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ASSESSMENT OF HEAVY METAL CONCENTRATIONS AND PHYSICOCHEMICAL PROPERTIES OF EFFLUENT FROM ADAMA BEVERAGE LIMITED: IMPLICATIONS FOR ENVIRONMENTAL COMPLIANCE AND PUBLIC HEALTH

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ABSTRACT

A study was conducted to assess Heavy Metal Concentrations and Physicochemical Properties of Effluent from Adama Beverage Limited: Implications for Environmental Compliance and Public Health. 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 beverage industry 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 Adama Beverage Limited (ABL) in Yola, Nigeria were collected from the ABL wastewater discharge point on three separate occasions (designated ABL $_{WW1}$, ABL $_{WW2}$, and ABL $_{WW3}$) using standard sampling protocols, evaluated and compared with the World Health Organization (WHO) and National Environmental Standards and Regulations Enforcement Agency (NESREA) permissible limits. Three effluent samples, ABL $_{WW1}$, ABL $_{WW2}$, and ABL $_{WW3}$ 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 indicated that pH values (6.09 ± 0.0071 to 6.21 ± 0.0100) fell below WHO guidelines (6.50 to 8.50) but within NESREA limits (6.00 to 9.00). Dissolved oxygen levels (1.2 ± 0.1000 to 1.4 ± 0.10000 mg/L) were critically below both WHO (>5 mg/L) and NESREA (>4 mg/L) standards, indicating significant organic pollution. Iron concentrations (6.982 ± 0.0007 to 8.038 ± 0.0011 mg/L) substantially exceeded WHO limits (0.3 mg/L) by approximately 23 to 27 times, while cadmium levels (0.008 ± 0.0002 to 0.010 ± 0.0003 mg/L) exceeded WHO guidelines (0.003 mg/L) by 2.7 to 3.3 times. However, chromium and lead were not detected and manganese was within acceptable limits. The results indicated significant non-compliance with international standards for water quality, especially with regard to DO depletion and iron contamination, which calls for improved interventions for wastewater treatment and stronger regulatory control to mitigate possible ecological and health risks. These findings can help regulators such as NESREA 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.

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Keywords: Heavy metals, effluent quality, beverage industry, wastewater treatment, environmental compliance, Nigeria

INTRODUCTION

Industrial wastewater discharge is a significant environmental problem in developing countries where the rapid urbanization and industrial growth often outpace regulatory enforcement and infrastructure development (Kolawole *et al.,* 2026). The beverage industry, in particular, generates large quantities of wastewater with high organic loads, variable pH, suspended solids and potentially toxic components that can have a serious impact on receiving water bodies and public health if not adequately treated (Gerson *et al.,* 2025). The beverage manufacturing industry in Nigeria has grown substantially, with companies like Adama Beverages Limited (ABL) expanding production capacity to meet the rising consumer demand (Ensign, 2016). These sectors, while vital to economic progress and job creation, are subject to strict oversight and adherence to established norms for their environmental impact.

Heavy metal-laden industrial effluents are a matter of great concern owing to their persistent, non-biodegradable nature and their tendency to bioaccumulate and biomagnify in ecosystems (Acharya, 2024). Cadmium, lead, chromium and iron are naturally occurring metals that are released into the environment at high concentrations through anthropogenic activities such as industrial processing, manufacturing operations and improper waste disposal (Obasi & Akudinobi, 2020). Human exposure to heavy metals from contaminated water sources has been linked to various health outcomes, including neurological disorders, renal dysfunction, reproductive toxicity, and carcinogenesis (Jannetto & Cowl, 2023; Mitra *et al.,* 2022).
Cadmium exposure, for instance, has been linked to a 31% increased risk of lung cancer, while lead toxicity particularly affects cognitive development in children (Farahmandian *et al.,* 2024; Kulkarni *et al.,* 2024).

The physicochemical characteristics of industrial effluents serve as critical indicators of wastewater quality and treatment efficacy. Parameters such as biochemical oxygen demand (BOD), chemical oxygen demand (COD), dissolved oxygen (DO), pH, and total dissolved solids (TDS) provide essential information about organic pollution levels, oxygen depletion potential, and overall wastewater suitability for discharge into natural water bodies (Nijhuis Saur Industries, 2025). Regulatory frameworks established by the World Health Organization and national environmental agencies such as Nigeria's National Environmental Standards and Regulations Enforcement Agency (NESREA) specify permissible limits for these parameters to protect aquatic ecosystems and human health. However, enforcement remains challenging in many Nigerian industrial settings due to inadequate monitoring infrastructure, limited technical capacity, and competing economic priorities (Okocha & Nuthall, 2025).

Adama Beverage Limited, established in 2005 in Yola, Adamawa State, represents a significant industrial operation in northeastern Nigeria, producing bottled water, fruit juices, and other beverages (Ensign, 2016). The company's wastewater management practices are of particular importance given its location and the potential impact on local water resources. However, limited published data exist on the quality of effluents from Nigerian beverage industries and their compliance with regulatory standards. This study aimed to assess the physicochemical properties and heavy metal concentrations in effluent samples from Adama Beverage Limited and evaluate their compliance with WHO and NESREA permissible limits.
The specific objectives were to: (1) determine the physicochemical characteristics including pH, temperature, conductivity, TDS, DO, BOD, and COD of effluent samples; (2) quantify the

concentrations of cadmium, chromium, iron, lead, and manganese; (3) compare measured values against established regulatory standards; and (4) discuss implications for environmental management and public health protection.

MATERIALS AND METHODS

The Area of Study

Adama Beverage Limited (ABL) is located in Yola, Adamawa State, northeastern Nigeria (approximate coordinates: 9°12'N, 12°29'E). The facility operates as a beverage production plant manufacturing bottled water and fruit juice products, with a production capacity of approximately 40,000 bottles per hour (Ensign, 2016).

Sample Collection

Effluent samples were collected from the ABL wastewater discharge point on three separate occasions (designated ABL $_{WW1}$, ABL $_{WW2}$, and ABL $_{WW3}$) using standard sampling protocols. Grab samples were collected in acid-washed polyethylene bottles and transported to the laboratory under refrigerated conditions (4 °C) for analysis within 24 hours of collection.

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 ± standard deviation in milligrams per liter (mg/L).

Data Analysis

Data collected were subjected to analysis of variabes as contained in SPSS version 23.0 (2017). Results were expressed as mean ± standard deviation.

Regulatory Comparison

The result of the study were compared against permissible limits established by the World Health Organization (WHO, 2017) for drinking water quality and effluent discharge guidelines, and the National Environmental Standards and Regulations Enforcement Agency (NESREA, 2011) for industrial effluent discharge in Nigeria.

RESULTS AND DISCUSSION

The physicochemical properties and heavy metal concentrations of effluent samples from Adama Beverage Limited are presented in Table 1, with comparative standards from WHO and NESREA.

Physicochemical Parameters

The pH values ranged from 6.09 ± 0.0071 to 6.21 ± 0.0100, indicating slightly acidic conditions across all samples. While these values fell below the WHO recommended range of 6.50 to 8.50 for drinking water and effluent discharge, they remained within the NESREA permissible limit of 6.00 to 9.00. Temperature readings were consistent across samples (32.9 ± 0.1000 to 33.1 ± 0.0707 °C), well below both WHO (<40 °C) and NESREA (<40 °C) limits.

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Electrical conductivity ranged from 39.7 ± 0.1000 to 48.6 ± 0.0707 µS/cm, significantly below the WHO guideline of 1000 µS/cm. Similarly, TDS values (23.7 ± 0.0707 to 29.7 ± 0.1000 mg/L) were substantially lower than both WHO (500 mg/L) and NESREA (2000 mg/L) standards.
Dissolved oxygen levels were critically low, ranging from 1.2 ± 0.1000 to 1.4 ± 0.10000 mg/L, falling well below both WHO (>5 mg/L) and NESREA (>4 mg/L) requirements. BOD values ranged from 7 ± 0.7071 to 10 ± 1.0000 mg/L, remaining below both regulatory limits (WHO: 30 mg/L; NESREA: 50 mg/L). COD concentrations ranged from 18 ± 1.0000 to 25 ± 1.0000 mg/L, well within acceptable standards (WHO: 250 mg/L; NESREA: 250 mg/L).

Heavy Metal Concentrations
Cadmium concentrations ranged from 0.008 ± 0.0002 to 0.010 ± 0.0003 mg/L, exceeding the WHO limit of 0.003 mg/L by approximately 2.7 to 3.3 times. However, all values were below the NESREA limit of 0.050 mg/L. Chromium and lead were undetectable in all samples (below detection limits of 0.0005 mg/L and 0.0004 to 0.0005 mg/L, respectively), complying with both WHO (Cr: 0.05 mg/L; Pb: 0.01 mg/L) and NESREA (Cr: 0.50 mg/L; Pb: 0.10 mg/L) standards.
Iron concentrations were notably elevated, ranging from 6.982 ± 0.0007 to 8.038 ± 0.0011 mg/L, exceeding the WHO guideline of 0.3 mg/L by approximately 23 to 27 times. However, these values remained below the NESREA limit of 20 mg/L. Manganese concentrations ranged from 0.060 ± 0.0002 to 0.077 ± 0.0002 mg/L, below both WHO (0.1 mg/L) and NESREA (5.0 mg/L) limits.

Physicochemical Quality Assessment
The slightly acidic pH values (6.09 ± 0.0071 to 6.21 ± 0.0100) observed in all effluent samples indicate that the wastewater discharged from Adama Beverage Limited tends toward acidity. While falling within NESREA's permissible range, the consistently below-neutral pH values suggest potential corrosion risks to receiving water infrastructure and possible impairment of aquatic ecosystem health (Gerson *et al.,* 2025). The pH observed in this study is lower than the generally acceptable range for drinking water but remains common in beverage industry effluents due to cleaning agents and product residues (Nijhuis Saur Industries, 2025).
The low electrical conductivity and TDS values indicate relatively low dissolved ionic content in the effluent, suggesting that inorganic pollutant loading is not a primary concern for this parameter. These values are substantially lower than typical beverage industry effluents, which often contain elevated dissolved solids from sugar, flavorings, and cleaning compounds (Gerson *et al.,* 2025). The low TDS levels suggest either effective water conservation practices or dilution effects, though further investigation would be required to determine the specific mechanisms.
The critically low dissolved oxygen levels (1.2 ± 0.1000 to 1.4 ± 0.10000 mg/L) represent the most significant physicochemical concern identified in this study. DO concentrations below 4 mg/L are generally considered hypoxic and can stress or eliminate sensitive aquatic organisms (Gerson *et al.,* 2025). The low DO values indicate high organic pollution loading and oxygen-consuming substances in the effluent. This finding is consistent with beverage industry wastewater characteristics, which typically contain high organic loads from sugars, starches, and other biodegradable compounds (Nijhuis Saur Industries, 2025). The DO depletion suggests inadequate treatment before discharge and poses risks to receiving water bodies through oxygen depletion and potential fish kills.
Despite the low DO levels, BOD (7 ± 0.7071 to 10 ± 1.0000 mg/L) and COD (18 ± 1.0000 to 25 ± 1.0000 mg/L) values were within regulatory limits, suggesting that while oxygen-demanding substances are present, their concentrations remain below thresholds for BOD/COD compliance. However, the ratio of BOD/COD (approximately 0.4 to 0.5) indicates moderate biodegradability, meaning the organic matter in the effluent is amenable to biological treatment but may persist in the environment if discharged untreated (Gerson *et al.,* 2025). The discrepancy between DO depletion

and BOD/COD compliance highlights the need for comprehensive wastewater treatment that addresses both carbonaceous oxygen demand and other oxygen-depleting processes.

Heavy Metal Contamination Assessment

The elevated cadmium concentrations (0.008 ± 0.0002 to 0.010 ± 0.0003 mg/L) exceeding WHO guidelines represent a significant health concern. Cadmium is a highly toxic heavy metal that has been implicated in renal dysfunction, bone demineralization, and carcinogenesis (Mitra *et al.,* 2022). The presence of cadmium in beverage industry effluent likely originates from raw materials, processing equipment, or cleaning agents used in production (Kolawole *et al.,* 2026). While concentrations remain below NESREA limits, the exceedance of WHO guidelines indicates potential health risks if this effluent contaminates drinking water sources. Chronic exposure to cadmium at concentrations even 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 undetectable chromium and lead concentrations suggest the absence of contamination from these metals, which is positive from both environmental and health perspectives. Chromium and lead are common industrial contaminants with well-established toxicity profiles; their absence likely reflects appropriate material selection and process control. However, Kolawole *et al.* (2026) found elevated lead levels near metal recycling facilities in Nigeria, emphasizing that industrial activities generally contribute significantly to environmental lead contamination. The absence of lead in ABL's effluent suggests effective source control, though continuous monitoring is essential to ensure sustained compliance.

The most notable heavy metal exceedance was for iron, with concentrations 23 to 27 times higher than WHO guidelines. Iron is an essential micronutrient but can cause aesthetic and operational problems in water systems, including discoloration, metallic taste, and staining of plumbing fixtures (Acharya, 2024). While iron is less acutely toxic than cadmium or lead, elevated concentrations can contribute to iron overload conditions in exposed populations and may indicate corrosion of equipment or pipelines within the production facility. The iron concentration, while substantial, is consistent with industrial effluents where metal piping and equipment contribute to metal loading (Obasi & Akudinobi, 2020).

Manganese concentrations remained within acceptable limits, reflecting controlled use of this metal in the production process. Manganese, like iron, is an essential nutrient but can be neurotoxic at high concentrations (Acharya, 2024).

Regulatory Compliance and Environmental Implications

The comparison of measured values against WHO and NESREA standards reveals a complex compliance picture. The effluent from Adama Beverage Limited meets most NESREA standards, including pH, temperature, TDS, BOD, COD, and all heavy metal parameters except iron (which falls below NESREA limits). However, the effluent fails to meet several WHO guidelines, particularly for DO, cadmium, and iron concentrations.

The discrepancy between WHO and NESREA standards reflects different applications (drinking water versus industrial effluent guidelines) and potentially different levels of regulatory stringency. The NESREA standards, while providing a baseline for environmental protection, may be less stringent than WHO guidelines in certain areas. This regulatory gap is not uncommon in developing countries, where enforcement capacity and economic considerations may influence standard-setting (Okocha & Nuthall, 2025).

The critical DO levels in the effluent suggest that wastewater treatment at ABL may be insufficient to prevent oxygen depletion in receiving water bodies. Kolawole *et al.* (2026) emphasize the importance of adequate pretreatment in industrial facilities to prevent ecosystem degradation. In the beverage industry, wastewater treatment typically involves screening, equalization, neutralization, and biological treatment to reduce organic loading and prevent DO depletion (Nijhuis Saur Industries, 2025). The observed DO values suggest that the biological treatment stage may be inadequate or that treatment capacity is insufficient for current production levels.

Health Risk Assessment Considerations

The exceedance of WHO guidelines for cadmium and iron in the effluent raises potential health concerns, particularly if this wastewater contaminates local water sources or is used for irrigation. Heavy metal contamination of water sources has been associated with various health outcomes, including renal dysfunction, neurological disorders, and carcinogenesis (Jannetto & Cowl, 2023; Mitra *et al.,* 2022). In Nigeria, studies have documented heavy metal contamination of drinking water sources near industrial areas, with associated health risks (Kolawole *et al.,* 2026; Ensign, 2016).

The elevated cadmium concentration is particularly concerning given its potent toxicity and carcinogenic properties. Cadmium has a long biological half-life (15 to 30 years) and accumulates in the kidneys, liver, and bones, causing chronic toxicity even at low exposure levels (Acharya, 2024). The presence of cadmium in effluent that exceeds WHO drinking water guidelines suggests that the local population may be at risk if the effluent contaminates water supplies.

While iron toxicity is less severe than cadmium, elevated iron concentrations can contribute to gastrointestinal irritation, organ damage, and increased risk of hemochromatosis in susceptible populations (Acharya, 2024). The discoloration and metallic taste associated with high iron concentrations also affect water quality perception and acceptance.

Potential Sources of Contamination

Several potential sources may contribute to the heavy metal concentrations observed in ABL effluent. In beverage production, metals can enter wastewater from raw materials, including fruits and flavorings that may contain trace metals (Nijhuis Saur Industries, 2025). Processing equipment made from metal alloys may also release metals through corrosion, particularly at elevated temperatures or acidic pH conditions. Cleaning agents and sanitizers used in production can contain metal residues. Additionally, the water source itself may contribute to metal loading, depending on the local groundwater chemistry.

The relatively high iron concentration could result from corrosion of iron pipes and equipment within the production facility, particularly if the slightly acidic pH of the effluent promotes metal leaching. Kolawole *et al.* (2026) found elevated concentrations of various metals in industrial wastewater from Nigerian manufacturing facilities, highlighting the need for careful monitoring of equipment materials and condition.

The presence of cadmium at concentrations exceeding WHO limits suggests intentional or unintentional use of cadmium-containing materials in the production process, though the source remains unclear. Cadmium contamination in industrial wastewater has been associated with metal plating, battery manufacturing, pigment production, and phosphate fertilizer use (Obasi & Akudinobi, 2020). The specific source in this facility warrants further investigation.

Table 1: Mean Concentration of Some Heavy Metals and Physicochemical Properties of Effluent from Adama Beverage Limited

Parameter\Sample Code	ABL $_{WW1}$	ABL $_{WW2}$	ABL $_{WW3}$	WHO Limit	NESREA Limit
pH	6.21± 0.0100	6.12± 0.0100	6.09± 0.0071	6.50 to 8.50	6.00 to 9.00
Temperature (^{o}C)	33.0± 0.0707	32.9± 0.1000	33.1± 0.0707	<40	<40
Conductivity (µS/cm)	48.6± 0.0707	39.7± 0.1000	46.9± 0.1000	1000	NS
TDS (mg/L)	29.7± 0.1000	23.7± 0.0707	28.0± 0.0707	500	2000
DO (mg/L)	1.3± 0.0707	1.4± 0.10000	1.2± 0.1000	>5	>4
BOD (mg/L)	10± 1.0000	7± 0.7071	10± 0.7071	30	50
COD (mg/L)	19± 0.7071	18± 1.0000	25± 1.0000	250	250
Cd (mg/L)	0.010 ± 0.0003	0.008 ± 0.0002	0.008 ± 0.0001	0.003	0.050
Cr (mg/L)	0.000 ± 0.0005	0.000 ± 0.0004	0.000 ± 0.0011	0.05	0.50
Fe (mg/L)	8.038 ± 0.0011	7.058 ± 0.0008	6.982 ± 0.0007	0.3	20
Pb (mg/L)	0.000 ± 0.0005	0.000 ± 0.0005	0.000 ± 0.0004	0.01	0.10
Mn (mg/L)	0.077 ± 0.0002	0.060 ± 0.0002	0.069 ± 0.0002	0.1	5.0

Key:
ABL $_{WW1}$ is waste water sample from Adama Beverage Limited location one
ABL $_{WW2}$ is waste water sample from Adama Beverage Limited location two
ABL $_{WW3}$ is waste water sample from Adama Beverage Limited location three
NS = Not specified.
BOD = Biochemical Oxygen Demand; COD = Chemical Oxygen Demand; TDS = Total Dissolved Solids; DO = Dissolved Oxygen

CONCLUSION

The effluent of Adama Beverage Limited meets the national NESREA standard but greatly exceeds the WHO standard for dissolved oxygen, cadmium and iron. This indicates a high risk of organic pollution and metal contamination. These exceedances, especially cadmium 2.7 to 3.3 times over and iron 23 to 27 times over WHO limits, pose potential ecological risks to receiving water bodies and public health concerns should contamination reach drinking water sources. The results show a large gap between national regulations and international safety standards and the urgent need to improve the treatment for the real protection of environment and human health.

APPLICATION OF THE STUDY

The company must immediately upgrade its wastewater system with advanced biological treatment and aeration to correct oxygen depletion and implement corrosion controls and source-tracing measures to specifically reduce iron and cadmium levels. Continuous real-time monitoring of all physicochemical and heavy metal parameters is a prerequisite for early detection and rapid corrective actions and should be institutionalized. The evolving Nigerian environmental governance framework requires proactive engagement with regulators like NESREA and the building of internal capacity. In addition, communication with public and community on the environmental performance should be prioritized in a transparent manner to build trust and demonstrate corporate social responsibility that goes beyond compliance with regulations (Consortium Legal, 2025 and Reworld, 2026).

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