



PHYSICOCHEMICAL CHARACTERIZATION AND HEAVY METAL POLLUTION ASSESSMENT OF ELECTROPLATING WASTEWATER IN CHANCHAGA, NIGERIA WITH IMPLICATIONS FOR SUSTAINABLE TREATMENT

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Abstract: *Electroplating wastewater is a major contributor of water contamination as a result of the presence of heavy metals, salts, and acid content. There have been many electroplating industries in Nigeria, but little attention has been paid to the analysis and characterization of the wastewater. Therefore, there is no suitable technique developed for the treatment of such wastewater which could serve to minimize environmental pollution. This work presents the physicochemical characterization of electroplating wastewater sampled from an electroplating industry in Chanchaga Area Council, Niger State, Nigeria. Water samples were taken and characterized using the standard methods recommended by the American Public Health Association (APHA, 2023). While physicochemical parameters were analyzed via standardized methods, the determination of heavy metals was done via the process of microwave plasma atomic emission spectroscopy (MP-AES). According to the study, the wastewater sample was strongly acidic with a pH value of 1.02, high electrical conductivity (EC) of 58,550 $\mu\text{S}/\text{cm}$, total dissolved solids (TDS) of 49,400 mg/L, chemical oxygen demand (COD) of 177.15 mg/L, and high chloride content (Cl) of 932.72 mg/L. All these parameters are above the permissible levels of NESREA and WHO/US-EPA standards. Similarly, high concentrations of nickel (46.43 mg/L), iron (44.41 mg/L), copper (25.46 mg/L), zinc (13.70 mg/L), cadmium (1.96 mg/L), arsenic (0.20 mg/L), and manganese (1.12 mg/L) have been found in electroplating wastewater. In contrast, very low concentrations of Biochemical Oxygen Demand (BOD) of 2.75 mg/L were measured. The obtained findings demonstrate that electroplating wastewater is rich in dissolved inorganic substances and posed a significant threat when discharged to the environment in an untreated form.*

Key words: Electroplating wastewater; Heavy metals; Physicochemical characterization; Environmental pollution; Sustainable wastewater treatment.

Abbreviations: APHA — American Public Health Association; BOD — Biochemical Oxygen Demand (5-day); CF — Contamination Factor; COD — Chemical Oxygen Demand; EC —

Electrical Conductivity; MP-AES — Microwave Plasma Atomic Emission Spectroscopy; NESREA — National Environmental Standards and Regulations Enforcement Agency; TDS — Total Dissolved Solids; TSS — Total Suspended Solids;

USEPA — United States Environmental Protection Agency; WHO — World Health Organization

1. Introduction

One of the most commonly used techniques in the manufacturing industry for surface finishing is electroplating, since it provides corrosion and wear protection and improves the electrical conductivity and appearance of metallic items. Electroplating finds its application in making the elements for automotive, electrical and electronic equipment, building structures, household items, the aerospace industry, and decorative products (Guo *et al.*, 2024). Electroplating consists of several sequential stages: degreasing, acid pickling, rinsing, activation, electroplating, passivation, and washing. All of the above stages result in the generation of huge amounts of wastewater with high concentrations of different substances such as heavy metals, acids, alkalis, salts, surfactants, chelating compounds, and many more organic additives (Valencia *et al.*, 2019; Rajoria *et al.*, 2022).

Electroplating wastewater is among the most toxic industrial effluents due to the high persistence and toxicity of the effluents. Heavy metals like nickel, copper, zinc, chromium, cadmium, lead, and iron have been observed in electroplating wastewater and are considered to pose serious environmental problems because of the highly persistent nature of these metals, which cannot be easily broken down in nature and have the potential to bioaccumulate within aquatic species and even human beings (Chow *et al.*, 2021; Othman *et al.*, 2021; Soleimani *et al.*, 2023; Liu and Wang, 2024).

Nigerian electroplating industries exist as small- and medium-scale industries which usually face problems such as old machinery, poor wastewater management facilities, inconsistent electricity, poor regulatory control, and poor access to modern pollution control technology (Obokoh and Goldman, 2016). Where industrial effluent enters drainage channels or surface-water systems without adequate treatment, the combination of acidity, dissolved salts, and heavy metals can reduce receiving-water quality and increase the potential for metal transport. In areas where surface and groundwater are used for irrigation, livestock, or

domestic purposes, such discharges require particular attention. Physicochemical parameters such as pH, electrical conductivity, total dissolved solids, total suspended solids, BOD, COD, sulphate, chloride, and heavy metals provide complementary information on pollutant loading, ionic strength, metal mobility, and treatment requirements. These characteristics influence the applicability of chemical precipitation, membrane filtration, ion exchange, electrochemical treatment, and adsorption. Conventional physicochemical (e.g., chemical precipitation/coagulation–flocculation, oxidation, ion exchange, and membrane processes) processes may require substantial chemical inputs, energy, specialized equipment, sludge handling, or membrane maintenance; therefore, wastewater characterization is necessary for selecting a technically and economically appropriate treatment method (Rajoria *et al.*, 2022; Gao *et al.*, 2025).

Despite investigations of electroplating wastewater treatment internationally, comprehensive characterization of electroplating wastewater from Nigerian facilities remains limited. Existing Nigerian studies have commonly focused on selected metals or particular treatment approaches, including chromium and manganese removal (Yahya *et al.*, 2020), multiple-metal characterization and adsorption (Bankole *et al.*, 2019), and adsorption of selected metal ions from electroplating wastewater (Abdulkareem *et al.*, 2023; Ajala *et al.*, 2024). Comparable studies from other African settings also show substantial variation in wastewater composition. For example, an electroplating wastewater study in Nairobi, Kenya reported high concentrations of Cu, Pb, and Zn (Cherono *et al.*, 2021). Studies in Morocco have likewise reported metal-rich electroplating wastewater and emphasized adsorption or electrocoagulation as treatment options (Boukhlifi, 2020). These differences demonstrated that wastewater composition is strongly dependent on plating operations and local industrial practices. A site-specific Nigerian dataset that jointly considers physicochemical characteristics, multiple heavy metals, regulatory exceedances, and contamination factors is therefore useful for treatment planning. The specific gap addressed by this study is the limited information linking the physicochemical quality and heavy-metal pollution profile of electroplating wastewater from the Chanchaga industrial setting with implications for sustainable treatment.

Accordingly, this study focuses on the physicochemical characterization and heavy-metal assessment of electroplating wastewater collected from an electroplating facility in Chanchaga Area Council, Niger State, Nigeria. Physicochemical properties were determined using APHA-recommended methods (APHA, 2023), while heavy metals were quantified using Microwave Plasma–Atomic Emission Spectroscopy (MP-AES). The measured values were compared with the discharge limits presented NESREA (2009) and WHO/USEPA sources. Contamination factors were also calculated to contextualize the degree of contamination relative to the selected regulatory reference values. The resulting dataset is intended to provide a basis for environmental assessment and for the selection and development of sustainable treatment technologies, including adsorption using locally available bio-based materials.

2. Materials and Methods

2.1 Materials

The materials that were used in this experiment are 10-liter HDPE sample bottle, electroplating waste water, distilled water, concentrated nitric acid (HNO_3) which is analytical grade, barium chloride, silver nitrate, potassium chromate, filter papers, beakers, measuring cylinders, evaporating dishes, porcelain crucibles, hot plate, drying oven, digital pH meter, conductivity meter, digital thermometer, analytical balance, and Microwave Plasma – Atomic Emission Spectrometer (MP-AES). The chemicals used were analytical grade, and distilled water was used for all analyses.

2.2 Sample Collection, Preservation and Storage

The study samples were labelled to avoid misrepresentation in the course of processing within the period of two months (April – May, 2026) at the hours of 9–10 am. Five (5) processed electroplating wastewater samples were collected from an electroplating plant located at Chanchaga Area Council, Niger State, Nigeria (Lat: $9^\circ 33' 31''$ N; Long: $6^\circ 35' 97''$ E) (Johnson and Barton, 2004). The study area and sample collection point were presented in Fig. 1 and Plate 1, respectively. The electroplating plant consists of different plating tanks, viz., copper, nickel, zinc, acid pickling, and

degreasing baths, with a capacity of about 400 L each.

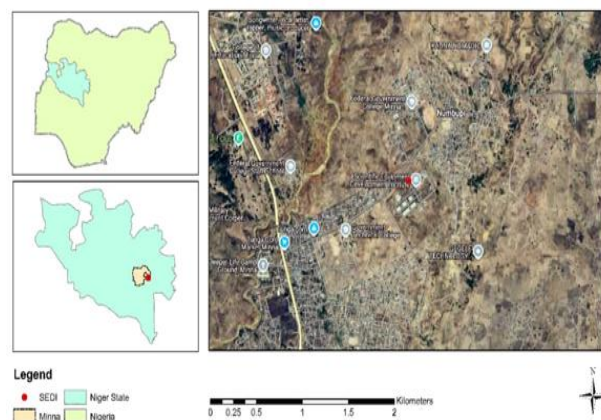


Figure 1: Location Map showing the Study Area



Plate 1: Sample Collection Point

Electroplating effluent samples were collected from the discharge point using 10 L HDPE plastic bottles that were washed with soap, thoroughly rinsed with distilled water, soaked in 10% nitric acid for 24 h, and then rinsed again with distilled water to avoid contaminating the sample. Before collecting the sample, the bottle was rinsed three times with the sample. Sampling, preservation, transportation and storage of samples were done according to the standard procedure recommended by the (APHA, 2023). The pH, temperature, and conductivity were measured at the sampling site. For heavy metal determination, the samples were preserved through acidification to $\text{pH} < 2$ with concentrated nitric acid, while BOD and COD samples were stored in the fridge at 4°C without acidification.

2.3 Physicochemical Analysis

The wastewater samples were analyzed for their physicochemical properties using the Standard Methods for the Examination of Water and Wastewater (APHA, 2023). All the analyses were carried out in triplicate, and the data were presented in the form of average $\pm$ standard deviation.

A calibrated digital pH meter (APHA Method 4500-H⁺ B) was used to measure the pH value, and a conductivity meter (Method 2510 B) was used to measure the electrical conductivity. A digital thermometer (Method 2550 B) was used to measure the temperature.

After filtration, the total dissolved solids (TDS) were found by gravimetric procedure (Procedure 2540 C) and evaporated to constant weight. Total suspended solids (TSS): The amount of suspended matter in a given volume of wastewater was determined by gravimetric procedure (Procedure 2540 D), which involved filtering a measured volume of wastewater through a pre-weighed glass fibre filter and drying to constant weight at 103-105 °C.

Biochemical oxygen demand (BOD) was measured using a five-day incubation method (Procedure 5210 B). COD was measured by the closed reflux colourimetric method (Procedure 5220 D).

Sulfate content was analyzed by turbidimetric procedure (Procedure 4500-SO₄²⁻ E). Chloride content was analyzed by argentometric titration procedure (Procedure 4500-Cl⁻ B).

Table 1: APHA Methods used for Physicochemical Analyses

Parameter	APHA Method (24 th ed.)	Analytical Technique
pH	4500 H B	Electrometric
Conductivity	2510 B	Conductivity meter
Temperature	2550 B	Thermometric method
TDS	2540 C	Gravimetric
TSS	2540 D	Gravimetric
BOD	5210 B	5-day incubation
COD	5220 D	Closed reflux colorimetric
Sulfate	4500-SO ₄ E	Turbidimetric
Chloride	4500-Cl B	Argentometric titration

2.4 Sample Digestion for Determination of Heavy Metals

Sample digestion of heavy metals was performed as recommended by (APHA, 2023). About 50 ml of well-mixed and undiluted wastewater sample was placed in a clean borosilicate glass beaker, and 10 mL of concentrated nitric acid (HNO₃) was added to the solution.

Afterwards, the solution was allowed to stand for 30 min to allow for pre-digestion, then heated on a hot plate at 95-100 °C for a period of 45-120 min, without boiling, until only 10-15 mL of the solution was left.

The digested solution was filtered using Whatman No. 42 filter paper, and then the filtrate solution was poured into a 50 mL volumetric flask.

2.5 Heavy Metal Determination

Heavy metal concentrations were determined using an Agilent Microwave Plasma-Atomic Emission Spectrometer (MP-AES) model MY17380004 located at the Centre for Dryland Agriculture, Bayero University, Kano, Nigeria. Instrument calibration was performed using certified multi-element standard solutions prepared at different concentration levels. Calibration curves with coefficients of determination ($R^2 \geq 0.999$) were obtained for all analytes before sample analysis. All operational procedures and wavelengths suggested by the manufacturer were strictly adhered to during the analysis process. Periodic testing of blanks and verification standards was carried out in order to achieve accurate results and reduce instrumental drift. Levels of nickel (Ni), copper (Cu), zinc (Zn), chromium (Cr), cadmium (Cd), lead (Pb), mercury (Hg), arsenic (As), manganese (Mn), iron (Fe), cobalt (Co), and selenium (Se) were quantified.

The contamination factor (CF) was calculated according to the method proposed by Håkanson (Hakanson L, 1980) expressed as equation (1).

$$CF = \frac{C_{\text{sample}}}{C_{\text{reference}}} \quad (1)$$

Where C_{sample} is the measured concentration of each heavy metal in the electroplating wastewater,

$C_{\text{reference}}$ is the corresponding permissible concentration specified by NESREA

2.6 Quality Assurance and Quality Control (QA/QC)

In order to validate the accuracy of the findings, all the glassware used in the experiments was first cleaned with 10% nitric acid, followed by thorough rinsing with deionized water. Analytical-grade reagents were used throughout the experiment. All experiments were conducted in triplicate and included reagent blanks to check for contamination. Instruments were calibrated on a daily basis following manufacturers' guidelines prior to the analysis. QC standards were run every ten samples to confirm the consistency of the results, and all the calibration curves had R^2 values greater than 0.999.

2.7 Statistical Analysis

The data obtained were expressed as the mean value $\pm$ standard deviation from three separate experiments. Statistical analysis and plotting were done through Microsoft Excel 2021 software.

3 Results and Discussion

3.1 Physicochemical Analysis of Electroplating Wastewater

Physicochemical properties of electroplating wastewater provide valuable insight into its pollution status and the feasibility of treatment processes. The analytical data obtained were presented in Table 2 along with acceptable limits for discharge according to NESREA and WHO/USEPA standards.

Table 2: Physicochemical Analysis of Electroplating Wastewater

Parameters	Present study	(Morsy <i>et al.</i> 2022)	(NESREA, 2009) Standard Limits	(WHO, 2005)/ (USEPA, 2018) Standard Limits
pH	1.02 $\pm$ 0.27	2.00	6.00-9.00	5.50-8.50
Electrical Conductivity (EC) (μ S/cm)	58,550 $\pm$ 75.8	1.70	NR	300.00
Temperature ($^{\circ}$ C)	25.50 $\pm$ 0.71	25.00	< 40.00	25.00
Total Dissolved Solid (TDS) (mg/L)	49400 $\pm$ 56.10	1180.00	2000.00	2100.00
Total Suspended Solid (TSS) (mg/L)	4.83 $\pm$ 0.81	100.00	30.00	100.00
Chemical Oxygen Demand (COD) (mg/L)	177.15 $\pm$ 2.90	1,430.00	80.00	10.00
Biochemical Oxygen Demand (BOD) (mg/L)	2.75 $\pm$ 0.35	1.56	30.00	5.00
Chloride (mg/L)	932.72 $\pm$ 76.77	NR	600.00	250.00
Sulphate (mg/L)	297.53 $\pm$ 3.50	NR	500	250

BDL: Below Detection Limit; NR: Not Reported; NA: Not Applicable

Table 2 presents the results of the physicochemical analysis of electroplating wastewater, and Fig. 3 presents the ratios of the measured physicochemical parameters of the electroplating wastewater to the corresponding NESREA and WHO/USEPA reference limits; the wastewater exhibited a strongly acidic pH (1.02), which is considerably lower than the permissible discharge limits of 6.0–9.0 (NESREA, 2009) and 5.5–8.5 (WHO, 2005/USEPA, 2018). The value is comparable with 2 and 0.83 reported by (Morsy *et al.* 2022) and

(Bankole *et al.*, 2019), respectively. These differences can be attributed to the effluent sources, as the electroplating operation involves several stages, each with the potential to generate wastewater. This observation is consistent with the extensive use of mineral acids such as hydrochloric acid and sulfuric acid during metal cleaning, pickling, activation, and electroplating operations. The acidic condition promotes the dissolution and mobility of heavy metal ions, thereby increasing their transport, bioavailability, and toxicity in

receiving water bodies. Additionally, acidic wastewater may accelerate corrosion of drainage systems and adversely affect aquatic organisms by disrupting physiological and metabolic processes. Similar acidic conditions have been reported for electroplating effluents in previous (Morsy *et al.*, 2022; Rajoria *et al.*, 2022).

The electrical conductivity (EC) was observed to be 58,550 $\mu\text{S}/\text{cm}$, which is extremely higher than the 1.695 $\mu\text{S}/\text{cm}$ reported by (Morsy *et al.*, 2022). This large variation was attributed to the difference in analytical methods and source effluent discharges. The recorded value exceeds the 300 $\mu\text{S}/\text{cm}$ standard limit (WHO, 2005). The higher EC value indicates the presence of a significant amount of dissolved metals, electrolytes, acids, sulfates, and chlorides in the wastewater (Elfeky *et al.*, 2024; Li and Du, 2025). This high value suggests the wastewater largely contains inorganic matter. According to Macena *et al.* (2025), such wastewater may reduce adsorption efficiency because dissolved ions compete with target contaminants for available adsorption sites. Moreover, wastewater with extremely high conductivity may require pretreatment before biological or membrane-based treatment processes to prevent operational inefficiencies and membrane fouling.

The temperature of the effluent water was 25.5 $^{\circ}\text{C}$, which met the (NESREA, 2009) discharge requirement ($<40^{\circ}\text{C}$), and it was almost equal to the temperature of the environment. This indicates that the effluent water had been cooled before being discharged into the environment, and there will not be any risk of thermal pollution. However, the temperature is an important variable since it affects reaction rates, oxygen solubility, microbial activity, and adsorption properties of heavy metals.

The recorded TDS value of 49,400 mg/L was very high compared to the permissible levels of 2,000 mg/L (NESREA, 2009) and 2,100 mg/L (USEPA, 2018); hence, it exceeds their respective values by more than twenty times. From the results obtained, one can conclude that the wastewater is mainly composed of dissolved inorganic components such as metal salts, acids, and other soluble electrolytes used during the electroplating processes. The results obtained from the TDS value show that there is a high level of correlation between dissolved solids and ionic content in wastewater. Excess TDS leads to increased salinity, degrading the quality of freshwater for consumption, making water

unsuitable for irrigation purposes, and adversely affecting aquatic life due to osmosis (Brent *et al.*, 2022)

The recorded TSS concentration value was 4.83 mg/L, which is significantly below 100 mg/L as reported by (Morsy *et al.* 2022), and much below 30 mg/L limits set by (NESREA, 2009) and 100 mg/L by (USEPA, 2018). This suggests that the wastewater sample analyzed has very little suspended particulate matter, but mostly consists of dissolved matter (Elfeky *et al.*, 2024). (Barakat *et al.*, 2015) Strongly acidic conditions prevent precipitation of metal hydroxides, and thus, the majority of heavy metals will remain in solution form. Thus, the treatment process aimed at the removal of dissolved matter, such as adsorption, ion exchange, chemical precipitation after adjusting the pH level, or membrane separation, would be preferable to solid waste removal techniques.

The chloride level was determined to be 932.72 mg/L, above the 600 mg/L (NESREA, 2009) and 250 mg/L (USEPA, 2018) discharge limits. The high chloride levels are associated with the excessive use of hydrochloric acid, electrolytes that contain chloride ions, and chlorides of metals during electroplating processes. High chloride levels greatly increase the corrosiveness of the wastewater and are responsible for the high electrical conductivity (Cao *et al.*, 2022).

The elevated chloride concentration also has important implications for wastewater treatment. Unlike many heavy metals, chloride remains highly soluble and is not readily removed through conventional chemical precipitation used for heavy-metal treatment. Consequently, a treatment process may substantially reduce the concentrations of Ni, Cu, Zn and other metals while leaving a significant proportion of chloride in the treated effluent. Chloride persistence is particularly important when treated wastewater is intended for discharge or reuse because high chloride concentrations can increase salinity and corrosion and may impose additional constraints on downstream treatment processes (Li *et al.*, 2022; Duan *et al.*, 2024).

The high chloride concentration may also affect the performance of some advanced treatment systems. High ionic strength can influence membrane separation and reduce the rejection of certain contaminants; studies on electroplating wastewater

have shown that the presence of monovalent chloride ions can affect the separation of divalent metal ions during nanofiltration (Hegoburu *et al.*, 2020). Therefore, chloride control should be considered alongside heavy-metal removal when designing a treatment system for this wastewater. Where chloride reduction is required, technologies such as ion exchange, adsorption, reverse osmosis, nanofiltration, electrodialysis, or other membrane-based processes can be considered, although their suitability depends on wastewater composition, target discharge requirements, cost, and the potential for membrane fouling or concentrate generation (Li *et al.*, 2022; Duan *et al.*, 2024).

Thus, the chloride concentration of 932.72 mg/L indicates that treatment of the investigated electroplating wastewater should not focus exclusively on heavy-metal removal. An integrated treatment approach may be necessary to simultaneously control dissolved metals, chloride, acidity, and the high ionic strength of the effluent. This is consistent with reviews of electroplating wastewater treatment, which indicate that combined treatment processes can provide broader contaminant removal than reliance on a single treatment technology (Kamar *et al.*, 2024).

Moreover, the level of sulfate (297.53 mg/L) was slightly higher than 226.49 reported by (Supromin and Potivichayanon, 2024) and above the WHO/USEPA guideline of 250 mg/L, but it was still lower than the (NESREA, 2009) of 500 mg/L. The presence of sulfate ions is normally attributed to the addition of sulfuric acid in the process of pickling and surface treatment. The presence of higher levels of sulfates contributes to ionic strength and salinity, thus exhibiting difficulties during the process of wastewater treatment (Chang and Kim, 2007).

The elevated sulphate may affect adsorption and precipitation processes through changes in ionic strength and interactions with dissolved metal ions. During chemical treatment, sulphate can contribute to scaling, particularly where calcium-based reagents are used, potentially affecting treatment equipment and downstream filtration or membrane systems (Cai *et al.*, 2024). Membrane treatment is also influenced by sulphate speciation and the overall ionic strength of the wastewater; under the

strongly acidic conditions typical of electroplating effluents, part of the sulphate may occur as bisulphate (HSO_4^-), which can reduce sulphate rejection during nanofiltration (Hegoburu *et al.*, 2020).

COD of the wastewater was 177.15 mg/L, which is lower than 1,430 mg/L by (Morsy *et al.*, 2022). These variations in the concentrations may be linked to the source of effluents and analytical approaches adopted. The measured value is higher than 80 mg/L (NESREA, 2009) and 10 mg/L (WHO, 2005) permissible levels, implying that there are pollutants with the ability to oxidize in the water. Although electroplating wastewater contains mainly inorganic pollutants, the recorded COD implies the contribution of some organic substances such as surfactants, brightening, leveling, wetting, and complexing agents that are used for enhancing electroplating. Despite the very high TDS and conductance values recorded, the comparatively low COD shows that inorganic pollutants are the major group of pollutants (Fu and Wang, 2011; Crini *et al.*, 2019).

The recorded BOD₅ of 2.75 mg/L was comparable to 1.56 mg/L reported by (Morsy *et al.*, 2022). This value falls within the range of the acceptable discharge limit, indicating the presence of less organic material. The low BOD₅ is an indicator that the electroplating effluent is inorganic, with pollutants present mostly as dissolved ions rather than biodegradable substances. Thus, biological treatment is not an effective method in the management of electroplating wastewaters because most of the pollutants are inorganic in nature (Morsy *et al.*, 2022; Rajoria *et al.*, 2022).

It is clear from the physicochemical properties of the wastewater studied that the wastewater is highly acidic, has high ionic strength, high levels of total dissolved solids, and is highly contaminated with inorganic substances. The values of the parameters assessed were above the allowable limits as specified by NESREA and WHO/USEPA. This shows the threat to environmental safety posed by the discharge of such wastewater without undergoing proper treatment. This knowledge will help choose the appropriate wastewater treatment technologies which can remove dissolved heavy metals.

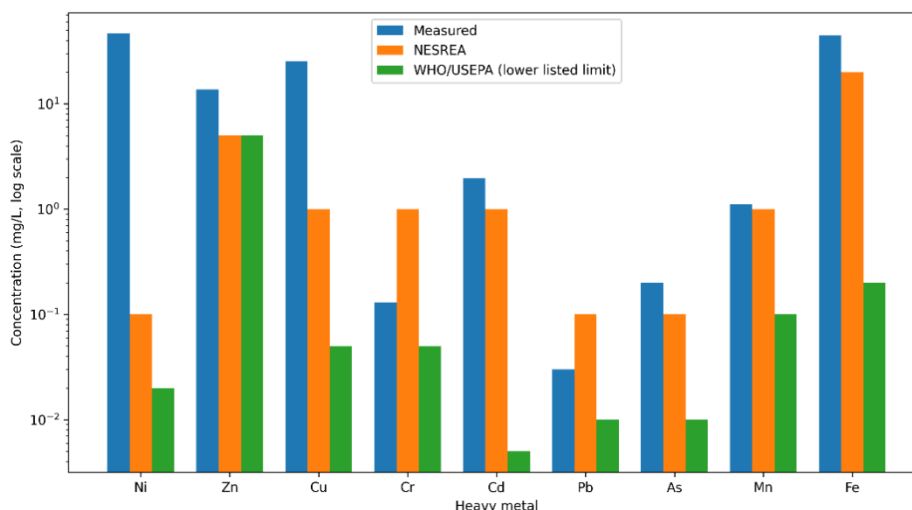


Figure 2: Comparative heavy-metal concentrations in the electroplating wastewater and the reported NESREA and WHO/USEPA discharge limits. The WHO/USEPA series uses the lower listed limit where two values are reported.

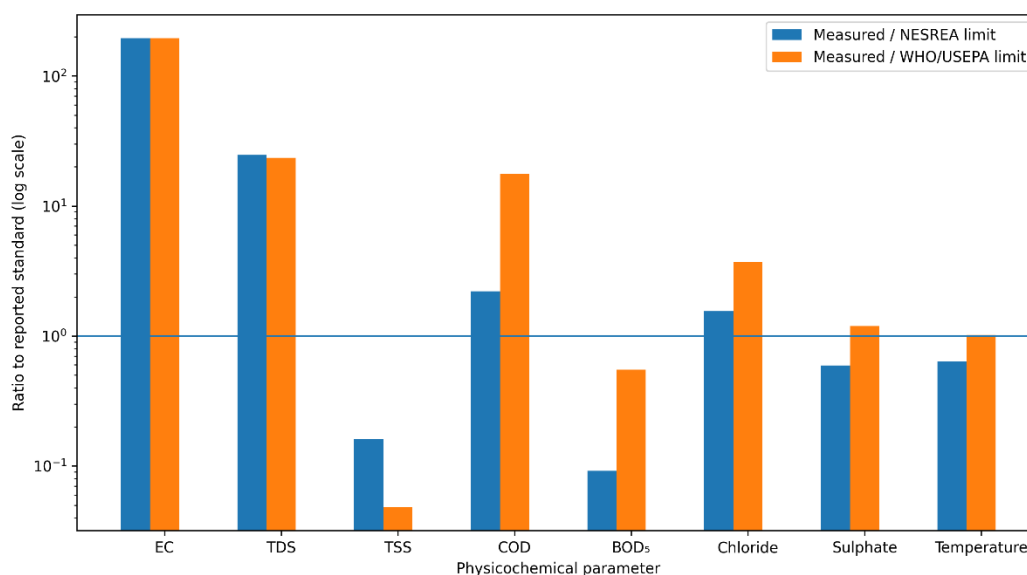


Figure 3: Physicochemical parameters relative to the reported NESREA and WHO/USEPA discharge standards. Ratios above 1 indicate exceedance of the corresponding standard.

3.2 Heavy Metal Characterization of Electroplating Wastewater

Table 3 presents the concentrations of heavy metals identified in the electroplating wastewater samples while Fig. 2 and 4 depicted the graphical representation, along with their corresponding

permissible levels under NESREA and WHO/USEPA standards. Heavy metals are considered the major contaminants in electroplating wastewater due to their biologically recalcitrant nature and ability to bioaccumulate in living organisms. The presence of these metal ions beyond

permissible limits pose a serious environmental and public health problems.

Table 3: Heavy metal analysis of electroplating wastewater

Heavy metal	Present study (mg/L)	(Bankole <i>et al.</i> , 2019) (mg/L)	(NESREA, 2009) Standard Limits (mg/L)	(WHO, 2005)/(USEPA, 2018) Standard Limits (mg/L)	Contamination Factor	Contamination Level
Nickel	46.43±1.13	106.10	0.10	0.07/0.02	464.30	Very high
Zinc	13.70±1.30	167.60	5.00	5.00	2.74	Moderate
Copper	25.46±2.40	97.57	1.00	2.0/0.05	25.46	Very high
Chromium	0.13±0.14	72.34	< 1.00	0.05	0.13	Low
Cadmium	1.96±0.65	3.02	< 1.00	0.005	1.96	Moderate
Lead	0.03±0.004	4.94	0.10	0.01/0.05	0.30	Low
Mercury	BDL	NR	0.01	NR	NA	NA
Arsenic	0.20±0.10	58.03	0.10	0.01/0.05	2.00	Moderate
Manganese	1.12±0.16	NR	1.00	0.10	1.12	Moderate
Iron	44.41±0.28	NR	20.00	NR	2.22	Moderate
Cobalt	BDL	NR	0.50	NR	NA	NA
Selenium	BDL	NR	< 1.00	NR	NA	NA

BDL: Below Detection Limit; NR: Not Reported; NA: Not Applicable ($CF < 1$ = Low contamination, $1 \leq CF < 3$ = Moderate contamination, $3 \leq CF < 6$ = Considerable contamination, $CF \geq 6$ = Very high contamination (Hakanson L, 1980)).

The heavy metal composition of the electroplating wastewater analysed in this study (Table 3) reveals a contamination profile of critical ecological concern, dominated by extreme nickel enrichment (46.43 ± 1.13 mg/L; contamination factor, $CF = 464.30$) and very high copper loading (25.46 ± 2.40 mg/L; $CF = 25.46$). These concentrations exceed NESREA (2009), WHO (2005), and USEPA (2018) effluent limits by one to three orders of magnitude, placing the effluent in a category associated with acute toxicity to aquatic organisms and long-term sediment contamination.

All measured metals except chromium, lead, mercury, cobalt, and selenium exceeded at least one regulatory threshold, with nickel, copper, zinc, cadmium, arsenic, manganese, and iron classified as moderate to very high contamination according to Hakanson's (1980) CF scheme ($CF < 1$ = low; $1 \leq CF < 3$ = moderate; $3 \leq CF < 6$ = considerable; $CF \geq 6$ = very high). Nickel at 46.43 mg/L is ~464-fold above the WHO guideline (0.1 mg/L) and ~2,300-fold above the USEPA aquatic-life criterion (0.02 mg/L), while copper at 25.46 mg/L surpasses WHO (2.0 mg/L) and USEPA (0.05 mg/L) limits by factors of 12 and 509, respectively. Zinc (13.70 mg/L; $CF = 2.74$), cadmium (1.96 mg/L; $CF = 1.96$), arsenic (0.20 mg/L; $CF = 2.00$), manganese (1.12 mg/L; $CF = 1.12$), and iron (44.41 mg/L; CF

$= 2.22$) fall within the moderate contamination band, yet their co-occurrence with Ni and Cu amplifies overall ecotoxicological risk through additive or synergistic effects (Gök and Gülyaşar, 2025).

The metal profile also differs from other African electroplating wastewater studies, demonstrating the influence of local plating operations. Bankole *et al.* (2019) reported higher concentrations of Ni, Cu, Zn, Fe, Cr, Cd, Pb, and As in another Nigerian electroplating wastewater, while Cherono *et al.* (2021) reported particularly high Cu, Pb, and Zn concentrations in wastewater from an electroplating company in Nairobi, Kenya. Moroccan studies have likewise reported metal-rich electroplating wastewater and emphasized adsorption or electrocoagulation as treatment options (Boukhelifi, 2020; Ngala *et al.*, 2019). These regional comparisons support the need for site-specific characterization rather than assuming a single composition for African electroplating wastewater.

Heavy metals are non-biodegradable, persistent pollutants that accumulate in sediments and biota, initiating trophic transfer and potential biomagnification through aquatic food webs. The extreme Ni and Cu levels recorded here are well within ranges reported to cause acute lethality,

growth inhibition, reproductive failure, gill damage, and oxidative stress in fish and invertebrates. Although moderate in CF, cadmium and arsenic are priority toxicants with documented bioaccumulation potential and carcinogenicity; chronic exposure via contaminated water and biota poses significant risks to ecosystem integrity and human health (Peters *et al.*, 2022).

Upon discharge into surface waters, dissolved metals will partition between the water column and suspended or bed sediments, where benthic organisms experience prolonged exposure. Algae, macroinvertebrates, and fish take up metals such as Ni, Cu, Cd, and As via gill uptake and dietary ingestion, leading to bioaccumulation in tissues such as the liver, kidney, and gonads. Over time, this results in biomagnification, where predators (including fish-eating birds and humans) accumulate metal burdens orders of magnitude higher than ambient water concentrations (Ma and Xiong, 2025).

Given the “very high” CF values for nickel and copper, this effluent cannot be discharged without advanced treatment. Conventional chemical precipitation may reduce bulk metal loads but generates hazardous sludge requiring secure disposal. Biosorption using low-cost adsorbents

(e.g., chitosan, shell-derived materials, or agricultural wastes) offers a promising polishing step to achieve compliance with NESREA, WHO, and USEPA limits while minimizing secondary waste. The ecological urgency is underscored by the fact that even moderate CF metals (Cd, As, Zn) contribute to long-term sediment contamination and food-chain transfer, making multi-metal removal essential for protecting aquatic ecosystem integrity and human health (Gök and Gülyaşar, 2025).

The heavy-metal composition therefore provides a basis for selecting a treatment sequence. A practical approach may involve pH adjustment and precipitation as an initial step for bulk metal removal, followed by adsorption, ion exchange, membrane separation, or another polishing process for residual dissolved metals. The high chloride and sulphate concentrations should also be considered because competing ions and high ionic strength can influence metal speciation and adsorption behaviour. The results consequently support further investigation of low-cost bio-based adsorbents, but such materials should be evaluated using real wastewater to account for competitive adsorption and the effects of the complex wastewater matrix.

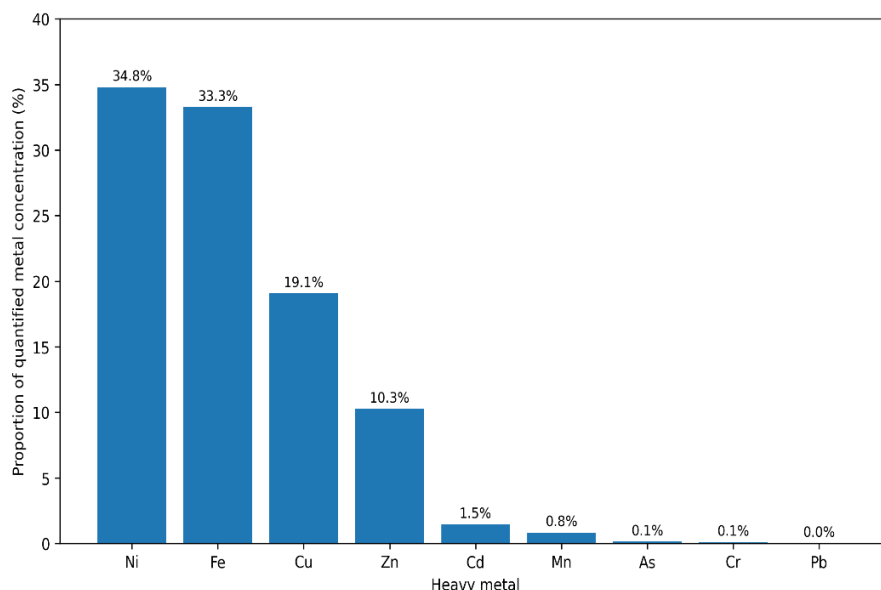


Figure 4: Proportional distribution of quantified heavy metals in the electroplating wastewater. Nickel accounts for 34.8% of the total quantified metal concentration, based on the concentrations reported in Table 3.

4 Conclusion

This study characterized the physicochemical properties and heavy-metal composition of wastewater collected from an electroplating facility in Chanchaga Area Council, Niger State, Nigeria. The wastewater was strongly acidic ($\text{pH } 1.02 \pm 0.27$) and contained very high electrical conductivity and TDS, together with elevated COD, chloride, and sulphate. The low TSS and BOD values indicate that the contaminant burden was predominantly dissolved and inorganic. Heavy metals of particular concern were nickel, iron, copper, zinc, cadmium, arsenic, and manganese, while chromium and lead occurred at comparatively low concentrations. Chromium ($0.13 \pm 0.14 \text{ mg/L}$) was below the reported NESREA limit of $<1.0 \text{ mg/L}$.

The contamination factor analysis showed extremely high contamination to be present in the sample for nickel and copper, moderate contamination for zinc, iron, cadmium, arsenic and manganese, while low contamination for chromium and lead. The high levels of dissolved chloride and sulphate also show that removing metals may not be enough to remove all the dissolved salts from the wastewater. Thus, treatment design should take into account a treatment sequence that can handle acidity, high ionic strength, dissolved metals and, if required, residual salts. Depending on the discharge or reuse purpose, therefore, pH adjustment, chemical precipitation, adsorption, ion exchange, membrane separation, electrochemical treatment, or a combination of these processes could be evaluated.

waste stream is not suitable for treatment by traditional biological techniques. In addition, the low value of biochemical oxygen demand confirms the above-mentioned conclusion about the predominance of metal ions in the composition of contaminants. Therefore, the application of effective physicochemical methods of wastewater

treatment, such as pH correction, chemical precipitation, adsorption, ion exchange, membrane filtration or a combination of them, can be recommended.

The study has added a site-specific data set for electroplating wastewater in Nigeria and has served as a guide for environmental monitoring, designing of treatment processes and planning pollution control in Nigeria. The outcome also indicates the need for further research on sustainable treatment materials, especially bio-based adsorbents, which are available in the region. The present characterization is for the discharge-sampled condition and is not meant to be a temporal characterization of the facility without repeated sampling. Therefore, temporal sampling and pilot-scale testing of treatment systems in the real multicomponent wastewater matrix should be included in future studies.

Future studies are recommended to examine the efficacy of using environmentally friendly adsorbents made from locally available agricultural and industrial waste products in both batch and flow-through treatments of electroplating wastewater. Such studies would help in designing efficient wastewater treatment technologies that can be easily implemented by the electroplating industries in Nigeria and developing nations generally.

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