

Environmental Impact Assessment of Microbiological and Physicochemical Quality of Soil and Water During Dry Season in Udege Mining Area, Nasarawa State, Nigeria

Idris Adam Muhammed^{1*}, J. E. Owuna¹, S. O. Obikezie¹, U. Owuna²

¹Department of Microbiology, Faculty of Natural and Applied Sciences, Nasarawa State University, Keffi, Nigeria.

²Department of Environmental Management, Federal Polytechnic, Nasarawa, Nasarawa State, Nigeria

*Corresponding Author

DOI: <https://doi.org/10.51584/IJRIAS.2025.101100150>

Received: 12 December 2025; Accepted: 20 December 2025; Published: 27 December 2025

ABSTRACT

Mining activities significantly alter environmental quality during the dry season, when evaporation concentrates contaminants in soil and water. This study assessed the microbiological and physicochemical characteristics of soil and water during the dry season from the Udege mining area of Nasarawa State, Nigeria. Soil microbiological analysis revealed total heterotrophic bacterial counts of $1.89 \times 10^1 \pm 2.03$ cfu/g, with *Escherichia coli*, *Salmonella* spp., *Staphylococcus* spp., *Micrococcus* spp., *Bacillus* spp., and fungi present. Water samples showed total coliforms ($1.36 \times 10^1 \pm 3.2$ cfu/mL), *E. coli* ($2.25 \times 10^1 \pm 4.1$ cfu/mL), and fungi ($6.8 \times 10^1 \pm 2.1$ cfu/mL). Physicochemical analysis revealed slightly acidic water (pH 5.72–5.95), moderate conductivity (107.55 ± 7.06 μ S/cm), and elevated heavy metals. Soil characteristics included pH 6.78 ± 0.10 , organic carbon 2.21 ± 0.14 mg/kg and metals like Cd (0.029 mg/kg), Pb (0.031 mg/kg) and Cr (0.438 mg/kg). Results show increased pollutant concentration in the dry season, increasing health risks. This study provides baseline environmental data, signals the impacts and presence of resilient, potential environmentally utilizable organisms and highlights the need for improved mining regulation.

Keywords: Dry season, Udege mining, microbial contamination, heavy metals, physicochemical properties

INTRODUCTION

Mining activities remain one of the most significant anthropogenic drivers of environmental degradation, particularly in regions with extensive artisanal and small-scale mining operations. These activities introduce a combination of physicochemical and microbiological stressors into the ecosystem, altering soil quality, surface water integrity, and overall ecological resilience. The aim of this study was to assess the microbiological and physicochemical characteristics of soil and water during the dry season from the Udege mining area of Nasarawa State, Nigeria. Seasonal variations further modulate these impacts, influencing contaminant mobilization, microbial proliferation, and nutrient cycling in mining-impacted landscapes. During the dry season, reduced moisture and limited hydrological flow promote the concentration, persistence, and surface accumulation of contaminants, thereby increasing the vulnerability of exposed soil and water bodies to pollution (Edokpayi et al., 2016). In the Udege mining area of Nasarawa State, where artisanal mining constitutes a primary livelihood activity, the intensification of mining during the dry season enhances the release of heavy metals and microbial pollutants into adjacent environmental compartments (EA Journals, 2014; Ambo & Ogah, 2025). Understanding the seasonal dynamics of pollutants is therefore critical for environmental risk assessment. Seasonal differences in physicochemical parameters such as pH, dissolved oxygen, total hardness, nitrate, sulphate, and electrical conductivity are widely documented in mining environments and are key determinants of microbial survival and adaptation (Chapman, 1997; Bartram & Ballance, 1996). As observed in the Udege ecosystem, conductivity, total dissolved solids, and hardness were markedly higher in the dry season, reflecting enhanced mineral leaching and reduced dilution capacity (APHA, 2017). Similar trends have been reported in mining-impacted rivers in South Africa, where seasonal flow variations significantly shape trace metal distribution and water quality (Edokpayi et al., 2017). Microbial communities provide sensitive indicators of environmental change and contamination severity. Heavy metals derived from mining are known to exert selective pressure on microbial populations, promoting the emergence of resistant strains and altering ecological balance. Shahid et al. (2022)

demonstrated that heavy metal stress enhances co-resistance to antibiotics in microbial communities, while Zhang et al. (2021) reported the persistence of metal-tolerant bacteria in acid mine drainage environments. These mechanisms are consistent with observations in Nigerian gold-mining soils, where fungal assemblages maintain high diversity despite elevated cadmium and lead concentrations (Obayomi et al., 2023). Microbial proliferation and survival in mining-impacted environments are further influenced by physicochemical factors such as pH, temperature, organic matter content, and nutrient availability. Several studies emphasize the role of environmental parameters in shaping microbial distribution: Cheng & Chen (1999) established that pH and temperature regulate bacterial virulence, while Florini et al. (2020) observed that nutrient concentration significantly affects fecal coliform abundance in aquatic environments. In soils, microbial processes are intricately linked to moisture content, porosity, and organic carbon levels. Mining-disturbed soils often retain biological activity despite metal toxicity, as noted by Abdu et al. (2017), and fungi in particular exhibit remarkable adaptability to metal-rich or acidic substrates (Gadd, 2010). Furthermore, heavy metal contamination remains one of the most enduring signatures of mining activity. Metals such as iron, manganese, zinc, chromium, and lead are typically mobilized from geological formations during mining and persist in soils and water long after extraction has ceased (Eisler, 2004).

Given the environmental and public health implications associated with microbial and heavy metal contamination, comprehensive assessment of mining-impacted ecosystems is crucial. The Udege mining region, characterized by intense artisanal mining and limited environmental regulation, presents a clear case for such evaluation. Previous studies have also documented the socio-environmental challenges associated with Udege mining, including habitat degradation, water pollution, and health risks to local populations (EA Journals, 2014). By focusing specifically on dry-season conditions when pollutants are most concentrated and environmental dilution is minimal this study provides a clearer understanding of the peak ecological risks associated with mining activities. Through integrated microbiological and physicochemical assessment, the research contributes to a broader understanding of mining ecotoxicology and offers insights that support environmental monitoring, policy development, and remediation strategies.

MATERIALS AND METHODS

Soil and water samples were collected exclusively during the dry season around active mining areas. Microbiological analyses included enumeration of total heterotrophic bacteria (THB), heterotrophic fungi (THF), and indicator organisms using standard spread-plate techniques. Physicochemical parameters were analyzed following standard laboratory procedures, including pH, temperature, conductivity, TDS, hardness, and metals such as Mn, Fe, Zn, Cu, Pb, Ni, and Cr.

Samples Collection and Preparations

Soil and water samples were collected from active mining sites in the Udege area of Nasarawa State, Nigeria, exclusively during the dry season. About 100 soil samples were collected at a depth of 0–15 cm using a handdug soil auger and transferred directly into clean, sterile containers. Over 115 water samples were collected in sterile 500 mL bottles from surface sources near mining activity. All samples were transported immediately in cold storage containers to the laboratory to minimize microbial and chemical changes prior to analysis.

Isolation and Enumeration of Microorganisms from Soil and Water

Microbial populations in soil and water samples were determined using the spread plate technique. One gram of soil was suspended in 9 mL of sterile distilled water, while 1 mL of water sample was used directly. The suspensions were homogenized and subjected to ten-fold serial dilutions. Aliquots of 0.1 mL from appropriate dilutions were inoculated onto media like the Mannitol Salt Agar, Mineral Salt Agar, Salmonella shigella Agar and then Nutrient Agar (NA) for further bacterial growth enumeration and Sabouraud Dextrose Agar (SDA)/Potatoes Dextrose Agar (PSA) for fungal growth, in triplicates. Plates were incubated at $30 \pm 2^\circ\text{C}$ for 24–72 hours, and colonies were enumerated as colony-forming units per gram (cfu/g) for soil or per milliliter (cfu/mL) for water (Adams et al., 2014).

Indicator organisms including *Escherichia coli*, *Salmonella* spp., *Staphylococcus* spp., *Micrococcus* spp., *Bacillus* spp., and total coliforms were isolated using Eosin Methylene Blue agar, MacConkey agar, Xylose Lysine Deoxycholate agar, Salmonella–Shigella agar, Mannitol Salt Agar, Nutrient agar, and Violet Red Bile Agar.

Water samples were additionally analyzed for *Gluconobacter* and heterotrophic fungi. Microbial loads were expressed as mean \pm standard deviation.

Characterization and Identification of Bacterial and Fungal Isolates

Bacterial colonies were characterized based on colonial morphology, Gram staining, and biochemical tests including catalase, coagulase, indole, urease, MR-VP, citrate, and oxidase tests (Cheesbrough, 2006). Sugar fermentation tests were used to confirm species identity. Fungal isolates were identified through cultural and microscopic characteristics, observing colony morphology, mycelial structure, and spore arrangement using lactophenol cotton blue stain (David et al., 2007). Gram staining followed standard procedures, with Gram-positive organisms retaining purple color and Gram-negative organisms appearing red under $\times 100$ oil immersion microscopy.

Determination of Physicochemical Parameters

Physicochemical analyses were conducted on both soil and water samples using standard laboratory methods.

Soil Analyses: Soil parameters measured included temperature, pH, moisture content, porosity, bulk density, wet and dry density, organic carbon, nitrate, sulphate, and particle size distribution (sand, silt, clay). Temperature was measured using a laboratory thermometer, while moisture content was determined gravimetrically. Bulk and dry densities were calculated using the core method, and porosity was derived from bulk and particle densities. Nutrients (nitrate and sulphate) were measured using spectrophotometric methods (Awari et al., 2020).

Water Analyses: Water parameters included temperature, pH, conductivity, total dissolved solids (TDS), total suspended solids (TSS), total hardness, dissolved oxygen (DO), biological oxygen demand (BOD), chemical oxygen demand (COD), nitrate, chloride, and sulphate. Temperature and pH were measured using a calibrated meter, while conductivity and TDS were measured using a conductivity meter. BOD and COD were determined using standard titrimetric methods, and DO was measured via Winkler titration. All analyses were performed in triplicate, and results were expressed as mean \pm standard deviation.

Determination of Heavy Metals

Heavy metal concentrations in soil and water were determined using atomic absorption spectrophotometry (AAS) following standard procedures.

Soil: Air-dried soil samples were sieved (2 mm), weighed (1 g), and digested using a mixture of concentrated nitric acid (HNO_3) and perchloric acid (HClO_4). The digest was filtered and diluted with deionized water prior to analysis. Metals analyzed included cadmium (Cd), lead (Pb), chromium (Cr), iron (Fe), zinc (Zn), copper (Cu), nickel (Ni), manganese (Mn), calcium (Ca), magnesium (Mg), and potassium (K) (Abdulkarim et al., 2019).

Water: Water samples were filtered using Whatman No. 1 filter paper and acidified with 1% nitric acid to prevent precipitation. The filtrate was analyzed for Cd, Pb, Cr, Fe, Zn, Cu, Ni, and Mn using AAS. Calibration curves for each metal were constructed using certified metal standards, and results were expressed as mg/kg for soil and mg/L for water.

All physicochemical and heavy metal analyses were performed in triplicate, and data were reported as mean \pm standard deviation to ensure accuracy and reproducibility.

Statistical Analysis

All analyses were carried out in triplicate, except particle size distribution and heavy metal concentrations which were determined once per composite sample. Results are presented as mean \pm standard deviation (SD). Data were summarized using descriptive statistics and analyzed using Microsoft Excel.

RESULTS AND DATA PRESENTATION

The microbiological, physicochemical, and heavy metal characteristics of soil and water samples during the dry season are presented in Tables 1–6. Overall, the results reflect moderate microbial presence, relatively stable physicochemical conditions, and low concentrations of heavy metals, consistent with dry season environmental dynamics.

Microbiological Characteristics of Soil and Water

Dry season soil microbial counts (Table 1) showed that total heterotrophic bacteria recorded a mean value of $1.89 \times 10^1 \pm 2.03$ cfu/g, indicating active but moderate microbial activity in the soil matrix. Among the pathogenic indicators, *Bacillus* spp. exhibited the highest population ($6.68 \times 10^1 \pm 2.65$ cfu/g), reflecting their spore-forming ability and persistence under low-moisture conditions. *Staphylococcus* spp. and *Escherichia coli* were also detected at $4.5 \times 10^1 \pm 1.6$ cfu/g and $3.2 \times 10^1 \pm 1.4$ cfu/g, respectively, suggesting limited fecal and anthropogenic influence during the dry season. *Salmonella* spp. and *Micrococcus* spp. occurred at comparatively lower levels, while heterotrophic fungi recorded $4.2 \times 10^1 \pm 1.5$ cfu/g, indicating reduced fungal proliferation due to moisture limitation.

Water microbial counts during the dry season (Table 2) followed a similar trend of moderate contamination. Total coliforms recorded $1.36 \times 10^1 \pm 3.2$ cfu/mL, reflecting minimal fecal input under low runoff conditions. *Gluconobacter* showed the highest bacterial count ($6.41 \times 10^1 \pm 1.16$ cfu/mL), possibly due to its adaptability to nutrient-limited aquatic environments. *Escherichia coli* and *Salmonella* spp. were detected at $2.25 \times 10^1 \pm 4.1$ cfu/mL and $2.48 \times 10^1 \pm 3.8$ cfu/mL, respectively, indicating the presence of pathogenic indicators, albeit at relatively low levels. Fungal counts were moderate ($6.8 \times 10^1 \pm 2.1$ cfu/mL), consistent with reduced organic matter inflow during the dry season.

Table 1: Dry Season Soil Microbial Counts

Parameter	Value	Unit
Total Heterotrophic	$1.89 \times 10^1 \pm 2.03$	cfu/g
Bacteria		
<i>E. coli</i>	$3.2 \times 10^1 \pm 1.4$	cfu/g
<i>Salmonella</i> spp.	$2.7 \times 10^1 \pm 1.1$	cfu/g
<i>Staphylococcus</i> spp.	$4.5 \times 10^1 \pm 1.6$	cfu/g
<i>Micrococcus</i> spp.	$1.89 \times 10^1 \pm 0.76$	cfu/g
<i>Bacillus</i> spp.	$6.68 \times 10^1 \pm 2.65$	cfu/g
Heterotrophic Fungi	$4.2 \times 10^1 \pm 1.5$	cfu/g

Table 2: Dry Season Water Microbial Counts

Parameter	Value	Unit
Total Coliform	$1.36 \times 10^1 \pm 3.2$	cfu/mL
<i>Micrococcus</i>	$1.28 \times 10^1 \pm 2.32$	cfu/mL
<i>E. coli</i>	$2.25 \times 10^1 \pm 4.1$	cfu/mL
<i>Gluconobacter</i>	$6.41 \times 10^1 \pm 1.16$	cfu/mL
<i>Salmonella</i> spp.	$2.48 \times 10^1 \pm 3.8$	cfu/mL
<i>Bacillus</i> spp.	$4.57 \times 10^1 \pm 8.13$	cfu/mL
<i>Staphylococcus</i> spp.	$1.68 \times 10^1 \pm 3.5$	cfu/mL
Heterotrophic Fungi	$6.8 \times 10^1 \pm 2.1$	cfu/mL

Physicochemical Properties of Soil and Water

The physicochemical characteristics of soil samples (Table 3) revealed a mean temperature of 28.35 ± 0.65 °C and a slightly acidic to near-neutral pH (6.78 ± 0.10), conditions favorable for microbial survival. Particle size distribution indicated a silt-dominated soil (41.76%), followed by sand (39.12%) and clay (19.12%), suggesting moderate permeability and nutrient retention capacity. Soil moisture content was low (0.29%), consistent with dry season conditions and the observed reduction in microbial abundance. Organic carbon (2.21 ± 0.14 mg/kg) and nutrient levels (sulphate: 38.25 ± 1.85 mg/kg; nitrate: 4.72 ± 1.05 mg/kg) were sufficient to sustain baseline microbial activity.

Water-0.62 °C and slightly acidic pH values (5.72–5.95). Electrical conductivity ($107.55 \pm 7.06 \mu\text{S/cm}$) and total dissolved solids ($59.36 \pm 4.11 \text{ mg/L}$) were relatively low, indicating limited mineral dissolution during the dry season. Dissolved oxygen ($3.31 \pm 0.30 \text{ mg/L}$) and biochemical oxygen demand ($1.44 \pm 0.17 \text{ mg/L}$) suggest moderate oxygen availability and low organic pollution. Nutrient concentrations, including nitrate ($1.43 \pm 0.28 \text{ mg/L}$) and sulphate ($22.10 \pm 1.02 \text{ mg/L}$), were within ranges typical of dry season surface waters

Table 3: Dry Season Soil Physicochemical Properties

Parameter	Value	Unit
Temperature	28.35 ± 0.65	°C
pH	6.78 ± 0.10	–
Sand	39.12	%
Silt	41.76	%
Clay	19.12	%
Moisture	0.29	%
Porosity	30.42 ± 4.80	%
Wet Density	1.03 ± 0.05	g/cm^3
Dry Density	1.05 ± 0.04	g/cm^3
Bulk Density	1.06 ± 0.05	g/cm^3
Organic Carbon	2.21 ± 0.14	mg/kg
Sulphate	38.25 ± 1.85	mg/kg
Nitrate	4.72 ± 1.05	mg/kg

Heavy Metal Concentrations in Soil and Water

Soil heavy metal concentrations (Table 4) showed that major elements such as calcium (17.02 mg/kg), potassium (11.08 mg/kg), and magnesium (8.12 mg/kg) predominated, reflecting natural soil mineral composition. Trace metals including cadmium (0.029 mg/kg), lead (0.031 mg/kg), nickel (0.079 mg/kg), and chromium (0.438 mg/kg) occurred at low concentrations, suggesting minimal contamination and limited anthropogenic input during the dry season.

Similarly, water heavy metal concentrations (Table 6) were generally low, with iron (0.52 mg/L) and manganese (0.11 mg/L) being the most abundant. Toxic metals such as lead (0.02 mg/L), nickel (0.01 mg/L), and chromium (0.06 mg/L) were detected at trace levels, indicating limited mobilization of metals into the aquatic environment under dry season hydrological conditions.

Table 4: Dry Season Soil Heavy Metals

Metal	Value	Unit
Calcium	17.02	mg/kg
Magnesium	8.12	mg/kg
Potassium	11.08	mg/kg
Manganese	0.93	mg/kg
Copper	3.92	mg/kg
Iron	4.12	mg/kg
Zinc	0.93	mg/kg
Cadmium	0.029	mg/kg
Lead	0.031	mg/kg
Nickel	0.079	mg/kg
Chromium	0.438	mg/kg

Table 5: Dry Season Water Physicochemical Properties

Parameter	Value	Unit
Temperature	27.45 ± 0.62	°C
pH	5.72–5.95	-
Conductivity	107.55 ± 7.06	µS/cm
Total Dissolved Solids	59.36 ± 4.11	mg/L
Total Suspended Solids	0.06 ± 0.005	mg/L
Total Hardness	256.65 ± 15.55	mg/L
Nitrate	1.43 ± 0.28	mg/L
Total Chlorine	3.39 ± 0.25	mg/L
Sulphate	22.10 ± 1.02	mg/L
BOD	1.44 ± 0.17	mg/L
COD	8.00 ± 0.81	mg/L
Dissolved Oxygen	3.31 ± 0.30	mg/L

Table 6: Dry Season Water Heavy Metals

Metal	Value	Unit
Manganese	0.11	mg/L
Iron	0.52	mg/L
Zinc	0.13	mg/L
Copper	0.01	mg/L
Lead	0.02	mg/L
Nickel	0.01	mg/L
Chromium	0.06	mg/L

DISCUSSION

The dry-season assessment of soil and water in the Udege mining area revealed notable microbial and physicochemical variations, indicative of the impact of mining activities on environmental quality. From Tables 1 and 2, the microbial populations in soil and water were elevated, with *Bacillus* spp., *Staphylococcus* spp., and *E. coli* dominating both matrices. The high heterotrophic bacterial and fungal counts observed may be attributed to microbial adaptation and utilization of organic and inorganic nutrients present in mining-impacted soils and water. Similar observations were reported by Idowu et al. (2017), who noted that mining operations significantly increase microbial populations in impacted soils due to nutrient enrichment and pollutant availability.

In soil, *Bacillus* spp. recorded the highest counts ($6.68 \times 10^1 \pm 2.65$ cfu/g), while in water, *Gluconobacter* and heterotrophic fungi were predominant ($6.41 \times 10^1 \pm 1.16$ cfu/mL and $6.8 \times 10^1 \pm 2.1$ cfu/mL, respectively). These microbial patterns reflect differences in nutrient accessibility and environmental resilience. For instance, *Bacillus* spp. are well-known for their ability to survive under low moisture conditions characteristic of the dry season, and their metabolic versatility may account for their dominance in soil (Onuoha et al., 2014). Fungal proliferation in water could be linked to elevated dissolved organic matter, providing carbon sources for fungal growth (Wokem & Madufuro, 2020).

Physicochemical analysis (Tables 3–5) revealed slightly acidic water (pH 5.72–5.95) and moderately acidic soil (pH 6.78 ± 0.10), which can influence microbial diversity and activity. Elevated heavy metals in soil and water, including Pb, Cr, and Cd, indicate potential contamination from artisanal mining, which aligns with findings by

Abdulkarim et al. (2019). The accumulation of metals during the dry season is likely due to low rainfall and high evaporation rates, which concentrate pollutants in the environment.

Soil properties, such as moderate organic carbon (2.21 ± 0.14 mg/kg), porosity ($30.42 \pm 4.80\%$), and bulk density (1.06 ± 0.05 g/cm³), support microbial colonization by providing suitable habitats and substrates. The presence of microbial genera capable of tolerating heavy metals, such as *Bacillus* and *Micrococcus*, suggests potential for natural attenuation, but also highlights health risks if pathogenic species persist (Ijah et al., 2013).

Overall, these results demonstrate that the dry season amplifies pollutant concentrations, which influences microbial populations and poses environmental and public health concerns. The observed trends suggest that interventions aimed at mitigating heavy metal contamination and microbial pollution are essential, particularly during periods of low rainfall.

CONCLUSION

This study revealed that mining activities in the Udege area significantly impact soil and water quality during the dry season. Elevated microbial counts, presence of pathogenic species, and accumulation of heavy metals highlight the environmental risks associated with artisanal mining. Soil and water physicochemical parameters suggest that dry season conditions exacerbate pollutant concentration, potentially affecting ecosystem and human health.

Notably, this study provides the first comprehensive baseline dataset integrating microbiological, physicochemical, and heavy metal analyses for soils and waters in the Udege mining area, filling a critical knowledge gap for environmental monitoring in artisanal mining regions. These findings add significant value and underscore the need for stricter mining regulation, effective waste management, and remediation strategies to reduce contamination. Future research should investigate seasonal variations and explore the potential for microbial-mediated bioremediation in mining-impacted environments.

REFERENCE

1. Adams, G. O., Tawari-Fufeyin, P., & Ehinomen, I. (2014). Bioremediation of spent oil-contaminated soils using poultry litter. *Research Journal in Engineering and Applied Sciences*, 3(2), 124–130.
2. Abdulkarim, A. Y., Bello, A. A., Abdulsalam, S., Umar, S. A., & Sadiq, M. B. (2019). Bioremediation of soil contaminated with spent motor oil. *Iconic Research and Engineering Journal*, 3(3), 16–22.
3. Ambo, A. I., & Ogah, G. O. (2025). Evaluation of the impact of mining activities and environmental remediation strategy in Udege-Beki town, Nasarawa LGA, Nasarawa State. *Science World Journal*, 20(1). <https://dx.doi.org/10.4314/swj.v20i1.14>
4. APHA. (1998). *Standard methods for the examination of water and wastewater* (20th ed.). American Public Health Association.
5. American Public Health Association (APHA), American Water Works Association (AWWA), & Water Environment Federation (WEF). (2017). *Standard methods for the examination of water and wastewater* (23rd ed.). APHA Press.
6. Anthony, H., Arnscheidt, J., Joyce, E., & O'Toole, J. (2018). An assessment of the performance of municipal constructed wetlands in Ireland. *Journal of Environmental Management*. <https://www.sciencedirect.com>
7. Anyamene, N. C., & Ojiagu, D. K. (2014). Bacteriological analysis of sachet water sold in Awka Metropolis, Nigeria. *International Journal of Agriculture and Biosciences*, 3(3), 120–122. <http://www.ijagbio.com/pdf-files/volume-3-no-3-2014/120-122.pdf>
8. Awari, V. G., Ogbonna, D. N., & Nrior, R. R. (2020). Bio-stimulation approach in bioremediation of crude oil-contaminated soil using fish waste and goat manure. *Microbiology Research Journal International*, 30(1), 33–46.
9. Baker-Austin, C., Wright, M. S., & Stepanauskas, R. (2006). Co-selection of antibiotic and metal resistance. *Trends in Microbiology*, 14(4), 176–182. [https://www.cell.com/trends/microbiology/fulltext/S0966-842X\(06\)00051-5](https://www.cell.com/trends/microbiology/fulltext/S0966-842X(06)00051-5)

10. Bartram, J., & Ballance, R. (1996). *Water quality monitoring: A practical guide to the design and implementation of freshwater quality studies and monitoring programmes*. CRC Press. <https://doi.org/10.4324/9780203476796>
11. Bhaduri, D., Purakayastha, T. J., Patra, A. K., & Chakraborty, A. (2022). A review on effective soil health bio-indicators for monitoring anthropogenic impacts. *Frontiers in Microbiology*, 13, 938481. <https://doi.org/10.3389/fmicb.2022.938481>
12. Brady, N. C., & Weil, R. R. (2019). *The nature and properties of soils* (15th ed.). Pearson Education.
13. Brennan, F. P., Grant, J., Botting, C. H., O'Flaherty, V., Richards, K. G., & Abram, F. (2013). Centers for Disease Control and Prevention. National Shiga Toxin-Producing *Escherichia coli* (STEC) Surveillance Annual Report. CDC.
14. Chapman, D. (1997). *Water quality assessment: A guide to the use of biota, sediments and water in environmental monitoring*. UNESCO/WHO/UNEP.
15. Cheesbrough, M. (2006). *District laboratory practice in tropical countries* (2nd ed.). Cambridge University Press.
16. Cheng, W., & Chen, J. C. (1999). Effect of cultivation broth pH, temperature and NaCl concentration on virulence of an *Enterococcus*-like bacterium. *Diseases of Aquatic Organisms*, 36, 233–237.
17. David, E., Stephen, D., Alexious, H., Handike, R., & Bartley, R. (2007). *Description of medical fungi* (2nd ed.). National Library of Australia.
18. Dunling, W., & Fiessel, W. (2008). Evaluation of media for enumeration of coliform and *E. coli* in drinking water. *Journal of Environmental Sciences*, 20, 273–277.
19. EA Journals. (2014). Socio-economic and environmental impacts of surface mining, Udege District, Nasarawa State, Nigeria. *International Journal of Environmental and Public Health Research*.
20. Edberg, S. C., Rice, E. W., Karlin, R. J., & Allen, M. J. (2000). *Escherichia coli: The best biological indicator for public health protection*. Symposium Series of the Society for Applied Microbiology, 88, 106S–116S.
21. Edokpayi, J. N., Odiyo, J. O., & Durowoju, O. S. (2017). Impact of wastewater on surface water quality in developing countries. *Water Quality. InTech*.
22. Edokpayi, J. N., Odiyo, J. O., Popoola, O. E., & Msagati, T. (2016). Assessment of trace metals contamination of surface water and sediment. *Sustainability*.
23. Eisler, R. (2004). Arsenic hazards to humans, plants and animals from gold mining. *Reviews of Environmental Contamination and Toxicology*. https://link.springer.com/chapter/10.1007/0-387-21729-0_3
24. Emerson, S., & Abell, J. (2001). The biological pump in the subtropical North Pacific Ocean. *Global Biogeochemical Cycles*. <https://agupubs.onlinelibrary.wiley.com>
25. Escobar-Paramo, P., Le Menac'h, A., Le Gall, T., Amorin, C., Gouriou, S., Picard, B., Skurnik, D., & Denamur, E. (2006). Forces shaping commensal *E. coli* genetic structure. *Environmental Microbiology*, 8, 1975–1984.
26. Evans, T. M., LeChevallier, M. W., Waarvick, C. E., & Seidler, R. J. (1981). Coliform species from surface water and drinking water. *Applied and Environmental Microbiology*, 41, 657–663.
27. Florini, S., Shahsavari, E., Ngo, T., Aburto-Medina, A., Smith, D. J., & Ball, A. S. (2020). Factors influencing fecal coliforms in oysters. *Water*, 12, 1086.
28. Fomina, M., & Skorochod, I. (2020). Microbial interaction with clay minerals and its environmental and biotechnological implications. *Minerals*.
29. Gadd, G. (2010). Fungal adaptation to metal-rich environments. *Microbial Biotechnology*, 10(5). <https://doi.org/10.1111/1751-7915.12767>
30. Obayomi, O. O., Sulaiman, M. B., Oluwasola, H. O., Sulaiman, A. B., Akpomie, K. G., Odewole, O. A., Otunomo, I. I., & David, M. K. (2023). Ecological risk assessment of potentially toxic elements in bottom sediments of a stream in Oke-Ere, Kogi State, Nigeria. *International Journal of Environmental Science and Technology*, 20, 13107–13118. <https://doi.org/10.1007/s13762-023-05076-3>
31. Onuoha, S. C., & Fatokun, K. (2014). Bacterial contamination and public health risks associated with the use of ATMs in Ebonyi State, Nigeria. *American Journal of Public Health Research*, 2(2), 46–50. <https://doi.org/10.12691/ajphr-2-2-2>
32. Shahid, M., Natasha, N., Bibi, I., Iqbal, J., Khalid, S., Murtaza, B., Bakhat, H. F., Farooq, A. B. U., Amjad, M., Hammad, H. M., Niazi, N. K., & Arshad, M. (2022). Zinc in soil–plant–human system: A

- data-analysis review. *Science of the Total Environment*, 808, 152024. <https://doi.org/10.1016/j.scitotenv.2021.152024>
33. Wokem, V. C., & Madufuro, C. (2020). Application of cow dung and sawdust as biostimulants for enhanced bioremediation of diesel-contaminated soil. *Journal of Applied Sciences and Environmental Management*, 24(1), 49–57.
34. Zheng, X., Lu, Y., Xu, J., Geng, H., & Li, Y. (2023). Assessment of heavy metals leachability characteristics and associated risk in acid mine drainage-contaminated river sediments from North China. *Journal of Cleaner Production*, 413, 137338. <https://doi.org/10.1016/j.jclepro.2023.137338>