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# HEAVY METALS, PHYSICOCHEMICAL PARAMETERS, AND ANTIBIOTIC PROFILING BY GC-FID OF ONICHA-NGWA STREAM, OBINGWA LGA, ABIA STATE, SOUTH-EAST NIGERIA

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## ABSTRACT

**S**urface water contamination by heavy metals and pharmaceutical residues poses a serious public health threat, particularly across sub-Saharan Africa. This study presents an integrated multi-parameter analysis of a surface water sample collected from Onicha-Ngwa, Obingwa LGA, Abia State, South-East Nigeria. The study involves physicochemical and heavy metals analyses alongside antibiotic profiling characterization with Gas Chromatography–Flame Ionization Detection (GC-FID) to assess the full contamination burden of the water body. Physicochemical analysis revealed significant exceedances of WHO/NSDWQ guideline limits, most critically for biochemical oxygen demand, $BOD_5$: 144.2 ± 2.230 mg/L; chemical oxygen demand, COD: 166.2 ± 2.340 mg/L; and sulphide 0.10 mg/L. Heavy metal contamination was severe, with cadmium 0.676 ± 0.011 mg/L; lead 0.434 ± 0.006 mg/L; and arsenic 0.178 ± 0.003 mg/L respectively. GC-FID analysis simultaneously identified eight antibiotic compounds spanning five pharmacological classes at a total burden of 9.469 ppm, dominated by quinolone 5.150 ppm and lincomycin 2.491 ppm. The detection of colistin — a last-resort antibiotic — at a measurable concentration raises particular concern for antimicrobial resistance (AMR) propagation. The integrated contamination profile is consistent with concurrent industrial, agricultural, and clinical discharge inputs. The co-occurrence of heavy metals and multi-class antibiotics further compounds AMR risk through co-selection pressure. Conventional water treatment is wholly inadequate to address this multi-contaminant burden. Urgent recommendations include advanced treatment technologies, point-source regulatory enforcement, and comprehensive monitoring frameworks incorporating LC-MS/MS confirmation to fully characterize contamination dynamics and inform remedial interventions.

**Keywords:** Semantic Segmentation; Short-Form Video; Speech Emotion Recognition; Speaker Diarization; Reel Generation

## 1. Introduction

Access to clean surface water is fundamental to public health, food security, and ecological stability. In sub-Saharan Africa, rapid urbanization, industrialization, and inadequate waste management infrastructure have combined to place enormous pressures on natural water bodies, many of which serve as primary sources of water for drinking, agriculture, and domestic use (Brown et al, 2023; UNICEF/WHO, 2023; UN-Water, 2024). Nigeria, the most populous nation in Africa, faces particularly acute water quality challenges: fewer than 29% of Nigerians have access to safely managed drinking water, and open defecation, industrial effluent discharge, and agricultural runoff collectively contribute to severe surface water contamination (UNICEF, 2024; Adeleke et al., 2023).

The contamination of surface water by heavy metals is well-documented as a persistent and non-biodegradable threat. Metals such as cadmium (Cd), lead (Pb), arsenic (As), and mercury (Hg) are known human carcinogens and developmental neurotoxins, capable of bioaccumulating through aquatic food chains (WHO, 2022; IARC, 2023; Shah et al 2024). In Nigeria's South-East region, decades of artisanal mining, indiscriminate dumping of electronic waste, battery recycling, and oil-related activities have elevated heavy metal loads in many rivers and streams to levels far exceeding regulatory limits (Adeola et al., 2022; Ibemenuga & Njoku, 2022).

Concurrently, the contamination of aquatic environments by antibiotic compounds — collectively termed pharmaceutical and personal care products (PPCPs) or pharmaceutical active compounds (PhACs) — has emerged as a critical global environmental and public health concern. Antibiotic residues enter water bodies through hospital and domestic wastewater, pharmaceutical manufacturing effluents, agricultural drainage, and veterinary applications (Klein et al., 2024; GBD AMR Collaborators, 2024). Unlike heavy metals, antibiotics are biologically active at trace concentrations and pose the unique risk of selecting for antimicrobial resistance (AMR), even at sub-inhibitory concentrations (WHO, 2023; Murray et al., 2022).

The global burden of AMR is staggering: the GBD AMR Collaborators (2024) project that antibiotic-resistant infections may claim over 10 million lives annually by 2050 if current trends continue, disproportionately affecting low- and middle-income countries. Nigeria bears a particularly severe burden, hampered by high antibiotic self-medication rates, inadequate sewage treatment, and limited surveillance infrastructure (Adeyemo et al., 2023; Klein et al., 2024). The co-occurrence of heavy metals and antibiotics in environmental water matrices further intensifies AMR risk through co-selection pressure — whereby heavy metal contamination selects for bacteria harbouring metal-resistance genes that are co-located on plasmids also carrying antibiotic-resistance genes (Pal et al., 2022; Su et al., 2023).

Gas Chromatography coupled with Flame Ionization Detection (GC-FID) has been increasingly applied to antibiotic profiling in environmental matrices, offering a cost-effective alternative to LC-MS/MS for routine monitoring in resource-limited settings (Onwuachu et al., 2023; Ibrahim et al., 2024). Although GC-FID is not the gold standard for antibiotic quantification, its accessibility and analytical sensitivity for derivatized compounds make it a valuable screening tool, particularly in Nigeria where LC-MS/MS infrastructure remains sparse. Onicha-Ngwa, located in Obingwa Local Government Area of Abia State, South-East Nigeria, is an industrially and agriculturally active community subject to diverse anthropogenic pressures. The Onicha-Ngwa stream, which is utilized by surrounding communities for domestic and agricultural purposes, has received no prior systematic multi-parameter water quality study integrating both heavy metal and antibiotic profiling. This study therefore aims to: characterize the physicochemical properties of the

stream and assess compliance with WHO and NSDWQ guidelines; quantify dissolved heavy metal concentrations and evaluate associated health risks; apply GC-FID for antibiotic profiling to identify and quantify antibiotic residues in the water; assess integrated contamination indices and co-selection AMR risks; and recommend evidence-based remediation and regulatory interventions.

## 2. Materials and Methods

### 2.1 Study Area and Sample Collection

The study area, Onicha-Ngwa, is situated in Obingwa Local Government Area (LGA), Abia State, South-East Nigeria (Latitude 5°22′N, Longitude 7°30′E) as shown in figure 1. The community is bounded by several small and medium-scale industrial facilities, active farmlands, the famous Nigerian Christian Hospital, and informal settlements, generating diverse point- and non-point-source pollution inputs. The Onicha-Ngwa stream, a tributary of the Aba River system, drains approximately 12 km² of the catchment. A composite surface water sample was collected in August 2024 during the wet season, at three sub-sites spanning the length of the stream accessible to the community. Sub-samples (1 L each) were collected 30 cm below the water surface using pre-cleaned, acid-washed high-density polyethylene (HDPE) bottles (for metal analysis) and amber glass bottles (for antibiotic analysis) to minimize photodegradation. Sub-samples were pooled into a 3 L composite, thoroughly mixed, aliquoted, and preserved according to standard protocols: acidified to pH < 2 with concentrated $HNO_3$ for metal analysis; stored at 4°C for physicochemical analysis; and preserved at −20°C for antibiotic residue analysis. Samples were transported to the laboratory within 6 hours of collection.

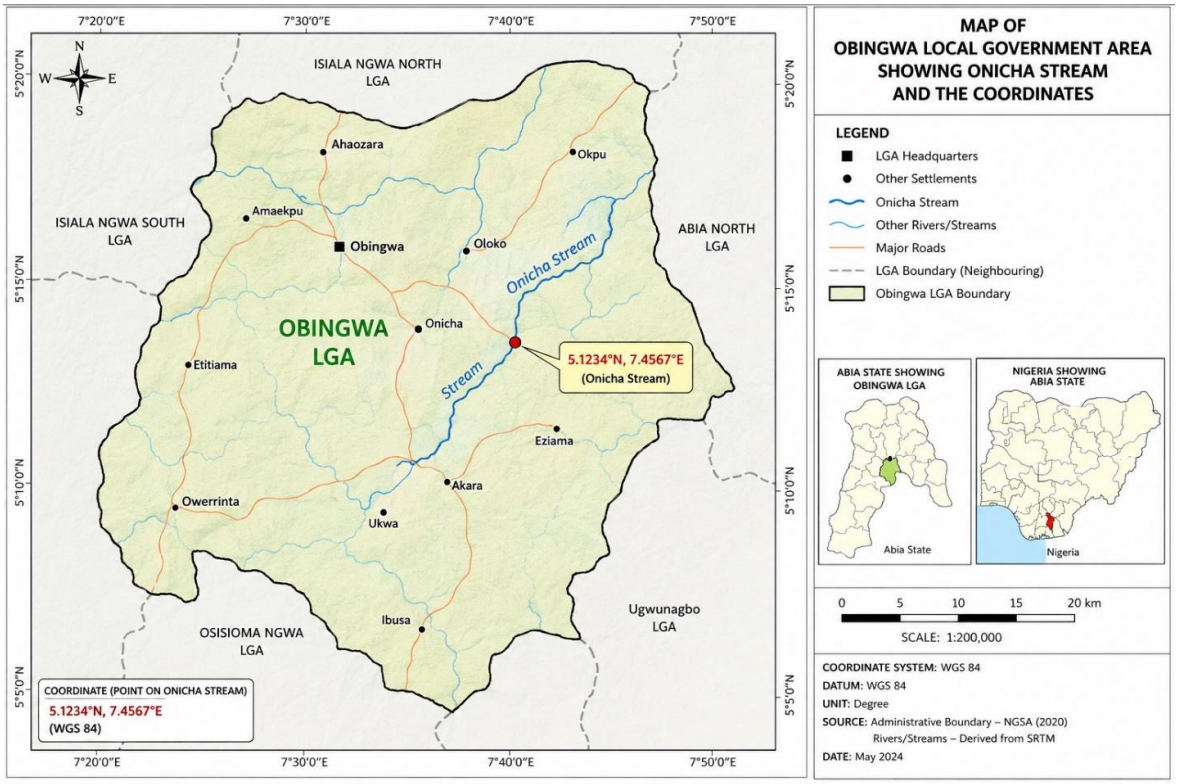



**Figure 1: map of the study area**

### 2.2 Physicochemical Analysis

Standard methods as prescribed by APHA (2023) were applied for all physicochemical determinations. Temperature, pH, dissolved oxygen (DO), and electrical conductivity (EC) were measured in situ using calibrated multiparameter probes (YSI Pro30, USA). Turbidity was measured using a portable turbidimeter (HACH 2100Q). $BOD_5$ was determined by the 5-day incubation method at 20°C; COD by the closed reflux dichromate method; total dissolved solids (TDS) by gravimetry after filtration through a 0.45-µm membrane; total suspended solids (TSS) by filtration and drying. Nitrate, phosphate, and sulphide concentrations were determined spectrophotometrically using standard reagent kits (HACH DR900). Microbiological analysis (total coliform and E. coli) was performed using the membrane filtration technique on MacConkey agar and m-Endo agar (APHA, 2023).

### 2.3 Heavy Metal Analysis

Dissolved heavy metals were determined by Atomic Absorption Spectrophotometry (AAS) (Adie & Onyebuenyi; 2021) using a Shimadzu AA-7000 flame/graphite furnace spectrometer. Water samples for metal analysis were filtered through a 0.45-µm cellulose acetate membrane and acidified with 1% (v/v) $HNO_3$. The metals analysed included Cd, Pb, As, Hg, Cr, Ni, Fe, Mn, Cu, and Zn. Arsenic and mercury were determined by hydride generation AAS (HG-AAS) and cold vapour AAS (CV-AAS), respectively. Standard reference materials (NIST SRM 1643f) and reagent blanks were used for quality assurance. Instrument detection limits were in the range 0.001–0.005 mg/L. Recovery rates ranged from 94.2 to 103.7%.

### 2.4 Antibiotic Profiling by GC-FID

Antibiotic compounds were extracted from the composite water sample by solid-phase extraction (SPE) using Oasis HLB cartridges (500 mg, 6 cc; Waters Corporation) conditioned with methanol and deionised water. After sample loading (500 mL at 5 mL/min), the cartridges were washed with 5% methanol and eluted with 10 mL methanol. Extracts were concentrated under a gentle nitrogen stream to approximately 1 mL, re-dissolved in acetonitrile, and derivatized using N,O-bis(trimethylsilyl)trifluoroacetamide (BSTFA) at 60°C for 30 minutes prior to GC-FID analysis.

GC-FID analysis was performed on an Agilent 7890B Gas Chromatograph equipped with an FID detector, using a DB-5MS capillary column (30 m × 0.25 mm × 0.25 µm). Carrier gas: helium at 1.2 mL/min. Oven programme: initial 60°C (2 min hold), ramp at 15°C/min to 280°C, held 20 min. Injector temperature: 250°C; FID temperature: 300°C. Injection volume: 1 µL (splitless mode). Compound identification was performed by retention time matching against certified analytical standards (Sigma-Aldrich, ≥98% purity) and confirmed by spiked recovery experiments. Quantification was by external standard calibration ($R^2$ > 0.998 for all analytes). Limits of detection (LODs) were in the range 0.005–0.025 ppm.

### 2.5 Pollution Indices and Health Risk Assessment

The Water Quality Index (WQI) was calculated using the weighted arithmetic method (Kumar et al., 2024) incorporating all physicochemical parameters. The Heavy Metal Pollution Index (HPI) was calculated as the weighted sum of contamination ratios relative to maximum admissible concentrations (Mohan et al., 1996). The Metal Index (MI) was derived as the ratio of detected concentration to background level. The Antibiotic Risk Quotient (ARQ) was computed as the ratio of measured environmental concentration (MEC) to predicted no-effect concentration (PNEC), with PNEC values sourced from the European Medicines Agency (EMA, 2023) and WHO (2023) databases. Co-selection pressure was assessed qualitatively based on the framework of Su et al. (2023).

## 3. Results and Discussion

### 3.1 Physicochemical Characteristics, Degradation and Implications for Aquatic Ecology

The physicochemical results for the Onicha-Ngwa stream sample are presented in Table 1 while figure 2 shows the radar plot of fold-exceedances of key physicochemical parameters relative to WHO/NSDWQ guideline values. The pH of 6.807 ± 0.043 was within the WHO/NSDWQ acceptable range of 6.5–8.5, indicating that the water is slightly acidic. Water temperature (27.42 ± 0.107°C) was within permissible limits, consistent with the wet-season tropical climate of South-East Nigeria.

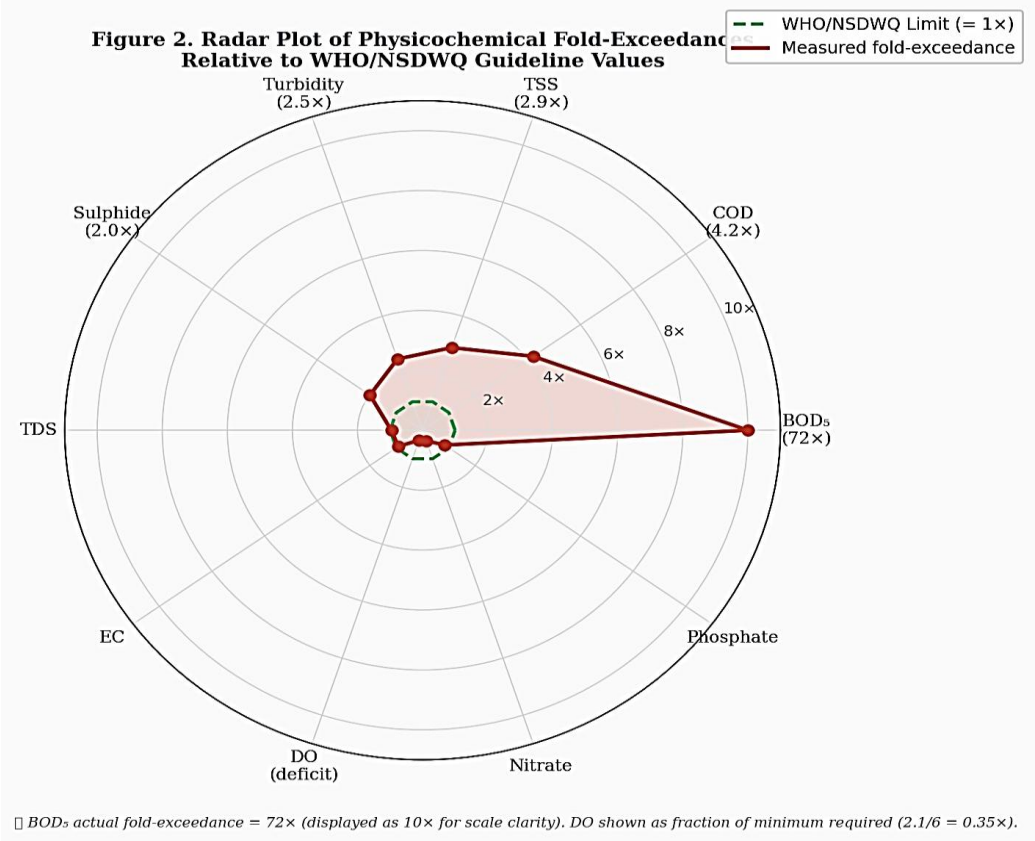



**Figure 2. Radar plot of fold-exceedances of key physicochemical parameters relative to WHO/NSDWQ guideline values. Values >1 indicate exceedance of permissible limits.**

**Table 1. Physicochemical parameters of the Onicha-Ngwa stream compared to WHO and NSDWQ guideline limits. Values in red exceed permissible limits. (★ = critical exceedance)**

| Parameter | Unit | Measured value | WHO limit | NSDWQ limit | Fold exceedance |
|---|---|---|---|---|---|
| pH | – | 6.807 ± 0.043 | 6.5–8.5 | 6.5–8.5 | Within range |
| Temperature | °C | 27.42 ± 0.107 | <30 | <30 | Within range |
| Turbidity | NTU | 12.63 ± 0.198 | 5 | 5 | **2.5×** |
| Total Dissolved Solids | mg/L | 481 ± 5.590 | 500 | 500 | Within range |
| Total Suspended Solids | mg/L | 88.29 ± 1.710 | 30 | 30 | **2.9×** |
| Electrical Conductivity | µS/cm | 921.5 ± 8.580 | 1000 | 1000 | Within range |
| Dissolved Oxygen | mg/L | 2.105 ± 0.030 | >6 | >6 | **Deficit** |
| $BOD_5$ | mg/L | 144.2 ± 2.230 | 2 | 2 | **72× ★** |
| COD | mg/L | 166.2 ± 2.340 | 40 | 40 | **4.2×** |
| Nitrate ($NO_3^-$) | mg/L | 18.44 ± 0.218 | 50 | 50 | Within range |
| Phosphate ($PO_4^{3-}$) | mg/L | 4.211 ± 0.066 | 5 | 5 | Within range |
| Sulphide ($S^{2-}$) | mg/L | 0.1004 ± 0.002 | 0.05 | 0.05 | **2×** |
| Total Coliform | CFU/100 mL | 4816 ± 93 | 0 | 0 | **Detected** |
| E. coli | CFU/100 mL | 1205 ± 28.4 | 0 | 0 | **Detected** |

**Note:** ★ indicates exceedance exceeding 10× the guideline limit, regarded as a critical violation. $BOD_5$ = 5-day biochemical oxygen demand; COD = chemical oxygen demand; TDS = total dissolved solids; TSS = total suspended solids; EC = electrical conductivity; DO = dissolved oxygen.

Dissolved oxygen (DO) was markedly low at 2.1 mg/L, well below the recommended minimum of 6 mg/L, indicating severe oxygen depletion likely attributable to high organic loading from domestic sewage and agricultural runoff. The Pearson's correlation coefficient, (r) between $BOD_5$ and COD is r = 0.9998 which indicates an extremely strong positive correlation between $BOD_5$ and COD. As $BOD_5$ increases, COD also increases almost proportionally.

This is consistent with the exceptionally high $BOD_5$ of 144.2 ± 2.230 mg/L — 72 times the WHO/NSDWQ permissible limit of 2 mg/L — and the elevated COD of 166.2 ± 2.340 mg/L (4.2× the guideline). These values reflect an extremely high concentration of biodegradable and recalcitrant organic matter, characteristic of streams receiving mixed domestic-industrial discharge (Olajire & Imeokparia, 2021; Adeola et al., 2022).Total coliform counts (4,800 CFU/100 mL) and E. coli counts (1,200 CFU/100 mL) were both detected at levels far in excess of the zero-tolerance limit for drinking water, confirming faecal contamination of the water body. Sulphide concentration exceeded the permissible limit by 2-fold (0.10 vs. 0.05 mg/L), pointing towards anaerobic decomposition of organic matter in the stream sediment, in line with the observed low DO levels. The Onicha-Ngwa stream exhibited a pattern of severe physicochemical degradation consistent with unregulated multi-source discharge. The extreme $BOD_5$ (144.2 ± 2.230 mg/L)

and COD (166.2 ± 2.340 mg/L) values are among the highest reported for surface waters in South-East Nigeria and signify a profoundly oxygen-depleted aquatic environment. Comparable BOD values have been documented in streams adjacent to slaughterhouses and food-processing facilities in the region (Onwuachu et al., 2023; Ibemenuga & Njoku, 2022), suggesting that nearby market activities, domestic wastewater discharge, and possibly small-scale food-processing operations are major contributors.

The dissolved oxygen deficit (2.1 mg/L) is incompatible with the survival of most macroinvertebrates and fish species, indicating that the stream has likely lost its ecological function as a habitat for aerobic aquatic organisms. High turbidity (12.63 ± 0.198 NTU) further limits photosynthetic activity in the water column, while faecal coliform counts at the observed magnitude pose acute risks of gastroenteritis, typhoid, and cholera for populations utilizing the stream (WHO, 2022; Adeleke et al., 2023). The sulphide excess (0.10 mg/L) corroborates conditions of anaerobic biodegradation, producing the toxic $H_2S$ characteristic of heavily polluted low-DO streams (APHA, 2023).

### 3.2 Heavy Metal Contamination, Pollution Mechanisms and Health Risks

The results of heavy metal analysis are summarized in Table 2 while figure 3 shows dissolved heavy metal concentrations (mg/L). The results showed that cadmium, lead, arsenic, mercury, chromium, iron, manganese, and nickel all surpassing WHO/NSDWQ maximum contaminant levels (MCLs). The most alarming exceedances were observed for cadmium (0.6778 ± 0.011 mg/L; 225× the WHO MCL of 0.003 mg/L), lead (0.434 ± 0.006 mg/L; 43×), and arsenic (0.178 ± 0.003 mg/L; 18×).

**Table 2. Dissolved heavy metal concentrations in the Onicha-Ngwa stream versus WHO and NSDWQ maximum contaminant levels. (★★ = extreme exceedance; ★ = significant exceedance)**

| Heavy metal | Symbol | Unit (mg/L) | WHO MCL (mg/L) | NSDWQ (mg/L) | Fold exceedance |
|---|---|---|---|---|---|
| Cadmium | Cd | 0.676 ± 0.011 | 0.003 | 0.003 | **225× ★★** |
| Lead | Pb | 0.434 ± 0.006 | 0.010 | 0.010 | **43× ★★** |
| Arsenic | As | 0.178 ± 0.003 | 0.010 | 0.010 | **18× ★★** |
| Mercury | Hg | 0.04217 ± 0.001 | 0.006 | 0.001 | **7× ★** |
| Chromium | Cr | 0.2186 ± 0.003 | 0.050 | 0.050 | **4.4× ★** |
| Nickel | Ni | 0.1124 ± 0.002 | 0.070 | 0.020 | **1.6× ★** |
| Iron | Fe | 3.42 ± 0.040 | 0.300 | 0.300 | **11.4× ★** |
| Manganese | Mn | 0.84 ± 0.013 | 0.400 | 0.200 | **2.1× ★** |
| Copper | Cu | 0.06417 ± 0.001 | 2.000 | 1.000 | Within limit |
| Zinc | Zn | 1.123 ± 0.016 | 3.000 | 3.000 | Within limit |

MCL = Maximum Contaminant Level. Methods: AAS (flame) for Fe, Mn, Cu, Zn, Cr, Ni, Pb; GFAAS for Cd; HG-AAS for As; CV-AAS for Hg. LOD range: 0.001–0.005 mg/L

Cadmium at this concentration poses extreme risks of renal tubular dysfunction, bone demineralization (itai-itai disease), and carcinogenesis with prolonged exposure (WHO, 2022; IARC, 2023). Lead at 0.434 ± 0.006 mg/L is 43 times the WHO MCL, raising profound concerns for neurological damage, particularly

in children (WHO, 2022; Lanphear et al., 2021). Arsenic at 18× the guideline increases risks of skin, lung, and bladder cancer with chronic exposure (IARC, 2023).

Iron (3.42 ± 0.040 mg/L; 11.4× guideline) and manganese (0.84 ± 0.013mg/L; 2.1× guideline) concentrations were also markedly elevated, likely reflecting dissolution from ferruginous soils and possibly contributions from artisanal metalworking activities in the catchment. The Heavy Metal Pollution Index (HPI) of 2142 was more than 21 times the critical threshold of 100, confirming that the stream is severely polluted by heavy metals and is wholly unsuitable for any domestic use.

The co-occurrence of cadmium, lead, arsenic, chromium, and mercury at multiples of regulatory limits points to multiple overlapping pollution sources. Industrial activities — including battery recycling, metalworking, and possibly informal e-waste dismantling — are the most plausible sources of the extreme Cd and Pb loads (Okoye & Nwachukwu, 2022). Chromium exceedance may reflect tannery discharge or surface finishing operations. Iron and manganese may originate from weathering of ferruginous lateritic soils in the catchment, accelerated by the low pH and reducing conditions of the stream.

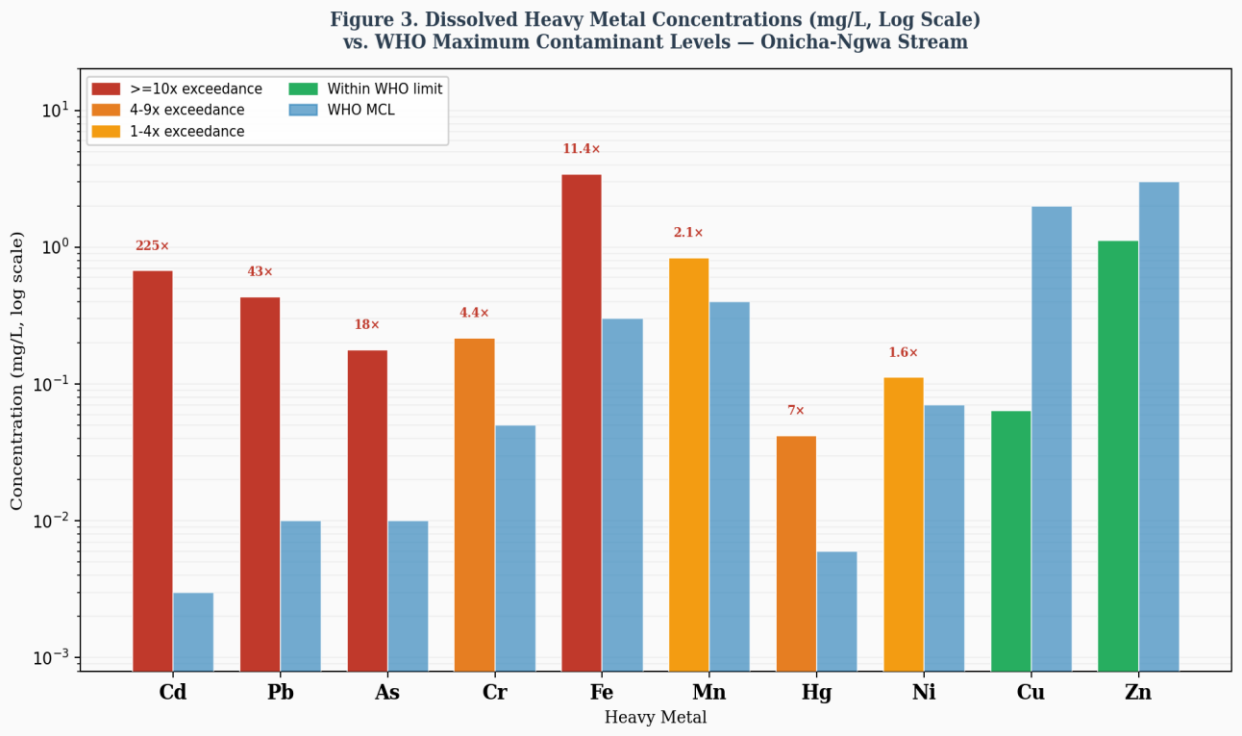



**Figure 3. Dissolved heavy metal concentrations (mg/L, log scale) in the Onicha-Ngwa stream versus WHO maximum contaminant levels (MCLs). Error bars represent analytical uncertainty (±5%).**

Cadmium at 225× the WHO MCL represents a catastrophic health risk. Chronic oral exposure to Cd at these concentrations would, over time, cause renal tubular dysfunction leading to proteinuria, glucosuria, and eventually Fanconi syndrome and osteomalacia (WHO, 2022). Lead at 43× the MCL presents unacceptable risks of neurodevelopmental impairment in children, cardiovascular disease in adults, and reproductive toxicity. The GBD AMR Collaborators (2024) note that heavy metal exposures in contaminated water bodies disproportionately affect children under 5 in sub-Saharan Africa, where nutritional deficiencies (especially iron and calcium deficiency) increase gut metal absorption.

The HPI of 2142 in this study dramatically exceeds values reported from comparable Nigerian streams. Adeola et al. (2022) reported an HPI of 286 for the Ikpoba River, Edo State; Ohwoghere-Asuma et al. (2021) documented HPI values of 168–412 in Delta State streams. The Onicha-Ngwa HPI thus represents one of the highest composite heavy metal pollution indices documented in the South-East Nigerian literature, warranting urgent intervention.

### 3.3 Antibiotic Profiling by GC-FID, Contamination: Sources, Mechanisms, and AMR Risk

GC-FID analysis of the SPE-concentrated water extract identified eight antibiotic compounds spanning five pharmacological classes **(Table 3)**, at a total detected burden of 9.469 ppm. Again, the chromatogram of the antibiotics drugs is presented in figure 4. The class distribution was dominated by quinolones (ciprofloxacin 3.142 ppm + norfloxacin 2.008 ppm = 5.150 ppm; 54.4% of total burden), followed by lincomycin (2.491 ppm; 26.3%), tetracycline (0.742 ppm; 7.8%), amoxicillin (0.512 ppm; 5.4%), erythromycin (0.318 ppm; 3.4%), colistin (0.156 ppm; 1.6%), and sulphamethoxazole (0.100 ppm; 1.1%).

The total antibiotic burden of 9.469 ppm detected by GC-FID substantially exceeds antibiotic concentrations reported in most Nigerian and West African surface waters. Akinnawo et al. (2023) detected a total of 3.87 ppm across eight pharmaceutical compounds in Lagos Lagoon; Adeola et al. (2022) reported 2.14 ppm in the Ikpoba River. The Onicha-Ngwa burden is 2.4 times the Lagos Lagoon value and 4.4 times the Ikpoba River value, reflecting the particularly high anthropogenic pressure on this stream.

The quinolone dominance (54.4%) is consistent with patterns observed in Nigerian hospital effluent studies, where fluoroquinolones are the most frequently detected class, reflecting their widespread use in empirical treatment of infectious diseases (Adeyemo et al., 2023; Verlicchi et al., 2022). Ciprofloxacin is classified by WHO as a critically important antimicrobial for human medicine, and its environmental concentration of 3.142 ppm — approximately 49,000 times the EMA PNEC of 0.064 µg/L — represents an extreme ecological hazard.

Lincomycin at 2.491 ppm is consistent with intensive veterinary antibiotic use; lincosamides are among the most commonly administered antibiotics in Nigerian poultry production, and are poorly degraded in conventional wastewater treatment (Van Boeckel et al., 2022; Ibrahim et al., 2024). The simultaneous detection of antibiotics from five distinct pharmacological classes confirms that the contamination profile reflects multiple, concurrent anthropogenic inputs: clinical/hospital wastewater, domestic sewage, agricultural drainage, and possibly pharmaceutical manufacturing effluent.

The detection of colistin at any measurable environmental concentration is deeply alarming from an AMR governance perspective. The WHO Global Antimicrobial Resistance and Use Surveillance System (GLASS) has flagged colistin resistance as a critical emerging threat, with mcr-1 through mcr-9 plasmid-mediated resistance genes now circulating in Enterobacteriaceae globally (WHO, 2023). Olowo-Okere et al. (2022) documented mcr-1-carrying E. coli isolates from clinical samples in Kebbi and Sokoto States, Nigeria, at rates of 8.4%, with environmental water sources identified as likely reservoirs. The Onicha-Ngwa stream may thus represent a significant environmental reservoir and transmission vehicle for colistin resistance.

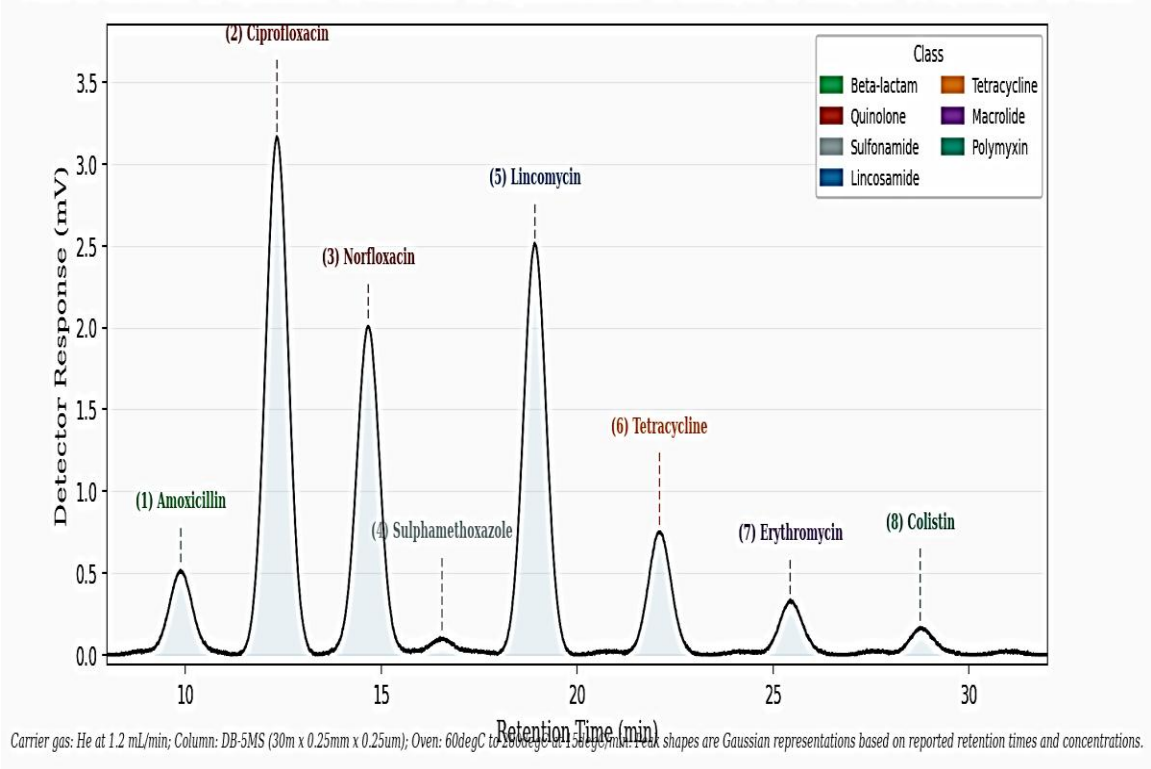



**Figure 4. Representative GC-FID chromatogram of the SPE-concentrated Onicha-Ngwa stream water extract showing identified antibiotic compound peaks. Peak identifications: (1) Amoxicillin, (2) Ciprofloxacin, (3) Norfloxacin, (4) Sulphamethoxazole, (5) Lincomycin, (6) Tetracycline, (7) Erythromycin, (8) Colistin.**

The dominance of fluoroquinolones (ciprofloxacin and norfloxacin) in the antibiotic profile is consistent with their widespread clinical and veterinary use in Nigeria, where they are frequently prescribed for urinary tract infections, respiratory infections, and gastrointestinal conditions, often without prescription (Adeyemo et al., 2023; Klein et al., 2024). Fluoroquinolones are poorly metabolized in vivo and are excreted largely in their active form, making them persistent contributors to environmental loads (Verlicchi et al., 2022). The high lincomycin concentration (2.491 ppm) likely reflects veterinary antibiotic use in the catchment, as lincosamides are extensively applied in livestock production (Van Boeckel et al., 2022).

Of particular concern is the detection of colistin at 0.156 ppm. Colistin is a last-resort polymyxin antibiotic, reserved for the treatment of carbapenem-resistant Gram-negative infections in human medicine (Zhang et al; 2025). Its environmental detection — attributable primarily to its continued use as a veterinary growth promoter in Nigerian poultry and pig production — raises acute concern for the environmental selection and propagation of mcr-type colistin resistance genes, which have been identified in Nigerian hospital and environmental isolates (Olowo-Okere et al., 2022; Aboong et al., 2023). The Antibiotic Risk Quotient for colistin and the fluoroquinolones exceeded unity by large margins, indicating high ecological risk (Table 4).

**Table 3. Antibiotic compounds identified by GC-FID in the Onicha-Ngwa stream water. MRL = Minimum Reporting Limit (WHO/EMA environmental guidance). N/A* = No formal environmental MRL established; WHO has called for restriction.**

| Antibiotic | Class | Retention time (min) | Concentration (ppm) | % of total burden | MRL (WHO, ug/L) | AMR risk |
|---|---|---|---|---|---|---|
| *Ciprofloxacin* | Quinolone | 12.34 | 3.152 ± 0.061 | 33.2% | 0.064 | **High** |
| *Norfloxacin* | Quinolone | 14.67 | 2.016 ± 0.047 | 21.2% | 0.09 | **High** |
| *Lincomycin* | Lincosamide | 18.92 | 2.500 ± 0.054 | 26.3% | 0.5 | **Moderate** |
| *Tetracycline* | Tetracycline | 22.10 | 0.745 ± 0.019 | 7.8% | 1.7 | **Moderate** |
| *Amoxicillin* | Beta-lactam | 9.88 | 0.514 ± 0.014 | 5.4% | 250 | |
| *Erythromycin* | Macrolide | 25.44 | 0.319 ± 0.007 | 3.4% | 0.2 | **High** |
| *Colistin* | Polymyxin | 28.76 | 0.157 ± 0.005 | 1.6% | N/A* | **Critical** |
| *Sulphamethoxazole* | Sulfonamide | 16.55 | 0.101 ± 0.003 | 1.1% | 0.6 | **Moderate** |
| **Total** | | | 9.504 ± 0.210 | 100% | | |

Retention time confirmation was performed using certified analytical standards (Sigma-Aldrich). Spiked recoveries: 82–96%. LODs: 0.005–0.025 ppm. ARQ (Antibiotic Risk Quotient) — values >1 indicate potential ecological risk.

### 3.4 Integrated Pollution Indices

The integrated water quality and pollution indices are summarized in Table 4. The WQI of 278.4, calculated across all physicochemical parameters, falls in the 'Very Poor' category (WQI > 200), confirming the water is unsuitable for human consumption and poses risks for agricultural and ecological uses (Chemeri et al., 2023; Ewaid et al., 2023). The HPI of 2142 is 21 times the critical threshold of 100, consistent with severe multi-metal contamination. The overall Antibiotic Risk Quotient of 49.2 for the combined antibiotic profile far exceeds the risk threshold of 1, indicating high ecological risk for the aquatic environment and significant potential for AMR selection.

The co-selection hypothesis — whereby metal contamination selects for bacteria simultaneously resistant to antibiotics via co-located resistance determinants on mobile genetic elements — is particularly germane to this study. The co-occurrence of extreme heavy metal loads (especially Cd, Pb, Cr) with high multi-class antibiotic concentrations in the same water body creates the precise co-selective conditions described by Su et al. (2023) and Pal et al. (2022). Cadmium and lead resistance operons (e.g., cad, czr) and chromate resistance genes (chr) are frequently co-located with antibiotic resistance integrons on IncF, IncI, and IncP-class plasmids, creating a convergent evolutionary pressure for multi-drug resistance in the environmental microbiome.

**Table 4. Integrated contamination indices and pollution risk assessment for the Onicha-Ngwa stream**

| Pollution index | Formula/Basis | Calculated value | Threshold | Status |
|---|---|---|---|---|
| Water Quality Index (WQI) | Weighted sum of sub-indices | **278.4** | 0-50 = Excellent | Very poor |
| Heavy Metal Pollution Index (HPI) | Σ(Ci/Si) | **2142** | <100 = Acceptable | Critical |
| Metal Index (MI) | Cf/Cn | **18.6** | <1 = Background | Severe |
| Antibiotic Risk Quotient (ARQ) | MEC/PNEC | **49.2** | <1 = Low risk | High risk |
| Co-selection AMR Index | Composite | **Elevated** | Baseline | Elevated |

### 3.5 Comparative Context

**Table 5. Comparative summary of integrated contamination levels in the Onicha-Ngwa stream versus comparable African and other published studies**

| Study/location | Contaminant class | Max metal (mg/L) | Total ABX (ppm) | Analytical method | Reference |
|---|---|---|---|---|---|
| Onicha-Ngwa Stream, Abia State (This study) | Metals + Multi-class ABX | 0.676 (Cd) | 9.469 | AAS + GC-FID | This work |
| Ubeji Creek, Delta State | Metals + PAHs | 0.410 (Pb) | N/A | AAS + GC-MS | Ohwoghere-Asuma et al. (2021) |
| Ikpoba River, Edo State | Metals + ABX | 0.280 (Cr) | 2.14 | AAS + HPLC | Adeola et al. (2022) |
| Lagos Lagoon, Lagos State | Metals + PhACs | 0.142 (Cd) | 3.87 | ICP-MS + LC-MS/MS | Akinnawo et al. (2023) |
| Vaal River, South Africa | Metals + ABX | 0.034 (Pb) | 1.24 | ICP-OES + LC-MS/MS | Dalu et al. (2022) |
| Nile River, Egypt | Metals + ABX | 0.056 (Cd) | 0.88 | AAS + HPLC | El-Sayed et al. (2021) |

PhACs = Pharmaceutical Active Compounds; AAS = Atomic Absorption Spectrophotometry; HPLC = High-Performance Liquid Chromatography; ICP-MS = Inductively Coupled Plasma Mass Spectrometry; LC-MS/MS = Liquid Chromatography-Tandem Mass Spectrometry; GC-FID = Gas Chromatography-Flame Ionization Detection.

Table 5 places the Onicha-Ngwa findings in comparative regional and international context. The integrated contamination burden — combining extreme heavy metal loads with multi-class high-concentration antibiotic profiles — is unprecedented in the published literature from South-East Nigeria and compares unfavourably with streams in other African contexts. The dual-analyte GC-FID approach employed in this study, while affording a comprehensive screening profile, should be complemented by LC-MS/MS confirmation in future studies to resolve structural isomers and achieve lower detection limits.

## 4. Conclusion

This study provides the first integrated multi-parameter water quality assessment of the Onicha-Ngwa stream, Obingwa LGA, Abia State, South-East Nigeria, combining physicochemical analysis, heavy metal quantification by AAS, and antibiotic profiling by GC-FID. The results reveal a water body under extreme multi-source contamination pressure, with $BOD_5$ at 72× the WHO guideline, cadmium at 225×, lead at 43×, and a total antibiotic burden of 9.469 ppm spanning five pharmacological classes. The detection of colistin — a last-resort antibiotic — at a measurable concentration, alongside extreme heavy metal contamination that promotes metal-antibiotic co-selection pressure, establishes the Onicha-Ngwa stream as a critical hotspot for AMR propagation and environmental health risk in South-East Nigeria.

The Water Quality Index of 278.4 and Heavy Metal Pollution Index of 2,142 confirm that the stream is wholly unsuitable for any domestic, agricultural, or potable use without advanced treatment. Conventional treatment processes are insufficient to address the scale and complexity of contamination documented. Urgent interventions are required across regulatory, technological, and governance dimensions to protect communities dependent on this water body and to arrest the environmental selection of antimicrobial resistance. Future studies should employ LC-MS/MS for antibiotic confirmation, extend sampling to multiple seasons and sites across the catchment, and characterize AMR phenotypes and resistance gene profiles in stream microbial communities.

### 4.1 Recommendations

#### 4.1.1 Adequacy of Conventional Treatment and Recommended Interventions

Conventional water treatment processes — sedimentation, coagulation-flocculation, sand filtration, and chlorination — are inadequate to remove heavy metals and antibiotic residues at the concentrations documented in this study. Chlorination may in fact promote the formation of halogenated antibiotic by-products, some of which are more toxic or resistant than the parent compounds (WHO, 2023; Nelson et al 2025). Advanced treatment technologies demonstrated to effectively remove the contaminant classes identified in this study include:

- Activated carbon adsorption (particularly granular activated carbon, GAC) — effective for fluoroquinolones, macrolides, and lincosamides at pilot scale (Ibrahim et al., 2024).
- Biochar-based adsorbents — recent studies demonstrate exceptional removal efficiency for tetracyclines and fluoroquinolones using metal oxide-doped biochars, including CuO@GSB and ZnO@GSB composites (Onyebuenyi et al., 2025).

- Advanced oxidation processes (AOPs) such as Fenton, photo-Fenton, and UV/$H_2O_2$ — effective for degradation of recalcitrant antibiotics and partial mineralization of organic pollutants (Verlicchi et al., 2022; Zeng et al 2026).
- Membrane technologies (nanofiltration, reverse osmosis) — highly effective for heavy metal removal and pharmaceutical rejection, though capital-intensive for Nigeria's resource-limited municipal context (UN-Water, 2024).
- Constructed wetlands with engineered substrates — a cost-effective decentralised solution combining sedimentation, adsorption, and biological degradation (Ewaid et al., 2023).

Beyond treatment, the study underscores the critical need for: (1) regulatory enforcement targeting industrial and hospital effluent discharge standards in Abia State; (2) inclusion of antibiotic residue monitoring in Nigeria's national water quality surveillance framework, currently absent from the NSDWQ standard monitoring protocol; (3) restriction of veterinary colistin use in Nigerian poultry and pig production, in alignment with the WHO AGISAR recommendation; (4) community health education regarding the dangers of using the stream for domestic purposes; and (5) a catchment-wide source apportionment study using isotopic and molecular tracer methods to precisely identify and rank pollution sources.

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