

ASSESSMENT OF HEAVY METAL CONCENTRATIONS AND PHYSICOCHEMICAL PROPERTIES OF EFFLUENT FROM NUMAN ABATTOIR: IMPLICATIONS FOR ENVIRONMENTAL HEALTH AND REGULATORY COMPLIANCE IN NORTHEASTERN NIGERIA

Ezekiel, O. F¹; Sara G. Yahaya² and Caleb S. Nina³

^{1&3}Biomedical and Pharmaceutical Technology, Federal Polytechnic Mubi, Adamawa State, Nigeria, ²Chemistry Department, Umar Suleiman College of Education Gashu'a, Yobe State, Nigeria

¹frezonor@gmail.com, frezonor2003@yahoo.com

²sygalo0066@gmail.com

³elcalebson2995@gmail.com

ABSTRACT

A study was conducted to evaluate the physicochemical parameters and heavy metal concentrations in effluent samples from Numan Abattoir (NAB) in Adamawa State, Northeastern Nigeria, comparing them against World Health Organization (WHO) drinking water quality guidelines and Nigerian Standard for Drinking Water Quality (NSDWQ, SON, 2019): Implications for Environmental Health and Regulatory Compliance in Northeastern Nigeria. The specific objectives were to: determine the physicochemical characteristics including pH, temperature, conductivity, TDS, DO, BOD, and COD of effluent samples; quantify the concentrations of cadmium, chromium, iron, lead, and manganese; compare measured values against established regulatory standards; and discuss implications for environmental management and public health protection. The abattoir produces large amounts of wastewater containing organic pollutants and heavy metals that can pose risks to the environment and public health if not adequately treated before discharge. In this study the physicochemical parameters and heavy metal concentrations in effluent samples from Numan Abattoir (NAB) in Adamawa, Nigeria were collected from the NAB wastewater discharge point on three separate occasions (NAB_{WW1}, NAB_{WW2}, NAB_{WW3}) using standard sampling protocols, evaluated and compared with the World Health Organization (WHO) and National Environmental Standards and Nigerian Standard for Drinking Water Quality (NSDWQ, SON, 2019) permissible limits. The effluent samples, NAB_{WW1}, NAB_{WW2}, NAB_{WW3} were analyzed for pH, temperature, conductivity and total dissolved solids (TDS) using pH/conductivity meter (Jenway 430), dissolved oxygen (DO), biological oxygen demand (BOD) and chemical oxygen demand (COD) using DR Spectrometer and concentrations of cadmium (Cd), chromium (Cr), iron (Fe), lead (Pb) and manganese (Mn) using Atomic Absorption Spectrometer (model AA240FS Varian). Results revealed significant non-compliance with both WHO and NSDWQ standards across multiple parameters. pH values ranged from 8.28 ± 0.0071 to 10.11 ± 0.0100 , with NAB_{WW1} and NAB_{WW3} exceeding permissible limits, indicating alkaline conditions. Dissolved oxygen levels (1.2 to 1.2 ± 0.1000 mg/L) were critically below the minimum requirement, reflecting severe organic pollution. Iron concentrations (6.934 ± 0.0003 to 47.095 ± 0.0019 mg/L) exceeded limits by 23 to 157 times, with NAB_{WW1} showing exceptionally elevated levels. Manganese concentrations (0.934 ± 0.0010 to 1.282 ± 0.0013 mg/L) exceeded guidelines by 9 to 13 times. Cadmium levels (0.007 ± 0.0003 to 0.009 ± 0.0005 mg/L) exceeded limits by 2.3 to 3.0 times. Chromium and lead were undetectable. COD values for NAB_{WW3} (24 ± 1.0000 mg/L) substantially exceeded permissible limits, indicating high chemical oxygen demand. These findings highlight critical environmental and public health concerns, necessitating urgent implementation of wastewater treatment interventions, enhanced regulatory enforcement, and adoption of sustainable abattoir waste

management practices to protect receiving water bodies and surrounding communities. These findings can help regulators such as NSDWQ review national discharge limits, enforce stricter monitoring, and the methodology provides a replicable framework for other beverage industries in Nigeria to assess their environmental performance. Moreover, the results provide important information to local communities and public health officials to promote sound environmental management and protect downstream water users from potential heavy metal exposure.

Keywords: *Abattoir effluent, heavy metals, physicochemical parameters, wastewater treatment, environmental compliance, Nigeria, public health*

INTRODUCTION

The livestock processing industry, especially abattoir operations, constitutes a significant source of environmental pollution in developing countries, where rapid urbanization and increasing meat consumption have led to the proliferation of slaughterhouses without corresponding investment in waste management infrastructure (Adesina & Ogunyemi, 2025). Abattoir wastewater is characterized by high organic loads, suspended solids, nutrients, pathogenic microorganisms, and potentially toxic heavy metals, which can severely degrade receiving water bodies and pose substantial risks to human health and aquatic ecosystems (Adeyemi & Oladipo, 2024). In Nigeria, where traditional livestock processing practices often prevail and regulatory enforcement remains challenging, abattoir effluent constitutes a major environmental concern, particularly in peri-urban and rural areas (Ogunbiyi *et al.*, 2025).

Heavy metals of special significance in abattoir effluent include cadmium, chromium, iron, lead, and manganese. Cadmium, a highly toxic metal with a biological half-life exceeding 15 years, accumulates primarily in the kidneys and liver, causing renal dysfunction, bone demineralization, and increased cancer risk (Mitra *et al.*, 2022; Farahmandian *et al.*, 2024). Iron, while needed in trace amounts, causes aesthetic and operational problems at elevated concentrations and can contribute to iron overload conditions (Acharya, 2024). Manganese neurotoxicity has been observed at chronic exposure levels above WHO guidelines, specifically impacting cognitive function and motor control (Ogunbiyi *et al.*, 2025). Lead, even at low concentrations, causes cognitive damage in children and cardiovascular effects in adults (Farahmandian *et al.*, 2024; Kulkarni *et al.*, 2024).

In Nigeria, the regulatory framework for water quality includes the Nigerian Standard for Drinking Water Quality (NSDWQ, SON, 2019), issued by the Standards Organisation of Nigeria. This standard provides criteria for drinking water quality indicators and supports international standards such as those of the World Health Organization (WHO, 2018). However, enforcement of these standards remains challenging, particularly for industrial and agricultural operations (Okocha & Nuthall, 2025). The NSDWQ standards, while aligned with WHO guidelines in many respects, provide specific Nigerian context for water quality management.

The Numan Abattoir, located in Numan Local Government Area of Adamawa State, northeastern Nigeria, serves as a major livestock processing facility for the region. The abattoir processes cattle, sheep, and goats, generating substantial wastewater volumes that are often discharged directly into nearby water bodies without adequate treatment (Ibrahim *et al.*, 2025). Given the region's dependence on surface water for domestic, agricultural, and fishing activities, the quality of abattoir effluent and its potential environmental and health impacts warrant urgent investigation. Despite growing awareness of industrial pollution in Nigeria (Kolawole *et al.*, 2026; Okocha & Nuthall, 2025), limited published data exist on the quality of effluent from abattoirs in northeastern Nigeria and their compliance with both international and national standards.

This study aimed to assess the physicochemical properties and heavy metal concentrations in effluent from Numan Abattoir and evaluate compliance with World Health Organization (WHO) drinking water quality guidelines and Nigerian Standard for Drinking Water Quality (NSDWQ, SON, 2019). The specific objectives were to: determine the physicochemical characteristics including pH, temperature, conductivity, TDS, DO, BOD, and COD; quantify cadmium, chromium, iron, lead, and manganese concentrations; compare measured values against WHO and NSDWQ permissible limits; and discuss implications for environmental management, public health, and regulatory enforcement in the context of Nigerian abattoir operations.

MATERIALS AND METHODS

The Area of Study

Numan Abattoir is located in Numan Local Government Area, Adamawa State, northeastern Nigeria (approximate coordinates: 9°27'N, 12°02'E). The abattoir operates as a traditional livestock processing facility, handling approximately 150-200 cattle, 300-500 sheep, and 200-300 goats weekly, primarily supplying meat to Numan town and surrounding communities (Ibrahim *et al.*, 2025). The facility lacks a formal wastewater treatment system, with effluent discharged through open drains into a nearby stream that serves as a water source for downstream communities.

Sample Collection

Effluent samples were collected from the main discharge point of Numan Abattoir on three separate occasions (designated NAB_{WW1}, NAB_{WW2}, NAB_{WW3}) using standard sampling protocols. Grab samples were collected in acid-washed 2-liter polyethylene bottles, preserved according to standard methods, and transported to the laboratory under refrigerated conditions (4°C) for analysis within 24 hours of collection. Field measurements of temperature and pH were performed at the collection point using a calibrated portable meter.

Physicochemical Analysis

Physicochemical parameters were determined following standard analytical methods. pH, temperature, conductivity, and total dissolved solids (TDS) using a pH/conductivity meter (Jenway 430), dissolved oxygen (DO), biological oxygen demand (BOD) and chemical oxygen demand (COD) using a DR Spectrometer.

Heavy Metal Analysis

Heavy metal concentrations (cadmium, Cd., chromium, Cr., iron, Fe., lead, Pb and manganese, Mn) were determined using Atomic Absorption Spectrometer (model AA240FS Varian). Standard calibration curves were prepared using certified reference standards. All analyses were performed in triplicate, and results were expressed as mean $\pm$ standard deviation in milligrams per liter (mg/L).

Data Analysis

Data collected were subjected to analysis of variables as contained in SPSS version 23.0 (2017). Results were expressed as mean $\pm$ standard deviation.

Regulatory Comparison

The result of the study were compared against permissible limits established by the World Health Organization (WHO, 2018) for drinking water quality and effluent discharge guidelines, and the Nigerian Standard for Drinking Water Quality (NSDWQ, SON, 2019). Both standards were used as

they represent internationally recognized benchmarks for protecting human health and the Nigerian regulatory framework, respectively.

RESULTS AND DISCUSSION

The physicochemical parameters and heavy metal concentrations of effluent samples from Numan Abattoir are presented in Table 1, with comparative standards from WHO (2018) and NSDWQ (SON, 2019) drinking water quality guidelines.

Physicochemical Parameters

pH: The pH values ranged from 8.28 ± 0.0071 to 10.11 ± 0.0100 , indicating alkaline to strongly alkaline conditions in the effluent. Two samples (NAB_{ww1} at pH 10.11 and NAB_{ww3} at pH 9.90) substantially exceeded the WHO and NSDWQ permissible range of 6.5 to 8.5, while NAB_{ww2} (pH 8.28 ± 0.0071) marginally exceeded the upper limit. The wide variation in pH across samples suggests inconsistent wastewater characteristics, likely influenced by variations in abattoir operations, cleaning practices, and waste composition.

Temperature: Temperature readings were consistent across samples, ranging from 27.4 ± 0.1000 °C to 28.4 ± 0.0707 °C, well below the WHO and NSDWQ guideline of <40 °C for effluent discharge. These values are typical for tropical ambient temperatures and do not pose thermal pollution concerns.

Conductivity and TDS: Electrical conductivity values ranged from 7.8 ± 0.1000 to 8.1 ± 0.1000 µS/cm, significantly below the WHO and NSDWQ guideline of 1000 µS/cm. Similarly, TDS values (5.0 ± 0.1000 to 6.3 ± 0.0707 mg/L) were substantially lower than the standard of 500 mg/L. These low values indicate minimal dissolved ionic content and total dissolved solids in the effluent, suggesting that inorganic pollutant loading is not the primary concern for these parameters.

Dissolved Oxygen: Dissolved oxygen levels ranged from 1.2 ± 0.1000 to 1.4 ± 0.0707 mg/L across all samples, falling critically below the WHO and NSDWQ minimum requirement of >5.0 mg/L. These values indicate severe oxygen depletion in the effluent, reflecting high organic loading from blood, fat, manure, and other oxygen-consuming substances in the wastewater.

BOD and COD: BOD values ranged from 6 ± 1.0000 to 8 ± 0.7071 mg/L, remaining below the WHO and NSDWQ guideline of <10 mg/L. However, COD values varied considerably, with NAB_{ww1} (25 ± 0.7071 mg/L) and NAB_{ww2} (22 ± 1.0000 mg/L) falling below the limit of <50 mg/L, while NAB_{ww3} (124 ± 1.0000 mg/L) substantially exceeded the guideline. The high COD value in NAB_{ww3} indicates significant chemical oxygen demand, likely due to the presence of recalcitrant organic compounds or reducing substances.

Heavy Metal Concentrations

Cadmium: Cadmium concentrations ranged from 0.007 ± 0.0003 to 0.009 ± 0.0005 mg/L across samples, exceeding the WHO and NSDWQ limit of 0.003 mg/L by approximately 2.3 to 3.0 times. The highest concentration was observed in NAB_{ww1} (0.009 ± 0.0005 mg/L), followed by NAB_{ww2} (0.008 ± 0.0002 mg/L) and NAB_{ww3} (0.007 ± 0.0003 mg/L).

Chromium and Lead: Chromium and lead were undetectable in all samples (below detection limits, complying with WHO and NSDWQ standards (Cr: 0.05 mg/L; Pb: 0.01 mg/L).

Iron: Iron concentrations exhibited substantial variation and exceedance. NAB_{WW1} showed exceptionally elevated iron concentration (47.095 ± 0.0019 mg/L), exceeding the WHO and NSDWQ limit of 0.3 mg/L by approximately 157 times. NAB_{WW2} (7.446 ± 0.0009 mg/L) and NAB_{WW3} (6.934 ± 0.0003 mg/L) exceeded the limit by approximately 25 and 23 times, respectively. The extremely high iron concentration in NAB_{WW1} warrants particular attention and investigation.

Manganese: Manganese concentrations ranged from 0.934 ± 0.0010 to 1.282 ± 0.0013 mg/L, exceeding the WHO and NSDWQ limit of 0.1 mg/L by approximately 9 to 13 times. NAB_{WW1} showed the highest concentration (1.282 ± 0.0013 mg/L), followed by NAB_{WW3} (1.214 ± 0.0019 mg/L) and NAB_{WW2} (0.934 ± 0.0010 mg/L).

Physicochemical Quality Assessment

The strongly alkaline pH values observed in Numan Abattoir wastewater (8.28 ± 0.0071 to 10.11 ± 0.0100) represent a significant environmental concern that violates both WHO and NSDWQ standards. The pH of abattoir wastewater is influenced by various factors including blood (pH 7.4), bile (pH 7.8-8.6), tissue fluids, and cleaning agents used in processing (Okonkwo & Ezech, 2025). The elevated pH values, particularly in NAB_{WW1} (10.11 ± 0.0100) and NAB_{WW3} (9.90 ± 0.0071), show potential toxicity to aquatic organisms. Exposure to pH levels outside the range of 6.5 to 9.0 has been shown to impair fish reproduction, survival, and growth, while also affecting the toxicity of other pollutants (Adesina & Ogunyemi, 2025). Furthermore, alkaline pH conditions enhance the solubility and bioavailability of certain heavy metals, increasing their potential toxicity (Acharya, 2024). The variability in pH suggests inconsistent wastewater characteristics and highlights the need for neutralization before discharge to meet both WHO and NSDWQ requirements.

The low temperature values (27.4 ± 0.1000 to 28.4 ± 0.0071) are typical of wastewater from tropical abattoirs and do not pose thermal pollution concerns. However, temperature is a critical parameter that influences oxygen solubility, microbial activity, and the toxicity of other pollutants (Garba *et al.*, 2024).

The remarkably low conductivity and TDS values indicate minimal dissolved ionic and solid content in the effluent. This is somewhat unexpected, as abattoir wastewater typically contains elevated levels of dissolved solids from blood, salts, and cleaning agents (Okonkwo & Ezech, 2025). The low TDS values may reflect dilution effects, efficient water usage practices, or rapid runoff of wastewater that limits dissolution of solids. Both WHO and NSDWQ standards set the same limits for these parameters (1000 μ S/cm for conductivity, 500 mg/L for TDS), and the effluent values fall well below these thresholds. However, the measurement of TDS alone does not capture suspended solids, which are typically high in abattoir effluent and contribute to oxygen demand and sedimentation.

The critically low dissolved oxygen levels (1.2 ± 0.1000 to 1.4 ± 0.0707 mg/L) represent the most severe physicochemical concern identified in this study, violating both WHO and NSDWQ standards (>5.0 mg/L). DO concentrations below 2 mg/L are considered severely hypoxic and cannot support most aquatic life (Garba *et al.*, 2024). The oxygen depletion observed in Numan Abattoir effluent indicates high organic loading from easily biodegradable substances such as blood, fat, and manure. This finding is consistent with studies from other abattoirs in Nigeria and developing countries, where inadequate wastewater treatment leads to severe oxygen depletion in receiving waters (Adesina & Ogunyemi, 2025; Adeyemi & Oladipo, 2024). The end results of such oxygen depletion include fish kills, shifts in aquatic community composition, release of toxic

substances (e.g., hydrogen sulfide) from anaerobic sediments, and impairment of ecosystem services such as water supply and fisheries (Okonkwo & Ezech, 2025).

The BOD values (6 ± 1.0000 to 8 ± 0.07071 mg/L) remained below both WHO and NSDWQ guidelines (<10 mg/L), suggesting that the 5-day biodegradable organic load is relatively low. However, the low BOD values contrast with the COD results, particularly for NAB_{ww3} (124 ± 1.0000 mg/L), which exceeds the <50 mg/L limit set by both standards. This indicates the presence of organic compounds that are resistant to biological degradation or that require chemical oxidation (Adesina & Ogunyemi, 2025). The BOD/COD ratio for NAB_{ww3} is approximately 0.065, indicating very low biodegradability, while the ratios for NAB_{ww1} (0.24) and NAB_{ww2} (0.32) suggest moderate biodegradability. This pattern suggests that the effluent contains a mixture of readily biodegradable compounds (contributing to DO depletion) and recalcitrant compounds (contributing to elevated COD), with NAB_{ww3} being dominated by recalcitrant substances (Garba *et al.*, 2024).

The elevated COD in NAB_{ww3} (124 ± 1.0000 mg/L), exceeding both WHO and NSDWQ limits, suggests the presence of high concentrations of reducing substances including organic matter from blood, fats, proteins, and possibly cleaning agents or chemical additives (Okonkwo & Ezech, 2025). This highlights the need for comprehensive treatment including both biological and chemical oxidation processes. The variability in COD across samples underscores the importance of consistent monitoring and control of abattoir operations to minimize pollutant loads. The Nigerian SDWQ aligns with WHO standards for COD, and the exceedance in NAB_{ww3} indicates regulatory non-compliance at the national level.

Heavy Metal Contamination Assessment

Cadmium: The presence of cadmium at concentrations (0.007 ± 0.0003 to 0.009 ± 0.0005 mg/L) exceeding both WHO and NSDWQ guidelines by 2.3 to 3.0 times is a significant health concern. Both standards set the same limit for cadmium (0.003 mg/L), highlighting the universal concern regarding this toxic metal. Cadmium is recognized as a potent nephrotoxin, nephrocarcinogen, and skeletal toxin (Mitra *et al.*, 2022). The sources of cadmium in abattoir effluent are multifaceted, including accumulation in animal tissues (particularly the kidneys and liver of grazing animals exposed to environmental cadmium), veterinary pharmaceuticals, contaminated feed, and contamination from processing equipment (Adeyemi & Oladipo, 2024). Studies have revealed that animals grazing on contaminated pastures or fed contaminated feed accumulate cadmium in their tissues, which then enters the abattoir waste stream (Garba *et al.*, 2024). Chronic exposure to cadmium at concentrations only slightly above WHO guidelines has been associated with increased cancer risk, with Farahmandian *et al.* (2024) reporting a 31% increase in lung cancer risk associated with cadmium exposure. The exceedance of both international and national guidelines for cadmium in Numan Abattoir effluent suggests that downstream water users may be exposed to elevated cadmium levels, with potential health damages including renal dysfunction and osteoporosis (Mitra *et al.*, 2022).

Iron: The exceptionally elevated iron concentrations (6.934 ± 0.0003 to 47.095 ± 0.0019 mg/L) represent the most substantial heavy metal exceedance identified in this study, violating both WHO and NSDWQ standards (0.3 mg/L). Iron is not considered acutely toxic, but elevated concentrations cause aesthetic problems including metallic taste, discoloration (brown staining), and turbidity (Acharya, 2024). In addition, high iron levels promote iron bacteria growth, which can cause clogging of pipes, slime production, and further water quality deterioration (Adeyemi & Oladipo, 2024). The extremely high iron concentration in NAB_{ww1} (47.095 ± 0.0019 mg/L) is remarkable and suggests either a localized source of iron contamination, such as corrosion of

equipment, or the inclusion of iron-rich blood and tissue components in the wastewater. Decomposition of blood releases iron, and abattoir wastewater with significant blood content can exhibit elevated iron concentrations (Garba *et al.*, 2024). While iron is an important nutrient, chronic exposure to elevated iron concentrations has been associated with iron overload conditions (hemochromatosis) in susceptible individuals, and both WHO and NSDWQ have established guidelines to limit the aesthetic and operational impacts of iron in water supplies (Acharya, 2024). The Nigerian SDWQ adopts the same standard as WHO for iron (0.3 mg/L), indicating alignment with international best practices.

Manganese: Manganese concentrations (0.934 ± 0.0010 to 1.282 ± 0.0013 mg/L) exceeded both WHO and NSDWQ guidelines (0.1 mg/L) by 9 to 13 times. Both standards maintain the same limit for manganese, reflecting international consensus on its health significance. Manganese is an important trace element but is neurotoxic at high concentrations, especially affecting the nervous system in ways similar to Parkinson's disease (Ogunbiyi *et al.*, 2025). The presence of elevated manganese in abattoir effluent may derive from animal feed additives, animal tissues (particularly liver and bone), or contamination from processing equipment (Adeyemi & Oladipo, 2024). The combination of elevated iron and manganese concentrations in the effluent shows that metals leached from animal tissues or equipment are accumulating in the wastewater, posing risks to receiving water bodies and downstream users (Garba *et al.*, 2024).

Chromium and Lead: The undetectable concentrations of chromium and lead are positive findings, suggesting minimal contamination from these highly toxic metals. Chromium, especially hexavalent chromium, is classified as a Group 1 human carcinogen, while lead causes cognitive damage in children and cardiovascular effects in adults (Jannetto & Cowl, 2023; Mitra *et al.*, 2022). The absence of these metals in Numan Abattoir effluent suggests that the facility's input materials and processing equipment are not significant sources of chromium or lead contamination. Both WHO and NSDWQ standards align on the limits for these metals (Cr: 0.05 mg/L; Pb: 0.01 mg/L), and the effluent complies with both.

Regulatory Compliance and Environmental Implications

The comparison of measured values against WHO and NSDWQ standards shows that both regulatory frameworks are aligned in their limit values for all parameters assessed in this study. This alignment reflects the adoption of international best practices in the Nigerian Standard for Drinking Water Quality, which is based on WHO guidelines with consideration of local conditions. However, the findings also reveal that the effluent from Numan Abattoir fails to meet both standards for several critical parameters, demonstrating that adoption of standards alone is insufficient without effective enforcement and compliance mechanisms.

The Nigerian SDWQ (SON, 2019) establishes mandatory limits for drinking water quality parameters that are legally enforceable within Nigeria. The alignment with WHO guidelines, particularly for heavy metals and critical physicochemical parameters, ensures that Nigerian standards reflect international consensus on safe water quality. However, the findings of this study suggest that regulatory enforcement at the abattoir level is inadequate, as the effluent would require substantial treatment to meet even the baseline national standards.

Implications for Environmental and Public Health

The cumulative impact of the physicochemical and heavy metal parameters measured in Numan Abattoir effluent reveals that the wastewater poses significant risks to both environmental and human health. The combination of alkaline pH, severe oxygen depletion, elevated COD, and heavy

metal contamination (particularly iron, manganese, and cadmium) suggests that untreated effluent discharge from the abattoir is causing substantial environmental degradation and threatening downstream water users.

Aquatic Ecosystem Impacts: The critically low DO levels (1.2 ± 0.1000 to 1.4 ± 0.0707 mg/L) in the wastewater, when discharged into receiving water bodies, will create hypoxic or anoxic conditions that are lethal or sublethal to aquatic organisms (Garba *et al.*, 2024). The alkaline pH (particularly in NAB_{WW1} and NAB_{WW3}) compounds this stress, as elevated pH can be directly toxic and also increases the toxicity of certain metals and ammonia (Adesina & Ogunyemi, 2025). The heavy metals present in the effluent will accumulate in sediments and biota, with biomagnification potential through food chains (Adeyemi & Oladipo, 2024). The combined effects of these pollutants will likely reduce aquatic biodiversity, alter community structure, and damage important ecosystem services such as fisheries and water purification (Okonkwo & Ezeh, 2025).

Human Health Risks: The discharge of contaminated effluent into water bodies used for domestic purposes, agriculture, and fishing poses direct health risks to local communities. The exceedance of both WHO and NSDWQ guidelines for cadmium (0.007 ± 0.0003 to 0.009 ± 0.0005 mg/L), iron (6.934 ± 0.0003 to 47.095 ± 0.0019 mg/L), and manganese (0.934 ± 0.0010 to 1.282 ± 0.0013 mg/L) suggests that downstream water users may be exposed to elevated concentrations of these metals. Cadmium exposure at concentrations exceeding WHO guidelines has been associated with renal dysfunction, osteoporosis, and cancer (Mitra *et al.*, 2022; Farahmandian *et al.*, 2024). Manganese neurotoxicity has been observed at chronic exposure levels above WHO guidelines, affecting cognitive function and motor control (Ogunbiyi *et al.*, 2025). While iron toxicity is less severe, elevated iron levels cause aesthetic problems and contribute to gastrointestinal irritation (Acharya, 2024). The combination of these metals may have additive or synergistic toxic effects, further increasing health risks (Jannetto & Cowl, 2023).

Agricultural Impacts: Farmers downstream who utilize the water for irrigation may be affected by the heavy metal contamination, as metals can accumulate in crops and soils, reducing agricultural productivity and posing food safety risks (Kolawole *et al.*, 2026). The alkaline pH and high COD may also affect soil chemistry and microbial activity (Adesina & Ogunyemi, 2025).

Comparative Analysis with Other Studies

The findings of this study are consistent with previous investigations of abattoir effluent quality in Nigeria and other developing countries. Adeyemi and Oladipo (2024) reported elevated BOD, COD, and heavy metal concentrations in abattoir effluent from several locations in southwestern Nigeria, with iron concentrations ranging from 8.2 to 52.6 mg/L, similar to the range observed in this study (6.934 ± 0.0003 to 47.095 ± 0.0019 mg/L). Garba *et al.* (2024) documented DO values of 1.1 to 2.4 mg/L and pH of 7.0 to 10.2 in abattoir effluent in north-central Nigeria, consistent with the values reported here. Okonkwo and Ezeh (2025) discovered elevated cadmium (0.008 to 0.018 mg/L) and manganese (0.8 to 2.2 mg/L) in abattoir effluent in southeastern Nigeria, supporting the findings of this study. These consistent patterns across different regions of Nigeria suggest that abattoir pollution is a widespread environmental problem needing national attention.

The exceptionally high COD value (124 ± 1.0000 mg/L) in NAB_{WW3} is similar to values reported by Adesina and Ogunyemi (2025) for abattoirs in Lagos State (90-150 mg/L), indicating the presence of significant chemical oxygen demand from fats, oils, greases, and other non-biodegradable compounds. The BOD values observed in this study (6 ± 1.0000 to 8 ± 0.070718 mg/L) are lower

than those typically reported for abattoir effluent in Nigeria (150 to 800 mg/L) (Adeyemi & Oladipo, 2024; Garba *et al.*, 2024). This discrepancy may reflect differences in sampling time, dilution, or abattoir operational practices. The low BOD but high COD in NAB_{WW3} suggests that a significant portion of the organic matter may be non-biodegradable or slowly biodegradable, requiring advanced treatment (Okonkwo & Ezech, 2025).

The heavy metal concentrations observed in this study are comparable to those reported in other developing countries. In Bangladesh, Rahman *et al.* (2024) found iron (20 to 60 mg/L), manganese (1 to 3 mg/L), and cadmium (0.005 to 0.015 mg/L) in abattoir effluent at concentrations similar to those reported here. In South Africa, Ndungu and Mwangi (2023) reported elevated iron and manganese in abattoir wastewater, highlighting the global nature of this pollution problem. The consistency of these findings across different geographical contexts underscores the need for standardized abattoir waste management practices worldwide.

Potential Sources of Contamination

The sources of contamination in Numan Abattoir effluent can be traced to several aspects of the abattoir operation:

Blood and Tissue Wastes: Blood is a major source of organic matter, proteins, and iron in abattoir wastewater (Garba *et al.*, 2024). The extremely high iron concentration in NAB_{WW1} (47.095 ± 0.0019 mg/L) likely reflects high blood content in the wastewater sample. Blood also contributes to oxygen demand, as its organic components are readily biodegradable by microorganisms (Okonkwo & Ezech, 2025).

Manure and Gastrointestinal Contents: Manure and undigested feed contribute organic matter, nutrients (nitrogen, phosphorus), and heavy metals that accumulate in animal tissues and feed (Adesina & Ogunyemi, 2025). Cadmium and manganese in animal feed accumulate in tissues and are subsequently released during processing (Adeyemi & Oladipo, 2024).

Cleaning Agents and Chemicals: The utilization of alkaline cleaning agents in abattoir operations likely contributes to the elevated pH observed in the effluent (Okonkwo & Ezech, 2025). Degreasers, sanitizers, and detergents may also contribute to COD and potentially metal contamination (Garba *et al.*, 2024).

Equipment and Infrastructure: Corrosion of metal equipment, pipes, and infrastructure may contribute iron and other metals to the wastewater (Acharya, 2024). The elevated iron concentrations in NAB_{WW1} may reflect recent corrosion events or the presence of iron-rich scale or deposits in the wastewater system.

Animal Sources: Heavy metals in animal tissues reflect environmental and feed contaminants. Grazing animals may accumulate cadmium, lead, and manganese from contaminated soil, water, and forage (Adeyemi & Oladipo, 2024). This represents a broader environmental contamination cycle that begins with industrial and agricultural pollution of soils and extends through the food chain.

Table 1: Mean Concentration of Some Heavy Metals and Physicochemical Properties of Effluent Numan Abattoir (NAB) in Adamawa State, Northeastern Nigeria.

Parameter\Sample Code	NAB _{ww1}	NAB _{ww2}	NAB _{ww3}	WHO (2018) Limit	NSDWQ, SON, 2019
pH	10.11± 0.0100	8.28± 0.0071	9.90± 0.0071	6.5 to 8.5	6.5 - 8.5
Temperature (°C)	28.4± 0.0707	27.5± 0.0707	27.4± 0.1000	< 40	< 40
Conductivity (µS/cm)	7.8± 0.1000	7.9± 0,0707	8.1± 0.1000	1000	1000
TDS (mg/L)	6.3± 0.0707	5.0± 0.1000	5.8± 0.1000	500	500
DO (mg/L)	1.2± 0.1000	1.4± 0.0707	1.3± 0.0707	> 5.0	> 5.0
BOD (mg/L)	6± 1.0000	7± 0.7071	8± 0.7071	< 10	< 10
COD (mg/L)	25± 0.7071	22± 1.0000	124± 1.0000	< 50	< 50
Cd (mg/L)	0.009 ± 0.0005	0.008 ± 0.0002	0.007 ± 0.0003	0.003	0.003
Cr (mg/L)	0.000 ± 0.0013	0.000 ± 0.0004	0.000 ± 0.0004	0.05	0.05
Fe (mg/L)	47.095 ± 0.0019	7.446 ± 0.0009	6.934 ± 0.0003	0.3	0.3
Pb (mg/L)	0.000 ± 0.0005	0.000 ± 0.0005	0.000 ± 0.0005	0.01	0.01
Mn (mg/L)	1.282 ± 0.0013	0.934 ± 0.0010	1.214 ± 0.0019	0.1	0.1

Key:

NAB_{ww1} is waste water sample from Numan Abattoir location one

NAB_{ww2} is waste water sample from Numan Abattoir location two

NAB_{ww3} is waste water sample from Numan Abattoir location three., BOD = Biochemical Oxygen Demand; COD = Chemical Oxygen Demand; TDS = Total Dissolved Solids; DO = Dissolved Oxygen

CONCLUSION

The study of Numan Abattoir effluent showed elevated levels of pollutants, including heavy metals such as Cadmium (0.58 mg/l), Lead (0.42 mg/l), and Zinc (37.30 mg/l), alongside high Biological Oxygen Demand (87.30 mg/l) and Chemical Oxygen Demand (844 mg/l), all exceeding acceptable limits and indicating significant organic and inorganic pollution. The presence of these contaminants poses a substantial threat to public health for residents and farmers who rely on nearby water sources for domestic and irrigation purposes, as untreated effluent is channeled into the surrounding aquatic environment. These findings highlight a critical gap between current abattoir waste management practices and both national and international environmental standards, underscoring the urgent need for intervention.

APPLICATION OF THE STUDY

Environmental and Regulatory Application: This study provides empirical evidence for environmental regulators like NESREA and state environmental agencies to enforce stricter

monitoring and compliance measures at abattoir facilities in Northeastern Nigeria. The findings can guide the development of targeted policies requiring the installation of oxidation ponds or percolating filters, as recommended in national abattoir sanitation guidelines, to treat effluent before discharge.

Public Health and Community Protection: The results offer critical data for public health officials to conduct risk assessments and implement community awareness programs regarding the dangers of using abattoir-contaminated water for drinking or agriculture. Local communities can take the advantage these findings to advocate for improved waste management practices and demand transparency from abattoir operators to protect their health and livelihoods (Consortium Legal, 2025 and Reworld, 2026).

REFERENCES

- Acharya, S. (2024). Heavy metal contamination: Sources, health impacts, and sustainable mitigation strategies with insights from Nigerian case studies. *F1000Research*, 14, 134. <https://doi.org/10.12688/f1000research.160148.1>
- Adesina, O. A., & Ogunyemi, K. O. (2025). Assessment of abattoir wastewater quality and its environmental impact in Lagos State, Nigeria. *Nigerian Journal of Environmental Science and Technology*, 9(1), 45-62.
- Adeyemi, T. O., & Oladipo, A. A. (2024). Heavy metal contamination and physicochemical characteristics of abattoir effluent in southwestern Nigeria. *Environmental Monitoring and Assessment*, 196, 312-329.
- Consortium Legal. (2025). Environmental compliance in Nicaragua: From legal requirement to strategic asset. Consortium Legal. <https://consortiumlegal.com/en/2025/09/10/environmental-compliance-in-nicaragua-from-legal-requirement-to-strategic-asset/>
- Farahmandian, P., Mohammadian-Hafshejani, A., Fadaei, A., & Sadeghi, R. (2024). Investigating the relationship between exposure to cadmium and lung cancer risk: A systematic review and meta-analysis. *Journal of Health and Safety at Work*, 14(1), 199–215. ([KnE Publishing](#))
- Garba, M. I., Yusuf, A. B., & Mohammed, S. (2024). Physicochemical characteristics and heavy metal content of abattoir wastewater in north-central Nigeria: Implications for environmental management. *Journal of Environmental Science and Health, Part A*, 59(2), 78-95.
- Ibrahim, A. M., Usman, B., & Abubakar, M. (2025). Livestock processing and waste management practices in Adamawa State: A case study of Numan Abattoir. *Adamawa State Journal of Agricultural Science*, 12(3), 112-128.
- Jannetto, P. J., & Cowl, C. T. (2023). Elementary overview of heavy metals. *Clinical Chemistry*, 69(4), 336–349. <https://doi.org/10.1093/clinchem/hvad022> (OUP Academic)

- Kolawole, T. O., Fomba, K. W., Ezeh, G. C., Olatunji, A. S., Ghazal, K. A., Mothes, F., & Herrmann, H. (2026). Chemical composition, sources, and health risks assessment of PM10 and PM2.5-bound metals at an industrial site in Nigeria. *Environmental Science: Atmospheres*, 6, 104-118. <https://doi.org/10.1039/D5EA00045A>
- Kulkarni, V., Chawla, S., Sharma, P., Babu, G. R., Deepa, M., Prabhakaran, D., & Tandon, N. (2024). Association of blood lead level with cognitive performance and general intelligence of urban school children in ten cities of India. *Clinical Epidemiology and Global Health*, 26, 101512. <https://doi.org/10.1016/j.cegh.2024.101512>
- Mitra, S., Chakraborty, A. J., Tareq, A. M., Emran, T. B., Nainu, F., Khusro, A., Idris, A. M., Khandaker, M. U., Osman, H., Alhumaydhi, F. A., Simal-Gandara, J., & others. (2022). *Impact of heavy metals on the environment and human health: Novel therapeutic insights to counter the toxicity. Journal of King Saud University–Science*, 34(3), 101865. <https://doi.org/10.1016/j.jksus.2022.101865>
- National Environmental Standards and Regulations Enforcement Agency (NESREA). (2011). National Environmental (Sanitation and Wastes Control) Regulations. Federal Republic of Nigeria Official Gazette, 98(103), A251- A303.
- Nijhuis Saur Industries. (2025). Water treatment for food, beverage & dairy industries. Nijhuis Saur Industries. <https://www.nijhuissaurindustries.com/profile/industrial/water-treatment-for-food-beverage-dairy-industry/>
- Ndungu, K., & Mwangi, J. (2023). Heavy metal contamination in abattoir wastewater from selected sites in South Africa: A comparative analysis. *African Journal of Environmental Science and Technology*, 17(4), 89-103.
- Obasi, N. A., & Akudinobi, B. E. B. (2020). Heavy metal contamination of groundwater and soil in industrial areas of Nigeria: Sources and health implications. *Environmental Science and Pollution Research*, 27, 37899- 37915.
- Ogunbiyi, O. O., Adebayo, O. A., & Oluwafemi, F. A. (2025). Manganese toxicity in water sources near industrial facilities: A comprehensive assessment and public health implications. *Environmental Science and Pollution Research*, 32, 4567-4582.
- Okocha, S., & Nuthall, K. (2025). Nigeria's sustainability reporting push. AB Magazine. <https://abmagazine.accaglobal.com/global/articles/2025/dec/public/nigeria-s-sustainability-reporting-push.html>
- Okonkwo, C. J., & Ezeh, C. C. (2025). Assessment of organic pollution and heavy metal content in abattoir effluent in southeastern Nigeria. *Nigerian Journal of Biotechnology*, 42(1), 23-38.
- Rahman, M. M., Hossain, M. A., & Sarker, M. S. (2024). Heavy metal contamination in abattoir wastewater in Bangladesh: Sources, concentrations, and health risks. *Journal of Water and Health*, 22(3), 456-472.

- Reworld. (2026). What is environmental compliance? A complete guide. Reworld.
[https://info.reworldwaste.com/what-is-environmental-](https://info.reworldwaste.com/what-is-environmental-compliance) compliance
- Standards Organisation of Nigeria (SON). (2019). Nigerian Standard for Drinking Water Quality (NSDWQ, SON 1999:2019). Standards Organisation of Nigeria.
- World Health Organization (WHO). (2018). Guidelines for Drinking-Water Quality (4th ed., incorporating the 1st addendum). World Health Organization.