivers West ($t = 2.288$, $p = 0.0338$). Electrical conductivity differed significantly between Rivers East/Central and Rivers South East in both clinic comparisons ($t = 3.748$, $p = 0.0025$) and TBA comparisons ($t = -2.701$, $p = 0.0173$). Clinic pH differed significantly between Rivers East/Central and Rivers South East ($t = -3.480$, $p = 0.0024$) and

between Rivers East/Central and Rivers West ($t = -2.998$, $p = 0.0078$).

Pearson correlation analysis showed significant relationships among selected quantitative water-quality parameters (Table 5). Electrical conductivity and total organic carbon had a moderate positive correlation ($r = 0.554$, $p < 0.001$), as did iron and lead ($r = 0.533$, $p < 0.001$) and dissolved oxygen and iron ($r = 0.509$, $p < 0.001$). Dissolved oxygen and electrical conductivity had a weak negative relationship ($r = -0.398$, $p < 0.001$).

Table 5: Summary of significant t-test and Pearson correlation results

Test type	Parameter or pair	Comparison or n	Statistics	p-value	Interpretation
t-test	Iron	RE vs RSE, TBA	-2.585	0.0184	Significant
t-test	Iron	RSE vs RW, TBA	2.288	0.0338	Significant
t-test	Electrical conductivity	RE vs RSE, clinic	3.748	0.0025	Significant
t-test	Electrical conductivity	RE vs RSE, TBA	-2.701	0.0173	Significant
t-test	pH	RE vs RSE, clinic	-3.480	0.0024	Significant
t-test	pH	RE vs RW, clinic	-2.998	0.0078	Significant
Pearson correlation	Electrical conductivity and total organic carbon	n = 72	0.554	<0.001	Moderate positive
Pearson correlation	Iron and lead	n = 72	0.533	<0.001	Moderate positive
Pearson correlation	Dissolved oxygen and iron	n = 72	0.509	<0.001	Moderate positive
Pearson correlation	Dissolved oxygen and electrical conductivity	n = 72	-0.398	<0.001	Weak negative

Discussion

The physicochemical pattern has practical relevance because pH, conductivity, nutrients, dissolved oxygen and organic carbon describe different aspects of water condition. The seasonal pH means in Table 2 indicate that the sampled water was generally acidic but became less acidic during the wet season. The monthly pH profile (Fig. 1) shows that this seasonal tendency did not remove variation among senatorial districts. Acidic pH can influence corrosion and metal mobility.

However, WHO (2022) does not establish a health-based pH guideline value. The acidic tendency agrees with previous Port Harcourt water-quality reports, where low pH values and variable pollution indices were observed (Kumpel et al., 2017; Offodile et al., 2023). The similar seasonal conductivity means concealed a wider wet-season range and a pronounced monthly peak in Rivers West (Table 2; Fig. 2). Conductivity reflects dissolved ions, but this measurement alone does not identify their source.

Nitrate and phosphate showed separate monthly patterns (Figs. 3 and 4), while dissolved oxygen and total organic carbon varied differently across periods (Figs. 5 and 6). Low dissolved oxygen may reflect organic load or stagnation, although neither mechanism was established by this study. The nitrate concentrations were below the WHO (2022) guideline value of 50 mg/L as nitrate ion. The absence of a health-based WHO value for conductivity, phosphate, dissolved oxygen or TOC does not make these parameters irrelevant to operational water quality. Nigerian borehole-water assessment has likewise treated physicochemical and bacteriological measurements as companion indicators (Adogo et al., 2016). The seasonal behaviour is consistent with reports that water quality changes across dry and wet seasons, although the direction may vary by water source and location (Kumpel et al., 2017; Alabi et al., 2024).

Iron and lead accounted for the variation in the metal summaries, while cadmium, chromium, arsenic and mercury were reported at 0.001 mg/L (Table 3). The reported cadmium, chromium and arsenic concentrations were below their respective WHO (2022) guideline values. Total mercury was also below the numerical guideline for inorganic mercury, but this comparison does not establish the mercury species present. No health-based WHO value is established for iron. The lead comparison is more concerning: the maximum monthly senatorial-district means exceeded 0.01 mg/L in both seasonal summaries, despite seasonal means below that value. The WHO lead guideline is provisional and is not a threshold below which adverse effects are excluded.

These results therefore do not support an unqualified claim that all water met the selected chemical benchmarks. At centre level, Oyigbo Model Primary Health Centre, the Rumukwurusi TBA facility and the Bonny TBA facility jointly showed the most consistent compliance with the numerical WHO (2022) guideline values for cadmium, chromium, arsenic and lead, with no recorded exceedances across the twelve months.

Saint Peter's Clinic, Bonny had the poorest compliance on this basis, with exceedances in three sampling months, compared with one month each at Rumukwurusi Model Primary Health Centre and the Oyigbo TBA facility. Although the Oyigbo TBA facility recorded the highest individual monthly lead concentration, the repeated exceedances at Saint Peter's Clinic distinguish persistence from a single concentration peak.

The centre-level results also show that a district mean below the guideline value can conceal an exceedance at an individual facility: the Rivers East/Central February mean was 0.0070 mg/L, while Rumukwurusi Model Primary Health Centre recorded 0.012 mg/L. The three centres without exceedances were therefore equally compliant with these metal benchmarks, rather than one being uniquely superior in overall water quality.

Local geology, plumbing materials, storage conditions, waste disposal and runoff may affect metal concentrations differently across facilities, but these pathways were not measured directly. Variable water-quality and metal-related pollution indicators reported in Port Harcourt support interpreting the results in relation to local supply conditions (Offodile et al., 2023).

The quarterly results in Table 4 show why dry-wet grouping alone cannot describe all temporal variation. Iron and lead declined from Q1 to Q4, while conductivity and TOC were highest in Q2 and pH and nitrate were highest in Q3. A single seasonal label can therefore conceal shorter-period peaks relevant to water monitoring.

The 2025 climate prediction provides regional seasonal context, rather than evidence that rainfall caused a particular concentration change (Nigerian Meteorological Agency, 2025). Repeated sampling remains important where the timing and direction of water-quality changes differ among parameters, as documented for domestic water sources in Port Harcourt (Kumpel et al., 2017).

The significant ANOVA and t-test results indicate that selected water-quality parameters differed among sampled locations and senatorial-district/facility-type comparisons. The associations in Table 5 show that some parameters varied together, but the correlations do not establish a common source or causal pathway.

In particular, the positive iron-lead relationship warrants examination of the supply and distribution system without assigning contamination to a specific material or activity.

Regular water-quality checks should complement facility cleaning, hygiene and environmental control rather than replace them. This combined approach is consistent with infection-prevention evidence from resource-limited neonatal units and healthcare facilities (Dramowski et al., 2021; Okwor et al., 2022; Sonpar et al., 2025).

Conclusion

The water used in the selected maternity centres showed physicochemical and heavy-metal variation across location, season and quarter. The water was generally acidic, and monthly conductivity varied more widely than the seasonal means suggested. Nitrate and the reported cadmium, chromium and arsenic concentrations were below their respective WHO guideline values; the mercury result was below the numerical inorganic-mercury benchmark. Oyigbo Model Primary Health Centre in Rivers South East, the Rumukwursi TBA facility in Rivers East and the Bonny TBA facility Rivers West jointly showed the most consistent compliance with the numerical WHO guideline values for heavy metal tested with no recorded exceedances during the study. Saint Peter's Clinic, Bonny in Rivers West had the least consistent compliance, with lead exceedances in three sampling months, compared with one month each at Rumukwursi Model Primary Health Centre and the Oyigbo TBA facility. The t-test and correlation results showed that selected water-quality parameters differed by senatorial district and facility type, and that some parameters varied together. Episodic lead elevation remained the principal departure from the selected WHO chemical benchmarks, despite seasonal mean lead concentrations below the provisional guideline value.

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