JIGAWA JOURNAL OF
ENVIRONMENTAL AND EARTH SCIENCES
Federal University Dutse | Department of Environmental Sciences

Volume 1 • Issue 1 • November 2026 ISSN: 3093-8852 ISSN Online: 3093-8842

REVIEW ARTICLE

Heavy metal and polycyclic aromatic hydrocarbon contamination of water sources in Nigeria: A systematic review (2019–2024)

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RECEIVED	ACCEPTED	PUBLISHED
14/10/2026	14/11/2026	17/11/2026

How to cite: Sani Umar Usman, Naseer Inuwa Durumin Iya, Tukur Mohammed Ahijo (2026). Heavy metal and polycyclic aromatic hydrocarbon contamination of water sources in Nigeria: A systematic review (2019–2024). *Jigawa Journal of Environmental and Earth Sciences*, 1(1), 276–291.
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ABSTRACT

Background: Water pollution by heavy metals (HMs) and polycyclic aromatic hydrocarbons (PAHs) is a growing environmental and public health concern in Nigeria, driven by industrialisation, oil and gas exploration, agricultural runoff, and inadequate waste management. No comprehensive synthesis has mapped the extent, sources, and risks of both contaminant classes across Nigerian water bodies.

Methods: This systematic review, reported according to PRISMA 2020, searched five databases (Science Direct, Taylor & Francis, PubMed, Springer, and MDPI) in November 2024 for English-language studies published between 2019 and 2024 on HM and/or PAH contamination in Nigerian water sources. Screening and data extraction were performed in duplicate. Of 1,043 records identified, 46 studies met the inclusion criteria and were analysed for contamination levels, sources, geographic distribution, and associated health and ecological risks.

Results: Contamination of surface water, groundwater, and sediments was widespread and concentrated in the oil-producing South-South region, with substantial contributions from the South-West and South-East; no eligible studies were located from northern Nigeria. Reported sources included oil spills and gas flaring, waste dumping, and industrial and vehicular emissions, and several studies reported hazard or cancer-risk values above acceptable thresholds, with children most at risk.

Conclusion: Research effort is geographically imbalanced and lacks long-term and epidemiological evidence linking exposure to health outcomes. Expanded monitoring across all regions of Nigeria, standardised risk assessment, and locally adapted remediation research are needed.

Keywords: heavy metals; polycyclic aromatic hydrocarbons; water contamination; Nigeria

Introduction

Global water pollution – the contamination of rivers, lakes, oceans, and groundwater by chemicals, microorganisms, plastics, and heavy metals – threatens millions of people, ecosystems, and economies in industrialized and developing nations alike (Hannah et al., 2022; Ling, 2022; Zahoor & Mushtaq, 2023). Freshwater makes up only 2.5% of the Earth's water, and demand keeps rising with population growth and urbanization (Salehi, 2022; du Plessis et al., 2022; Morin-Crini et al., 2022); by 2050, an estimated 3.9 billion people will live in highly water-stressed river basins, with scarcity shaped as much by social and political

dynamics as by physical supply (Shemer et al., 2023; Van Vliet et al., 2021; Tang et al., 2022). Water pollution remains a persistent public health concern despite advances in sanitation and water delivery (Verma & Ratan, 2020).

Heavy metals and polycyclic aromatic hydrocarbons (PAHs) are two of the most hazardous contaminant classes. Heavy metals (lead, cadmium, mercury, arsenic, chromium, nickel, copper, zinc, and manganese) enter water through industry, agriculture, mining, and poor waste disposal; they are persistent and non-biodegradable, bioaccumulate through the food chain, and are linked to kidney failure, diabetes, and cancer (Sreedevi et al., 2023; Xu et al., 2024; Rashid et al., 2023; Munir et al., 2021; Singh et al., 2020; Mokarram et al., 2020; Zhang et al., 2023; Ali et al., 2021). PAHs are fused-ring organic compounds formed mainly by incomplete combustion and industrial activity; they are persistent, mutagenic, and carcinogenic, and sixteen are US-EPA priority pollutants (Liu et al., 2021; Janarthanam et al., 2023; Wu et al., 2021; US-EPA, 2007; Hasan et al., 2025). Their low solubility promotes attachment to particulates and transport into aquatic systems (He et al., 2021; Ambade et al., 2021), where they can be treated by bioremediation, adsorption, and advanced oxidation, among other approaches (Adeola et al., 2021; Yu et al., 2021; Dai et al., 2020; Gaurav et al., 2021).

In Nigeria, agricultural runoff, domestic sewage, industrial waste, and inadequate waste infrastructure degrade rivers, lakes, wells, and boreholes, while a large share of the population still lacks safe water and sanitation and relies on unsafe sources (Nwinyi et al., 2020; Emmanuel et al., 2022; Ngene et al., 2021; Omokaro et al., 2024; Ulakpaa et al., 2021; Igbani et al., 2024; Akpan et al., 2020; Nair et al., 2023; Campling, 2025). Oil pollution and PAH/heavy-metal contamination are especially acute in the Niger Delta, where decades of oil spills and gas flaring have caused extensive, UNEP-confirmed ecological damage (Sun et al., 2017; Amakiri et al., 2023; UNEP, 2011), and spilled hydrocarbons and metals accumulate in organisms and disrupt aquatic food webs (Isukuru et al., 2024; Kumari et al., 2021). Contamination levels vary with land use, hydrology, and proximity to pollution sources, so dependence on untreated water further increases public exposure.

Despite a growing body of individual research on water contamination in Nigeria, no comprehensive synthesis has combined evidence on both heavy metals and PAHs, or systematically mapped the extent, sources, and risk of co-contamination across water sources. This review therefore aims to systematically map and synthesise evidence on the contamination levels of heavy metals and PAHs in water sources across Nigeria. Its six objectives are: to identify and compile existing studies reporting contamination levels of heavy metals and polyaromatic hydrocarbons (PAHs) in different water sources across Nigeria, to assess the concentration levels of selected heavy metals (e.g., Lead, Cadmium, Mercury, Arsenic) and PAHs in surface water, groundwater, and other relevant water bodies, to compare contamination levels across different geographical regions and types of water sources in Nigeria, to examine the major sources and pathways of heavy metal and PAH contamination in Nigerian water bodies, to assess potential human health and ecological risks associated with the reported contamination levels, and to provide evidence-based recommendations for monitoring, policy formulation, and mitigation strategies to reduce contamination levels.

Methods and materials

This systematic review was conducted and reported in accordance with the PRISMA 2020 statement (Page et al., 2021). Eligible papers were original research articles focused on locations within Nigeria (regardless of authors' institutional affiliation) and addressing contamination of ground or surface water; papers authored exclusively by Nigerian researchers but not focused on Nigeria were excluded. The search covered 2019–2024 and was restricted to English-language publications. The terms ‘contaminated water’, ‘heavy metals’, ‘polycyclic hydrocarbons’, and ‘Nigeria’ were searched across five databases – Science Direct, Taylor & Francis, PubMed, Springer, and MDPI – in November 2024. Papers appearing in more than one database were counted once; funding sources were not considered, and eligibility was based solely on whether the study area fell within Nigeria.

Records were screened sequentially against the four eligibility criteria listed in the Results. Screening and data extraction were performed independently in duplicate by two reviewers. Data were extracted into a pre-designed table capturing paper title, aim, methodology, findings, and suggested future research, and were synthesised by author, publication year, study location/region, water type, contaminants detected, concentration levels, detection methods, and key findings and effects. Contamination levels were interpreted against Nigeria's regulatory standards (NESREA; National Standard for Drinking Water Quality, NIS 554:2015).

Quality appraisal. The methodological quality of each included study was appraised using an adapted checklist covering seven domains: (1) clear description of the study area and sampling design; (2) sampling frequency and seasonal coverage; (3) a validated analytical method; (4) reporting of quality assurance and quality control (blanks, replicates, reference materials) and detection limits; (5) comparison of results with national or international guideline values; (6) an explicit risk-assessment method where health or ecological risks were reported; and (7) complete reporting of results. Appraisal was performed independently in duplicate by the same two reviewers, and was used to qualify the strength of the evidence rather than to exclude studies.

Results

Figure 1 presents the PRISMA 2020 flow diagram of the screening process. Searching ‘contaminated water’, ‘heavy metals’, ‘polycyclic hydrocarbons’, and ‘Nigeria’ across the five databases between 2019 and 2024 returned 1,043 records, which were then screened against the four inclusion criteria below.

i. Research articles only
ii. Papers on contaminated water and
iii. Papers focussed on Nigeria only, and
iv. Papers authored by Nigerians but not focused on Nigeria are excluded (Levin *et. al.,* 2022).

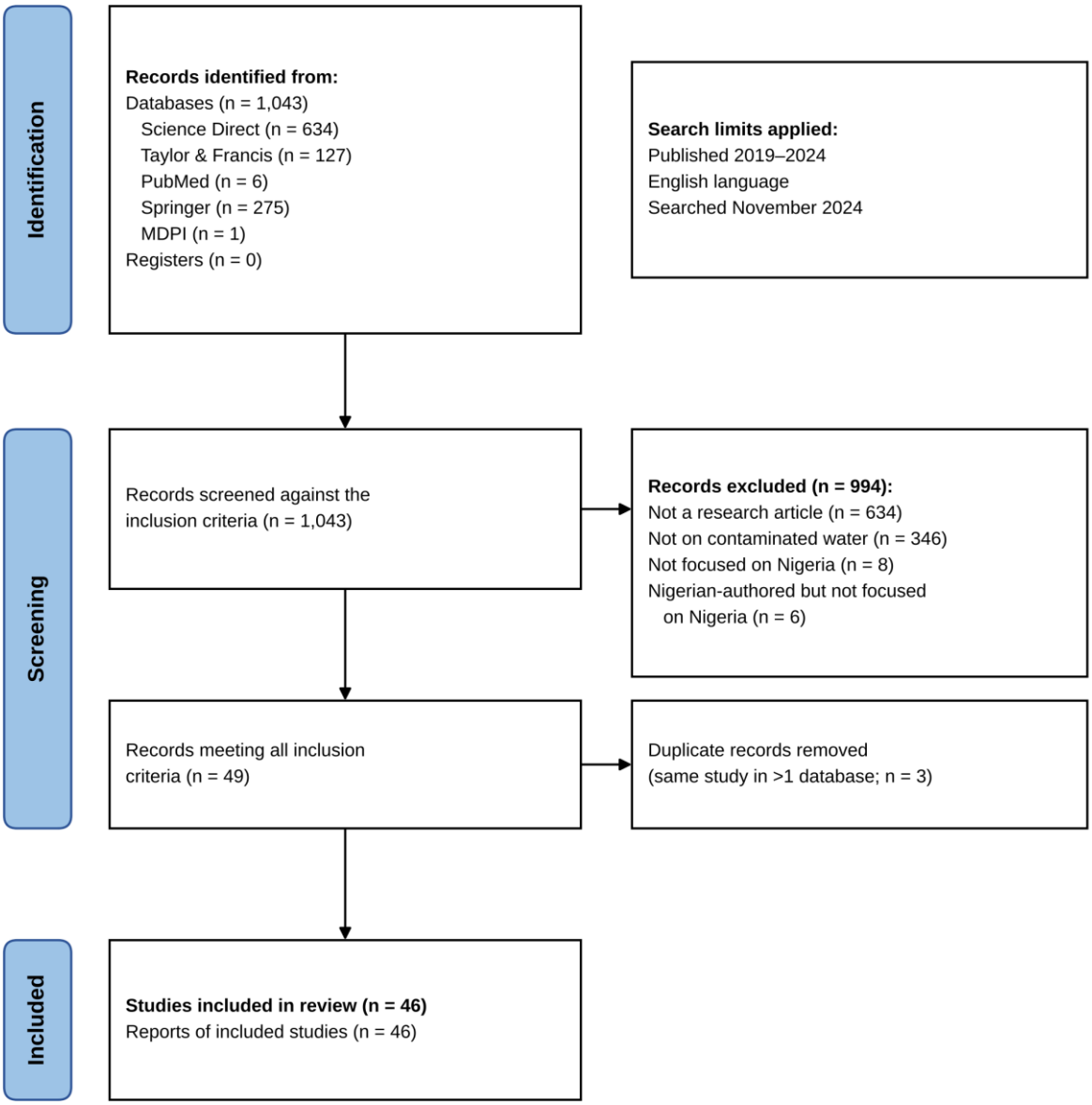


Figure 1: PRISMA 2020 flow diagram of study identification, screening, and inclusion.

Restricting to research articles reduced the initial 1,043 records to 409; requiring a focus on contaminated water reduced this to 63; restricting to Nigeria-focused studies gave 55; and excluding Nigerian-authored papers not focused on Nigeria gave 49. Three of these 49 papers appeared in more than one database, leaving 46 unique papers for analysis. Science Direct, Taylor & Francis, PubMed, Springer, and MDPI initially returned 634, 127, 6, 275, and 1 record respectively; per-database counts are shown in Figure 1.

The 46 analysed papers were geographically concentrated in southern Nigeria: South-South (17 papers), South-West (13), and South-East (11), with nine additional laboratory-based studies. The North-Central, North-East, and North-West regions had no eligible papers, indicating they remain understudied. By water type, 14 papers focused on surface water only, 15 on groundwater only, 12 on both surface and groundwater, 5 on wastewater, 2 on oil spills, and 1 on rainwater (Table 1).

Table 1: Geopolitical Regions of Papers Analysed

Region	Citation	Region	Citation	Region	Citation
South-South	Alani et al. (2020)	South-East	Umeh et al. (2023)	South-West	Ganiyu et al. (2024)
South-South	Obida et al. (2021)	South-East	Fagbenro et al. (2024)	South-West	Oyeniran et al. (2021)
South-South	Ullah et al. (2021)	South-East	Onydinma et al. (2021)	South-West	Unyimadu & Benson (2023)
South-South	Umar et al. (2024)	South-East	Ibe et al. (2020)	South-West	Shokunbi et al. (2024)
South-South	Lele et al. (2023)	South-East	Ugochukwu et al. (2021a)	South-West	Ololade et al. (2023)
South-South	Oyeyemi et al. (2024)	South-East	Okafor et al. (2023)	South-West	Adeyeye et al. (2023)
South-South	Anyanwu et al. (2021)	South-East	Aralu et al. (2023)	South-West	Anifowose et al. (2022)
South-South	Oyesanya & Omonona (2021)	South-East	Okafor et al. (2024a)	Laboratory	Madu et al. (2021)
South-South	Ighariemu et al. (2019)	South-East	Okafor et al. (2024b)	Laboratory	Bolade et al. (2021)
South-South	Edet et al. (2021)	South-East	Ugochukwu et al. (2021b)	Laboratory	Eboibi et al. (2023)
South-South	Omokpariola et al. (2022)	South-East	Okafor et al. (2024c)	Laboratory	Yakub et al. (2024)
South-South	Oyebamiji et al. (2024)	South-West	Oni et al. (2022a)	Laboratory	Ganiyu et al. (2023)
South-South	Iniaghe & Kpomah (2023)	South-West	Ibor et al. (2019)	Laboratory	Abatan et al. (2020)
South-South	Berezi et al. (2024)	South-West	Ojekunle et al. (2022)	Laboratory	Osadebe et al. (2024)
South-South	Eze et al. (2019)	South-West	Benson et al. (2020)	Laboratory	Eboibi et al. (2024)
South-South	Idomeh et al. (2021)	South-West	Oni et al. (2022b)		
South-South	Oyo-Ita et al. (2022)	South-West	Ferreira et al. (2023)		

Table 2 summarises the eight papers on heavy-metal contamination (three from the South-West, three from the South-East, one from the South-South, and one laboratory-based). Read together, the entries show that heavy-metal contamination is source-specific rather than uniform: lead and cadmium recur as the metals most often exceeding permissible limits or driving hazard quotients and cancer risk (Ojekunle et al., 2022; Ibe et al., 2020; Oyeyemi et al., 2024), while iron and nickel also exceed limits near dumpsites, scrap markets, and abattoirs (Oyeniran et al., 2021). The magnitude of contamination varies widely: leachate at a Kurata (Ogun State) dumpsite showed Fe > Zn > Pb > Cu > Cd; groundwater near an automobile scrap market in Owerri (Imo State) was acidic (pH 3.98–4.34) with Nickel (0.18 ± 0.03 mg/L) and Lead (0.04 ± 0.02 mg/L) above drinking-water thresholds; Warri (Delta State) recorded extreme Cadmium and Lead values (2102.12 and 619.98, respectively, as reported); and other sites showed no adverse risk (Okafor et al., 2023). Seasonal and ecological entries (poorer water-quality index in the wet season; high sediment ecological risk at four streams, including Cr and Cd risk in the Omambala river) indicate that a single sampling can understate or overstate risk. Finally, the only biomarker study (elevated serum Pb and Cd in exposed residents) and the single remediation study (eggshell powder adsorbing Chromium and Cadmium; Abatan et al., 2020) show that exposure–outcome evidence and tested treatment options remain scarce.

Table 2: Papers on Heavy Metal (HM) Contamination in Water

Citation	Findings
Ojekunle et al. (2022)	HM sources: industrial, battery waste, vehicular emissions; hazard quotients & cancer risk (Cd, Pb) exceeded permissible limits.
Ferreira et al. (2023)	Heavy metals, hardness & pH impaired water quality; WQI ranged excellent–unsuitable, worse in wet season.
Ibe et al. (2020)	14 metallic pollutants detected; Ni & Pb exceeded safe limits; HMPI showed groundwater unsuitable for drinking.
Oyeyemi et al. (2024)	Elevated serum Pb & Cd, altered liver enzymes/antioxidants in exposed residents; extreme Cd/Pb water contamination.
Oyeniran et al. (2021)	Nutrients & heavy metals (Fe, Pb) exceeded limits in abattoir wastewater; adverse effects on exposed fish.
Okafor et al. (2023)	4 of 8 metals undetected; no adverse cancer/non-cancer risk to residents.
Abatan et al. (2020)	Eggshell powder adsorbs Cr & Cd via functional groups; pseudo-second-order kinetics fit best.
Okafor et al. (2024a)	Sediment ecological risk low–moderate at most streams; high at Isiachala, Nabaloku, Atammele & Omambala.

Table 3 lists the 33 papers on PAH contamination (15 from the South-South, 9 from the South-West, 6 from the South-East, and 4 laboratory-based), and its entries point to three main patterns. First, the sources are overwhelmingly anthropogenic and petroleum-related: gas flaring (Alani et al., 2020), oil spills (Obida et al., 2021; Ullah et al., 2021), automobile workshops and fuel depots (Onydinma et al., 2021; Ganiyu et al., 2024), and abandoned coal mines (Ugochukwu et al., 2021a), with source apportionment generally petrogenic, pyrolytic, or mixed (Aralu et al., 2023; Anifowose et al., 2022). Second, risk is highly site- and season-dependent: several studies found PAHs within WHO limits or low health risk (Lele et al., 2023; Berezi et al., 2024), whereas others reported exceedances in more than 70% of samples (Ganiyu et al., 2023), high carcinogenic risk from ingestion (Iniaghe & Kpomah, 2023), and greater risk for children (Edet et al., 2021; Omokpariola et al., 2022), with wet-season concentrations generally higher (Ololade et al., 2023; Oyo-Ita et al., 2022) and sediments more contaminated than water (Adeyeye et al., 2023). Third, the table extends beyond PAHs to related pollutants (PCBs, total petroleum hydrocarbons, and microplastics) and to a cluster of remediation studies reporting reductions of up to 85% for PAHs (Madu et al., 2021) and near-complete or 76% TPH degradation (Bolade et al., 2021), all of which were laboratory- or bench-scale.

Table 3: Papers on Polycyclic Aromatic Hydrocarbon (PAH) Contamination in Water

Citation	Findings
Alani et al. (2020)	Pb exceeded WHO standard at 50m; PAHs linked to flare gas; contamination decreased with distance from flare.
Obida et al. (2021)	2008/9 Ogoniland spill released ~83M litres; 393 km^2 vegetation loss; >1M people exposed; impacts persist 10+ years.
Onydinma et al. (2021)	PAHs common near auto workshops; Benzo[a]pyrene exceeded limit; sources petrogenic/combustion; risk quotients below EPA limit.
Ullah et al. (2021)	Sabotage spill clusters concentrated south, shifting west by 2018–19; sabotage spills rising, operational spills declining.
Umar et al. (2024)	DRAPSTIC/DRASTIC maps show high vulnerability in Ahoada East; aquifers polluted, unfit without treatment.
Lele et al. (2023)	PAHs below WHO limits; WQI excellent except Ogoloma (not potable); low PAH health risk.
Madu et al. (2021)	Rice-husk-ash filters purified water; PAHs reduced up to 85%; treated water within irrigation HM limits.

Citation	Findings
Benson et al. (2020)	PAH/PCB higher in upper sediment depths; PCBs exceeded ERM, PAHs below it; ecotoxicological risk to estuarine life.
Ganiyu et al. (2024)	PAHs from incomplete combustion, vehicle emissions, depot effluent; hazard index <1 (no adverse non-carcinogenic risk).
Bolade et al. (2021)	TPH degradation near-complete at 0.3–0.5M persulphate dosage; 76% removed at 0.7M within 8 days.
Unyimadu & Benson (2023)	Low-Cl PCBs dominant in sediment, high-Cl PCBs dominant in water; PCB levels unprecedentedly high at most sites.
Eboibi et al. (2023)	Maize cob biosorbent removed crude oil via physical sorption/film diffusion; effective, inexpensive natural sorbent.
Yakub et al. (2024)	38 microplastic polymer types identified; linked to oil platforms/trawlers/vessel discharge; low overall but high ecological risk.
Shokunbi et al. (2024)	Microplastics (fragments, fibres, films) found in all sediment samples; waste dumping main source, esp. Odo-Ona River.
Anyanwu et al. (2021)	PAH, N-PAH & ^{210}Pb activity increased with depth in Bodo Creek sediment cores.
Ighariemu et al. (2019)	THC/TPH increased across sampling stations; some stations slightly polluted, below international guidelines.
Edet et al. (2021)	PAHs low-MW in groundwater, high-MW in soil; soils heavily polluted; cancer risk significant, higher in children.
Ganiyu et al. (2023)	Low resistivity anomalies coincide with PAHs exceeding limits in >70% of samples.
Omokpariola et al. (2022)	TPH concentrations varied by rain period/location; hazard index >1 for aromatics; children more at risk.
Aralu et al. (2023)	PAH sources mixed (petrogenic & pyrolytic); non-cancer risk low; adults more cancer-susceptible than children.
Oyebamiji et al. (2024)	High-risk zones concentrated in central Niger Delta; ~16% of region at moderate–high risk.
Ololade et al. (2023)	PAHs higher in wet season; sources from combustion & petroleum; moderate–high carcinogenic potential.
Iniaghe & Kpomah (2023)	PAHs in Okpare River exceeded Udu River; carcinogenic PAHs prevalent; high carcinogenic risk from water ingestion.
Berezi et al. (2024)	Low ecological risk from PAHs in mangrove sediment; concentrations moderate; petroleum-derived PAHs dominant.
Eze et al. (2019)	Modified seed-husk sorbent removed >50% crude oil; Langmuir/Freundlich isotherms fit well.
Adeyeye et al. (2023)	Sediments more PAH-contaminated than water; fluoranthene, pyrene, anthracene most concentrated in fish.
Osadebe et al. (2024)	Biochar-iron oxide nanocomposite with bacteria effectively removed crude oil; shift to Pseudomonas/Acinetobacter dominance.
Eboibi et al. (2024)	Oil-palm fiber is an effective natural bio-adsorbent for oil-spill removal.
Okafor et al. (2024b)	PAH accumulation harmful to health, linked to cancer risk; ecological risk above EPA background.
Idomeh et al. (2021)	Petroleum hydrocarbon concentrations varied by season/location; Methylotenera useful for bioremediation.
Ugochukwu et al. (2021a)	PAHs from automotive workshops & abandoned coal mines; petrogenic sources; low human health risk.
Oyo-Ita et al. (2022)	PAH levels higher in wet season (terrigenous wash-in); sources predominantly petroleum & wood combustion.
Anifowose et al. (2022)	PAHs in Osun River sediment mainly pyrogenic; higher accumulation & organic contamination upstream.

Table 4 presents seven papers that examined heavy metals and PAHs together (three from the South-East, three from the South-West, and one from the South-South), and it shows that co-contamination raises risk and extends the evidence from concentrations to biological effects. In Ekulu (Enugu State), PAH contamination exceeded that of heavy metals, hazard indices indicated no acute health risk, but modelled lifetime cancer risk remained elevated (1 in 10,000 for PAHs; 1 in 100,000 for heavy metals over 70 years' exposure). In Aba (Abia

State), concentrations of Al, As, Cd, Cu, Fe, Mn, Ni, Pb, and Zn in leachate exceeded national and international limits, although only 15.38% of detected PAHs were carcinogenic. In Ibadan (Oyo State), ingestion hazard quotients for Lead, Cadmium, and Arsenic exceeded 1 for both children and adults, and Cadmium, Arsenic, Lead, and Chromium exceeded carcinogenic risk thresholds (up to 1.00×10^{-2}), particularly for children (Oni et al., 2022a). In the Forcados River (South-South), oil-field brine discharge produced high sediment contamination by Cd, Pb, Ba, Cr, and Fe, with the highest metal and PAH, TPH, BTEX, and phenol concentrations at the discharge point (Oyesanya & Omonona, 2021). Beyond chemical measurements, the table also records oxidative stress in fish (Ibor et al., 2019) and in mice exposed to polluted well water (Oni et al., 2022b), and fetal malformation and heritable DNA damage from landfill leachate (Fagbenro et al., 2024); at the same time, one study detected several metals in groundwater without reporting a risk (Ugochukwu et al., 2021b), so the evidence is consistent in direction but limited in number and in the absence of human epidemiological data.

Table 4: Papers with Combined Heavy Metal and PAH Contamination

Citation	Findings
Umeh et al. (2023)	Ecological indices medium–high pollution; children at higher carcinogenic risk; most HMs within limits except Cr, Pb.
Fagbenro et al. (2024)	Landfill leachate caused fetal skeletal malformations, mortality, and heritable DNA damage in mice.
Oni et al. (2022a)	Fe, Pb, As, Cd & PAHs exceeded limits; hazard index >1 in children; carcinogenic risk from Cd, As, Pb, Cr.
Ibor et al. (2019)	Oxidative stress & obesogenic biomarkers elevated in fish from contaminated lake; linked to metal/PAH tissue levels.
Oni et al. (2022b)	Dose-dependent oxidative stress markers in mice from polluted well water; liver histology confirmed damage.
Ugochukwu et al. (2021b)	Cu, Zn, Pb, Cd, Cr(VI) detected in groundwater; As & Al not detected.
Oyesanya & Omonona (2021)	River parameters exceeded WHO limits; Pb, Cr, Ni, As, Ba from oil-field brine were main contaminants.

Discussion

Studies of heavy metals and PAHs are concentrated in southern Nigeria, particularly the oil-producing South-South region, though contamination occurs nationwide (Egbueri et al., 2024; Achife, 2021; Ekere et al., 2017). Contamination composition and severity vary by location and source: dumpsite-adjacent groundwater in Ogun State contains Iron, Zinc, Lead, Copper, and Cadmium linked to industrial activity, battery waste, and vehicular emissions, with some values exceeding safety limits and posing cancer risk, while Anambra State studies show Lead, Cadmium, and Mercury exceeding permissible levels, with Cadmium posing the greatest risk to children (Emmanuel et al., 2022). Lagos dumpsites show a different metal composition again, reflecting geographic and waste-type variation (Agbeshie et al., 2020). Groundwater near scrap markets in Owerri shows elevated Lead, Nickel, and unsafe pH; Lead is the most frequently reported contaminant overall, linked to mining and waste disposal (Emmanuel et al., 2022; Egbueri et al., 2024; Eyankware & Obasi, 2021), whereas Cadmium dominates in Warri. Streams generally show higher contamination than wells and rivers, and Mercury and Arsenic were largely absent across the reviewed literature, consistent with earlier findings (Idowu, 2022).

PAH studies are similarly concentrated in the South-South, followed by the South-West and South-East. Anthropogenic drivers – gas flaring, oil exploration, petroleum storage, automobile repair, industrial discharge, and waste dumping – are consistently implicated across surface water, groundwater, sediment, soil, and even atmospheric rainwater. In Delta State, gas flaring was linked to elevated Iron, Zinc, Chromium, Cadmium, and PAHs in groundwater, decreasing with distance from flare sites, while PAH concentrations across the Niger Delta more broadly range from below detection to well above permissible standards (Ofori et al., 2021). Around oil depots in Oyo State, PAH concentrations exceeded safety limits in over 70% of samples, with children most vulnerable to carcinogenic risk (Ganiyu et al., 2023; 2024), and studies in Rivers State and Ogoniland documented extensive oil-spill contamination and vegetation mortality (Obida et al., 2021; Ullah et al., 2021). Similar patterns – PAHs, PCBs, TPHs, and microplastics exceeding international safety standards – recur across Southeastern Nigeria, Lagos Lagoon, Delta State, and southwestern rivers (Benson et al., 2020; Unyimadu & Benson, 2023; Ololade et al., 2023, 2025; Yakub et al., 2024; Shokunbi et al., 2024), though some studies report lower contamination or acceptable ecological risk (Lele et al., 2023; Berezi et al., 2024; Adeyeye et al., 2023; Nsonwu-Anyanwu et al., 2024). Most studies identify mixed petrogenic and pyrogenic sources (Okedere & Elehinafe, 2022; Okafor et al., 2024; Le et al., 2025), with bioaccumulation and biomagnification threatening aquatic biodiversity and human health (Odali et al., 2024a, 2024b; Olowojuni et al., 2025). Seasonal patterns vary by study, and while some propose bioremediation via indigenous bacteria as a solution (Idomeh et al., 2021), others note its adaptability remains limited and warrants further research (Davletgildeeva & Kuznetsov, 2024).

Several reviewed studies evaluated remediation technologies for petroleum hydrocarbon-contaminated water. Alkaline-activated sodium persulphate achieved up to 76% degradation of total petroleum hydrocarbons within eight days (Bolade et al., 2021), while ceramic candle filters made from rice husk ash, polyethylene glycol, and clay improved water quality for irrigation and household use, though not to drinking-water standard (Madu et al., 2021). Biosorptive efficiency of plantain leaves, and maize cobs was found to depend on crude-oil concentration, dosage, and particle size (Eboibi et al., 2023a, 2023b), and pineapple leaves showed strong, reusable oil-sorption capacity (Kelle et al., 2024). Agricultural-waste sorbents such as Dialium guineense seed husk removed over 50% of crude oil (Eze et al., 2019), and oil palm mesocarp fibre achieved 97.25% bio-sequestration efficiency (Eboibi et al., 2024). The most advanced approach – biochar–iron oxide nanoparticles combined with hydrocarbon-degrading bacteria and slow-release monoammonium phosphate in a sodium alginate matrix – achieved 98.5% total petroleum hydrocarbon and 90.3% PAH removal after forty days (Osadebe et al., 2024), suggesting nanobioremediation as a particularly promising direction.

Studies examining combined PAH and heavy-metal exposure consistently report medium-to-high ecological risk and significant long-term cancer risk from anthropogenic sources (Umeh et al., 2023), with well water near an Ibadan automobile junk market exceeding regulatory standards for Iron, Lead, Arsenic, Cadmium, and two carcinogenic PAHs, and children particularly vulnerable to dermal exposure (Oni et al., 2022a). Toxicity depends on contaminant mixture, concentration, location, and season (Souza et al., 2023; Adegbola &

Adetutu, 2024; Hemati et al., 2024), with wet-season concentrations generally exceeding dry-season levels and contamination decreasing downstream. Experimental exposure of mice to contaminated groundwater produced significant oxidative stress (elevated MDA and MPO), suggesting metabolic and physiological risk from prolonged exposure (Oni et al., 2022b), consistent with heavy-metal and PAH detections in hand-dug wells in Enugu State (Ugochukwu et al., 2021). Broader impacts documented in the literature include dermal-absorption carcinogenic risk from Naphthalene and Chromium (Hosseini et al., 2023), an association between mixed HM/PAH exposure and depression risk (Jiang & Zhao, 2024), oxidative and obesogenic responses in fish from Eleyele Lake (Ibor et al., 2019), fetal malformation and trans-generational genetic damage from landfill leachate exposure in mice (Fagbenro et al., 2024), and Forcados River contamination from oil-field brine (Oyesanya & Omonona, 2021) – though some sites, such as Prahovo Port, showed comparatively lower risk despite evidence of pollution (Radomirović et al., 2023).

In reference to Table 2 (heavy-metal studies), the recurrence of lead and cadmium above permissible limits is consistent with earlier assessments that identify lead as the most frequently reported contaminant in Nigerian waters (Emmanuel et al., 2022; Egbueri et al., 2024; Eyankware & Obasi, 2021), and the near absence of mercury and arsenic across the tabulated studies agrees with the prior review by Idowu (2022). However, with only eight studies in Table 2, this pattern may reflect which metals were measured as much as which are present, and the single biomarker study and single adsorption study in the table show how little exposure–outcome and treatment evidence exists for heavy metals.

In reference to Table 3 (PAH studies), the concentration of entries in the South-South and the dominance of flaring-, spill-, and depot-related sources match the documented Niger Delta pollution history (UNEP, 2011; Sun et al., 2017). The contrast within Table 3 between low-risk sites (Lele et al., 2023; Berezi et al., 2024) and high-risk sites (Ganiyu et al., 2023; Iniaghe & Kpomah, 2023) shows that PAH risk depends on local source, season, and exposure route, so regional averages should be interpreted cautiously. The remediation entries in Table 3 (Bolade et al., 2021; Madu et al., 2021; Osadebe et al., 2024) are promising but remain laboratory-scale and need field validation.

In reference to Table 4 (combined heavy-metal and PAH studies), the medium-to-high ecological risk and elevated cancer risk, especially for children (Umeh et al., 2023; Oni et al., 2022a), together with oxidative stress and developmental damage in exposed organisms (Ibor et al., 2019; Oni et al., 2022b; Fagbenro et al., 2024), suggest that contaminant mixtures may be more harmful than single-contaminant assessments imply. These are, however, modelled or animal-based outcomes rather than human epidemiological evidence. Taken together, Tables 2–4 indicate that the contamination burden and its risks are real but unevenly documented, and that closing the gaps in geographic coverage, repeated sampling, and exposure–outcome evidence is necessary before national risk profiles can be drawn.

Conclusion and recommendations

This review of 46 studies shows that heavy metal and PAH contamination of Nigerian surface water, groundwater, and sediments is widespread, driven mainly by oil and gas activities, waste dumping, and inadequate effluent control, and that severity ranges from mild to

serious relative to national and international guidelines, with children often the most at-risk group. Research effort is strongly skewed towards southern Nigeria, particularly the oil-producing South-South, and no eligible studies came from the North-Central, North-East, or North-West regions. Most studies rely on one-time sampling, and none provides epidemiological or biomonitoring evidence directly linking exposure to disease outcomes. Together, these gaps prevent nationally representative risk profiles and evidence-based policy.

Based on these findings, we recommend the following actions:

1. **Close the geographic gap.** Federal and state water and environment agencies, working with research funders, should commission baseline surveys of surface water, groundwater, and sediments in the North-West, North-East, and North-Central regions, prioritising areas with mining, intensive agriculture, and urban dumpsites.
2. **Establish long-term monitoring.** NESREA and state environmental agencies should maintain fixed sampling stations at documented hotspots (for example, the Niger Delta, Owerri, and Ibadan) and sample at least quarterly across wet and dry seasons for a minimum of two years, extending monitoring panels to emerging contaminants such as PFAS and pharmaceuticals.
3. **Standardise methods and reporting.** Researchers, reviewers, and journals should adopt a common minimum protocol: report all 16 US-EPA priority PAHs and a defined metal panel (Pb, Cd, Hg, As, Cr, Ni, Cu, Zn, Mn) with detection limits and QA/QC data, and compare results with NESREA limits and NIS 554:2015 using uniform risk metrics (hazard quotient, hazard index, and lifetime cancer risk).
4. **Prioritise groundwater and vulnerable users.** State water boards and local governments should test boreholes and hand-dug wells near dumpsites, scrap markets, oil depots, and gas-flare sites, and issue treatment or alternative-supply advisories for affected communities, giving priority to households with children.
5. **Link exposure to health outcomes.** Health agencies and universities should launch biomonitoring (for example, blood lead and cadmium) and cohort studies in communities where water-quality exceedances are confirmed.
6. **Strengthen enforcement and transparency.** NESREA should enforce effluent and gas-flaring limits at oil depots, dumpsites, and industrial sites, and publish monitoring results in an open, regularly updated national database.
7. **Pilot remediation at field scale.** Promising low-cost sorbents and nano-bioremediation approaches should be trialled at spill and effluent sites, with cost and performance reported, before wider adoption.

Declarations

Authors' Contributions: Tukur Ahijo and Naseer Durumin Iya had the idea for the article, Tukur Ahijo performed the literature search and data analysis, Naseer Durumin Iya drafted the article, and Sani Usman critically revised the work and proofread it.

Funding: Not applicable

Competing Interests: Not applicable

Ethics Approval: Not applicable

Code availability: Not applicable

Consent to participate: Not applicable

Consent for publication: Not applicable

Statements and Declarations: The authors have nothing to declare.

Availability of data and material: Not applicable

Use of AI tools (where applicable): Not applicable

Acknowledgements: No funding was received to assist with the preparation of this manuscript.

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