

EVALUATION OF ATMOSPHERIC IMPURITIES IN EARLY RAINFALL AND ITS EFFECT ON AQUATIC ECOSYSTEM IN MINNA, ENVIRONS, NIGER STATE.

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Abstract

This study assessed the quality of rainwater in Minna Metropolis, Nigeria, to determine its suitability for domestic use. Rainwater samples were collected from three different stations with two samples collected from each station (zinc and direct from the sky) across the metropolis during the rainy season. Standard analytical methods were employed to evaluate a range of parameters, including physicochemical properties (temperature, pH, electrical conductivity, total alkalinity, total hardness, total dissolved solids, nitrate), heavy metal concentrations (lead, iron, copper, zinc, chromium), and microbial characteristics (total bacteria count, total coliform count, total fungal count). The results revealed that the mean physicochemical parameters were generally within acceptable limits. The mean pH was slightly acidic to near-neutral (6.71 - 6.88), while electrical conductivity and total dissolved solids were highest at Station 1 (131.82 $\mu\text{S}/\text{cm}$ and 84.36 mg/L, respectively). Significant variations ($p < 0.05$) were observed for electrical conductivity, total alkalinity, total hardness, and total dissolved solids of the water across the stations. Heavy metal analysis showed low concentrations, with the highest mean values for lead at Station C (0.018 mg/L), zinc at Station F (0.028 mg/L), and chromium at Station B (0.033 mg/L); lead, zinc, and chromium showed significant spatial differences ($p < 0.05$). However, microbial analysis indicated substantial contamination, with total bacteria counts ranging from 2.00×10^3 CFU/mL to 3.6×10^3 CFU/mL and total coliform counts from 1.8×10^3 CFU/mL to 2.5×10^3 CFU/mL, exceeding WHO standards. In conclusion, while the physicochemical and heavy metal characteristics of rainwater in Minna are largely compliant with standards, the widespread and significant microbial contamination renders it unsafe for consumption without prior treatment. The study recommends improved rooftop hygiene and mandatory disinfection before potable use.

KEYWORD: Atmospheric, Impurity, Rainfall, Aquatic, Eco System?

INTRODUCTION

Water is an essential natural resource that sustains life on Earth. Rainwater, a major component of the hydrological cycle, serves as an important water source for domestic, agricultural, and industrial purposes. In many regions, especially in developing countries, rainwater harvesting is a common practice due to inadequate access to treated water. However, as rainwater descends through the atmosphere, it interacts with various pollutants, including dust, aerosols, industrial emissions, and microbial contaminants, which can affect its quality (Adebayo & Oladipo, 2021). Minna, the capital of Niger State, is a rapidly growing urban center with increasing industrial and vehicular emissions. These activities contribute to atmospheric pollution, which, in turn, influences the quality of rainwater. Understanding the impurities present in rainwater is critical for assessing its safety for human consumption and other uses (Oloruntola *et al.*, 2022). This

study aims to identify the types and concentrations of rainwater impurities in Minna to provide insights for improved water resource management.

Rainwater is a crucial component of the hydrological cycle and has long been considered one of the purest forms of natural water due to its initial condensation from atmospheric vapor. However, as rainwater falls through the atmosphere and comes into contact with environmental surfaces, it may accumulate a variety of impurities. These impurities can range from particulate matter, heavy metals, and organic pollutants to microbial contaminants. Understanding the nature and extent of these impurities is essential, especially in urban and semi-urban settings where human activities contribute to environmental pollution.

Given the climatic and geographical conditions of Minna, there is a high potential for contamination of rainwater by both natural and anthropogenic sources. Windblown dust, industrial emissions, vehicular exhaust, and agricultural activities contribute to the presence of particulate matter, heavy metals, and other impurities in rainwater. Therefore, assessing the impurities in rainwater within Minna is essential for understanding pollution trends and ensuring public health safety.

Statement of Problem

Rainwater is a crucial natural resource that contributes significantly to water availability, particularly in regions where access to clean water is limited. However, increasing environmental pollution has led to the contamination of rainwater by various impurities, including particulate matter, heavy metals, and microbial contaminants. In urban and semi-urban settings like Minna, Niger State, the presence of industrial activities, vehicular emissions, and domestic combustion contribute significantly to atmospheric pollution, which, in turn, affects the quality of rainwater.

The presence of impurities in rainwater poses several health and environmental risks. Heavy metals such as lead (Pb), cadmium (Cd), and mercury (Hg) have been identified as hazardous to human health, potentially leading to neurological disorders, kidney damage, and other chronic conditions (Odeyemi *et al.*, 2021). Additionally, microbial contaminants in rainwater, including bacteria and fungi, increase the risk of waterborne diseases, particularly in communities that rely on rainwater harvesting for domestic consumption (Adekunle & Adedun, 2020).

Despite the significant reliance on rainwater in Minna, there is limited research on the nature and extent of its contamination. Atmospheric pollutants from vehicular emissions, industrial activities, and agricultural practices can introduce harmful substances into rainwater, posing potential health and environmental risks (Abubakar & Ibrahim, 2020). Without adequate monitoring and quality assessment, communities may unknowingly consume rainwater with unsafe levels of chemical and microbial contaminants. This study seeks to address this knowledge gap by determining the presence and concentration of various rainwater impurities in Minna, Niger State.

Aim and Objective

The primary aim of this study is to evaluate the physicochemical and bacteriological impurities in rainwater collected in Minna, Niger State.

Objectives of the Study

The specific objectives are to:

- i. evaluate the physical and chemical contaminants in rainwater samples.
- ii. evaluate the biological contaminants in rainwater samples
- iii. identify possible sources of impurities
- iv. evaluate the potential health risks associated with identified impurities.
- v. provide recommendations for improving rainwater quality management in Minna.

Justification

Ensuring access to safe water is a critical public health objective. Given the widespread practice of rainwater harvesting in Minna, it is essential to evaluate its quality and safety. Findings from this study will provide valuable data for policymakers, environmental agencies, and local communities to develop appropriate interventions for improving rainwater quality (Umar & Bello, 2019). Rainwater is a crucial water source in Minna, Niger State, especially for domestic and agricultural use. However, increasing urbanization, industrial activities, and atmospheric pollution pose significant risks of contamination. This study is essential to assess the quality of rainwater in Minna by identifying impurities such as heavy metals, particulate matter, and microbial contaminants. By addressing these concerns, this study aims to enhance sustainable water use and safeguard the health of residents in Minna, Niger State.

Scope of the Study: This study will focus on rainwater samples collected from various locations within Minna. The study will analyse physical, chemical, and biological impurities and examine seasonal variations in rainwater quality over a defined period.

Limitations of the Study

Potential limitations include variability in rainfall patterns, laboratory constraints for advanced impurity detection, and the influence of external environmental factors beyond the study's control.

Materials and Methods: Study Area

The study was conducted in Minna, Niger State, Nigeria, which lies within the Guinea savannah ecological zone and experiences a tropical climate characterized by distinct wet and dry seasons. Three stations were selected to represent different human and environmental settings: Maitumbi, a peri-urban settlement influenced by residential and semi-rural activities; Bosso, an urban settlement with higher population density, vehicular traffic, and localized emissions; and Gidan Kwano, located near Federal University of Technology Minna, which represents a semi-rural/educational environment with less industrial influence. Selection of the three stations was based on their accessibility, varying land use, and potential anthropogenic inputs, consistent with methods adopted in previous rainwater quality studies in Nigeria and other tropical regions (Musa *et al.*, 2017).

Minna is located in North Central region of Nigeria and serves as the administrative capital of Niger State. Geographically, Minna is positioned at approximately 9.61°N latitude and 6.56°E longitude, with an average elevation of about 256 meters above sea level. The city is characterized by a tropical savannah climate, marked by distinct wet and dry seasons.

The wet season in Minna typically spans from May to October, with heavy rainfall resulting from the south westerly monsoon winds. During this period, Minna receives significant precipitation, which is crucial from agriculture and water supply. The dry season, from November to April, is dominated by the harmattan winds, which bring dry and dusty conditions from the south Sahara Desert. These seasonal variations significantly impact air quality and the composition of rainwater, as atmospheric pollutants can be washed down during rainfall events.

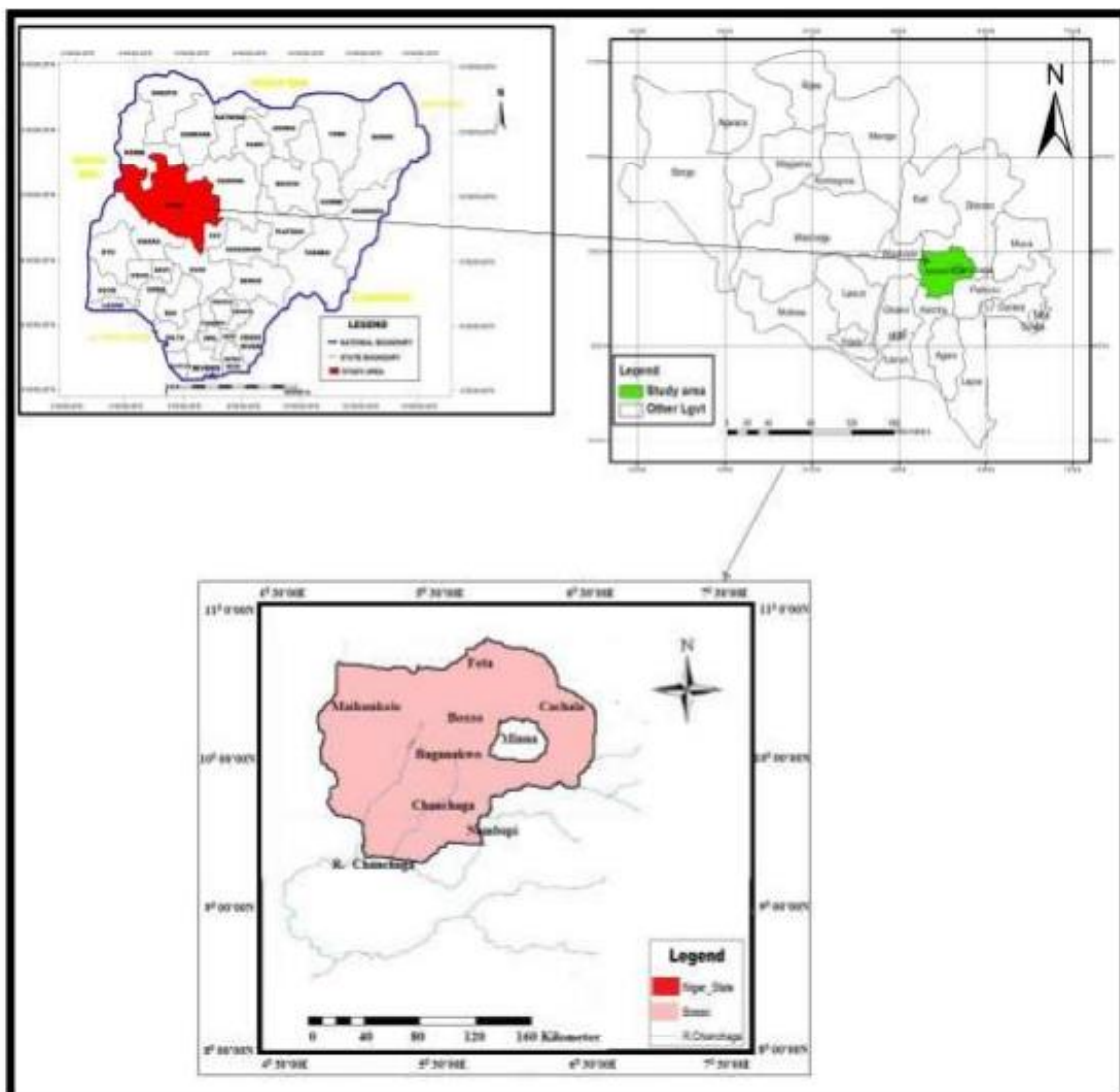


Figure 3.1: The Study Area (Bosso and Chanchaga Local Government Area)

Source: Jibrin and Suleiman, 2022

Samples Collection: At each station, rainwater samples were collected during rainfall events in the peak rainy season. Two types of samples were obtained: (i) direct sky samples, collected in open areas away from trees, buildings, and overhead wires, to represent atmospheric deposition without contact with surfaces; and (ii) roof-harvested samples, collected from zinc roofing sheets commonly used in Minna households. Samples were transported to Laboratory of Water Resources, Aquaculture and Fisheries Technology Department for further analysis.

Sampling Procedure: For direct sky collection, pre-cleaned high-density polyethylene (HDPE) containers were placed on elevated stands at least 1.5 meters above ground level to minimize splash contamination and dust interference, following the procedures of Ikumapayi *et al.* (2024). For zinc roof collection, gutter outlets were fitted with temporary collectors, and first-flush water (first 2–5 minutes of rainfall) was discarded to reduce debris and dust washed from the roof surface, in line with standard rooftop rainwater harvesting practice (Gulson *et al.*, 2016). Subsequent runoff was directed into acid-washed 2 L plastic containers. At each site and for each type (sky and zinc), triplicate samples were collected to ensure data reliability.

Sample Preservation and Transport: Immediately after collection, samples for trace-metal analysis were acidified to pH <2 with nitric acid, while samples for physicochemical parameters (pH, conductivity, alkalinity, hardness, nitrate, phosphate) were kept unacidified. All samples were stored in coolers with ice packs and transported to the laboratory of Water Resources, Aquaculture and Fisheries Technology, following APHA (2017) standard protocols.

Laboratory Analysis: Physicochemical parameters: Determination of temperature: Temperature (°C) of the water *was* measured by dipping a glass mercury thermometer into the water at each station for about 1-2 minutes then the readings were recorded (APHA, 2017).

Determination of pH: pH *was* measured with Hanna 420 pH meter; It *was* calibrated according to instructional manual provided by the manufacturer. The electrode of the pH meter *was* dipped into the water sample for 2-3 minutes and reading were recoded (APHA, 2017).

Determination of electrical conductivity: It is determined by using the conductivity meter which measure the amount of dissolved salt. The electrode of the pH meter *was* dipped into the water sample for 2-3 minutes and reading were recorded

Determination of water hardness: 50ml of sample *was* taken into conical flask with the help of measuring cylinder, 1ml of concentrated ammonium hydroxide buffer (NH₄OH) *was* added and (Erichrome black -T) *was* added as indicator and then titrated with 0.1N (EDTA) solution.

Calculation

$$\text{Hardness (mgCaCO}_3 \text{ L}^{-1}) = \frac{N \times M \times 100 \times 1000}{V} \quad \text{APHA, 2017}$$

Where:

N = Normality of titrate 0.1N

M = Mean of three readings

V = Volume of Sample

50,000 = standard value of equation APHA (2017).

Determination of total alkalinity: 50 ml of the samples *was* measured using volumetric flask and poured into a conical flask. 3 drops of methyl orange were added. Each sample *was* titrated using 0.02M of sulphuric acid until the colour changed.

Calculation

$$\text{CaCO}_3(\text{mg/L}) = \frac{\text{T.V} \times 0.02 \times 50000}{V} \quad \text{APHA, 2017}$$

Where T.V is Titre value, V is volume of sample(ml), 0.02 is the molarity of the sample and 50000 is the diluting value.

Determination of nitrate-nitrogen: One hundred (100) ml of water sample was poured into a beaker, evaporated to dryness, and cooled. 0.5 ml of phenoldisulphonic acid *was* added, 1.5ml of sodium hydroxide and smeared around the beaker after 10minutes, 5 ml of distilled water *was* added. Setting the spectrophotometer at the wave length 430nm, absorbance of the sample treated *was* obtained, using distilled water as blank. The concentration of nitrate-nitrogen *was* obtained from the Calibration curve in mgL^{-1} (APHA, 2017).

Heavy Metals: The EPA vigorous digestion method described by Bala *et al.* (2008) was adopted. 100 ml of each of the representative water samples were transferred into Pyrex beakers containing 10ml of concentrated HNO_3 . The samples were boiled slowly and then evaporated on a hot plate to the lowest possible volume (about 20ml). The beakers were allowed to cool and another 5ml of Conc. HNO_3 was added. Heating continued with the addition of Conc. HNO_3 as necessary until digestion was complete. Metallic elements were determined in the pre – treated samples of water using Atomic Absorption Spectrophotometry. The following metals *were* checked (Pb, Cd, Hg, As)

Bacteriological counts of rainwater samples: The heterotrophic bacterial count was determined using standard plate count (SPC). Nutrient agar was used for the cultivation of bacteria (APHA, 1985, Fawole and Oso, 2007). The total coliform count was determined using the 3-3-3 regime of multiple tube fermentation. MacConkey broth was used for the cultivation. After incubation, the number of positive tube with acid and gas production were noted and reference was made to MPN index table in order to obtain the most probable number (MPN) of coliform per 100ml of the water sample (Fawole and Oso, 2007). Eosin methylene blue (EMB) agar was used to determine the faecal coliform (*E. coli*) of the water samples using spread plate technique. The number of typical colonies of *E. coli* were counted and expressed in cfu/ml (Aneja, 2014).

Data Analysis: Results were analysed statistically by using analysis of variance and Least Significant Difference test (LSD) according to the statistical system (SPSS-23). One-Way ANOVA was used to compare heavy metals and bacterial count in stations. Mean, standard deviation, and range *was* computed for all parameters.

RESULTS AND DISCUSSION: RESULTS: Physicochemical characteristics of rainwater in Minna Metropolis: The physicochemical characteristics of rainwater in Minna metropolis is shown in Table 4.1. Station 1 recorded highest in mean water temperature (28.71 ± 1.78 °C), pH (6.88 ± 0.43), electrical conductivity ($131.82 \pm 24.49\mu\text{S/cm}$) and total dissolved solid (84.36 ± 15.37 mg/L) respectively. While station F recorded highest in total alkalinity (25.25 ± 29.97 mg/L). Total hardness was highest (30.11 ± 27.08 mg/L) in station D and Nitrate was highest (1.09 ± 1.94 mg/L) in station E. All the measured physicochemical parameters shows no

significant difference ($p > 0.05$) between the sampling stations except electrical conductivity, total alkalinity, total hardness and total dissolved solid that differs significantly ($p < 0.05$) between the sampling station.

Table 4.1: Physicochemical Characteristics of Rainwater in Minna Metropolis

Parameters	Station A	Station B	Station C	Station D	Station E	Station F
Temperature (°C)	28.71 ± 1.78 ^a	28.66 ± 1.64 ^a	28.71 ± 1.77 ^a	28.45 ± 1.25 ^a	28.61 ± 1.88 ^a	28.65 ± 2.01 ^a
Ph	6.88 ± 0.43 ^a	6.86 ± 0.49 ^a	6.71 ± 0.55 ^a	6.73 ± 0.61 ^a	6.85 ± 0.55 ^a	6.87 ± 0.47 ^a
Electrical conductivity (µS/cm)	131.82 ± 24.49 ^c	92.78 ± 99.00 ^b	87.00 ± 120.5 ^b	75.66 ± 88.45 ^b	59.82 ± 73.36 ^a	67.50 ± 30.07 ^a
Total alkalinity (mg/L)	17.83 ± 13.78 ^a	16.58 ± 18.33 ^a	12.50 ± 9.90 ^a	14.16 ± 11.63 ^a	15.08 ± 9.76 ^a	25.25 ± 29.97 ^b
Total hardness (mg/L)	22.50 ± 17.71 ^b	18.58 ± 10.59 ^a	22.67 ± 21.58 ^b	30.11 ± 27.08 ^c	14.91 ± 15.10 ^a	22.66 ± 6.27 ^b
Total dissolved solid (mg/L)	84.36 ± 15.37 ^b	59.38 ± 63.36 ^b	55.68 ± 72.15 ^b	48.42 ± 16.34 ^b	38.28 ± 46.93 ^a	42.31 ± 66.66 ^a
Nitrate (mg/L)	0.34 ± 0.14 ^a	0.48 ± 0.32 ^a	0.94 ± 1.49 ^a	0.32 ± 0.13 ^a	1.09 ± 1.94 ^a	0.58 ± 0.65 ^a

Mean values in the same row followed by the same superscript are not significantly different (P>0.05)

Heavy metal characteristics of rainwater in Minna metropolis: The mean heavy metal characteristics of rainwater in Minna Metropolis is presented in Table 4.2. The mean lead values was highest (0.018 ± 0.02) in station C and lowest (0.001 ± 0.00) in station D and F. The mean iron value was highest (0.008 ± 0.00) in station C and lowest (0.006 ± 0.00) in station F. The mean copper value was highest (0.002 ± 0.00) in station A, D and E while station B, C and F record the lowest mean copper value. The Zinc mean value was highest (0.028 ± 0.04) in station F while the lowest (0.008 ± 0.00) mean zinc was observed in station C. Chromium mean value was highest (0.033 ± 0.01) in station B and lowest (0.004 ± 0.00) in station F. All the measured heavy metal shows no significant ($p>0.05$) different between the sampling stations except lead, zinc and chromium that differs significantly ($p<0.05$) between the sampling stations.

Table 4.2: Heavy Metal Characteristics of Rainwater in Minna Metropolis

Parameters	Station A	Station B	Station C	Station D	Station E	Station F
Lead (mg/L)	0.002 ± 0.00 ^a	0.012 ± 0.02 ^b	0.018 ± 0.02 ^b	0.001 ± 0.00 ^a	0.002 ± 0.00 ^a	0.001 ± 0.00 ^a
Iron (mg/L)	0.009 ± 0.01 ^a	0.007 ± 0.00 ^a	0.008 ± 0.00 ^a	0.009 ± 0.00 ^a	0.006 ± 0.00 ^a	0.006 ± 0.00 ^a
Copper (mg/L)	0.002 ± 0.00 ^a	0.001 ± 0.00 ^a	0.001 ± 0.00 ^a	0.002 ± 0.00 ^a	0.002 ± 0.00 ^a	0.001 ± 0.00 ^a
Zinc (mg/L)	0.016 ± 0.01 ^b	0.024 ± 0.00 ^b	0.008 ± 0.00 ^a	0.017 ± 0.01 ^b	0.024 ± 0.02 ^b	0.028 ± 0.04 ^b
Chromium (mg/L)	0.011 ± 0.01 ^b	0.033 ± 0.01 ^b	0.024 ± 0.03 ^b	0.020 ± 0.03 ^b	0.020 ± 0.00 ^b	0.004 ± 0.00 ^a

Mean values in the same row followed by the same superscript are not significantly different (P>0.05)

Microbial characteristics of rainwater: The mean microbial characteristics of rainwater in Minna metropolis is presented in table 4.3. The mean total bacteria colony was highest (3.6×10^3) in station C and lowest in (2.00×10^3) in station B. The total colony count (TCC) was highest (2.5×10^3) in station A and lowest (1.8×10^3) in station F. The total fungal count was highest (3.00×10^3) in station D and was lowest (1.70×10^3) in station E.

Table 4.3: Microbial Characteristics of Rainwater in Minna Metropolis

PARAMETERS	Station A	Station B	Station C	Station D	Station E	Station F
TBC	2.4×10^3	2.00×10^3	3.6×10^3	3.56×10^3	3.13×10^3	2.73×10^3
TCC	2.5×10^3	2.20×10^3	2.40×10^3	2.46×10^3	2.36×10^3	1.8×10^3
TFC	2.4×10^3	1.86×10^3	2.83×10^3	3.00×10^3	1.70×10^3	1.93×10^3

TBC= Total Bacteria count, TFC=Total Faecal count, TCC= Total coliform count

Discussion: Physicochemical characteristics of rainwater: The physicochemical analysis of rainwater in Minna metropolis, as presented in Table 4.1, provides critical insights into its quality and the influence of local environmental factors. The mean pH values across all stations ranged from 6.71 ± 0.55 to 6.88 ± 0.43 . These values are slightly acidic to near-neutral but fall within the acceptable range of 6.5-8.5 for drinking water as stipulated by the World Health Organization (WHO, 2017) and the Nigerian Standard for Drinking Water Quality (NSDWQ, 2015). The absence of pronounced acidity (pH < 5.6, the typical pH of pure rainwater in equilibrium with atmospheric CO₂) suggests a significant neutralization of rainwater acidity by alkaline dust in the atmosphere of Minna. This finding is consistent with studies in other West African cities. Nduka *et al.* (2022) in River State, Nigeria, reported near-neutral rainwater pH (6.4-7.1), attributing it to the influence of crustal dust and particulate matter from arid regions. Similarly, Abdullahi (2020) in Sokoto found pH values above 6.5, which they linked to calcium carbonate-rich dust from the Sahara and local soils. However, this contrasts with studies in industrialized regions; for example, Nduka *et al.* (2018) in the Niger Delta, Nigeria, recorded more acidic rainwater (pH 4.8-5.5) due to higher atmospheric concentrations of SO_x and NO_x from fossil fuel combustion.

The mean Electrical Conductivity (EC) and Total Dissolved Solids (TDS) were highest at Station 1 (131.82 μ S/cm and 84.36 mg/L, respectively). These values are well below the WHO permissible limits of 1000 μ S/cm for EC and 500 mg/L for TDS, indicating low mineralization and overall good inorganic quality of the rainwater. The significant variation ($p < 0.05$) in these parameters between stations, however, points to localized pollution sources. Station 1's elevated levels could be due to its proximity to high-traffic areas, industrial activities, or

construction sites, which contribute more dissolved ions to the atmosphere. This aligns with the findings of Okoya *et al.* (2017), who reported higher TDS and EC in rainwater samples collected near industrial and commercial zones in Ile Ife compared to residential areas. The high total alkalinity and hardness recorded in stations F and D, respectively, further support the influence of terrestrial dust. As noted by Olarewaju *et al.* (2023), atmospheric dust rich in carbonates and bicarbonates of calcium and magnesium is a primary source of alkalinity and hardness in rainwater in semi-arid regions like Minna.

Heavy Metal Characteristics of Rainwater: The concentrations of heavy metals in the rainwater, detailed in Table 4.2, are generally low but reveal important spatial trends and potential anthropogenic influences. The mean concentrations for all metals (Lead, Iron, Copper, Zinc, and Chromium) were found to be below the maximum allowable limits set by the WHO (2017) and NSDWQ (2015). For instance, the highest mean lead concentration was 0.018 mg/L (Station C), which is below the WHO guideline of 0.01 mg/L for lead in drinking water, though it is crucial to note that no level of lead is considered completely safe, and its presence is a concern. The significant differences ($p < 0.05$) in lead, zinc, and chromium levels suggest point sources of contamination. Station C recorded the highest lead, which could be linked to residues from leaded gasoline (still a potential issue from older vehicles or certain fuels), industrial emissions, or the wear and tear of building materials. This agrees with the work of Ekwere (2023) in Enugu, who attributed elevated lead in urban rainwater to vehicular emissions and industrial fallout. Conversely, our findings show lower lead levels than those reported by Ojinka *et al.* (2025) in Port Harcourt's rainwater, where concentrations frequently exceeded 0.05 mg/L due to intense petrochemical and industrial activities.

Zinc was highest at Station F (0.028 mg/L). Zinc often originates from the corrosion of galvanized roofing materials, metal fittings, and urban runoff. This is consistent with Okudo *et al.* (2023), who identified roofing material corrosion as a major source of zinc in harvested rainwater in Enugu, Nigeria. The high chromium at Station B (0.033 mg/L) is particularly notable. Potential sources include emissions from tanneries, metal plating industries, or the burning of certain types of waste. Iroegbulema *et al.* (2023) found similar elevated chromium levels in dust and rainwater near industrial zones in Lagos, linking it to industrial paint and coating operations. The non-significant variation in copper and iron suggests these metals have more diffuse sources, such as soil dust and the natural weathering of minerals, which is a common background signal in many regions, as observed by Adetayo *et al.* (2013) in Ibadan.

Microbial Characteristics of Rainwater: The microbial analysis (Table 4.3) reveals that the rainwater in Minna is not safe for consumption without treatment, as it is contaminated with substantial bacterial and fungal loads. The Total Bacteria Count (TBC) ranged from 2.00×10^3 CFU/mL to 3.6×10^3 CFU/mL, and the Total Coliform Count (TCC) ranged from 1.8×10^3 CFU/mL to 2.5×10^3 CFU/mL. These values far exceed the WHO guideline which states that no coliform bacteria should be detectable in any 100 mL sample of drinking water. The presence of coliforms is a clear indicator of fecal contamination, potentially from animals, birds, or inadequate sanitation facilities.

The high microbial counts are consistent with several previous studies on roof-harvested rainwater in Nigeria. Michael *et al.* (2023) reported TBC and TCC in the range of 10^3 to 10^4 CFU/mL in rainwater samples from Owerri, attributing the contamination to direct deposition from bird droppings, lizards, and atmospheric dust carrying microorganisms. Similarly, Okoye *et al.* (2024) in Anambra found that over 80% of rainwater samples tested positive for coliform bacteria, linking it to poor rooftop and gutter hygiene. Our results also align with Gupta *et al.* (2025), who in a global review highlighted that roof-harvested rainwater often requires first-flush diversion and disinfection to be safe for potable use. The variation in counts between stations can be attributed to differences in local hygiene, the density of overhanging trees (which can harbor animals), and the frequency of roof cleaning. The presence of total fungal

counts further underscores the potential for the rain water to support the growth of microbes, which can pose health risks, particularly to immunocompromised individuals.

CONCLUSION:

The physicochemical analysis concludes that the rainwater in Minna metropolis is generally soft, low in mineral content, and possesses a near-neutral pH, making it chemically suitable for most domestic uses. The significant variation in parameters like Electrical Conductivity and Total Dissolved Solids between stations indicates a strong influence from localized anthropogenic activities and terrestrial dust, with Station 1 being the most impacted.

While the concentrations of heavy metals in the rainwater are currently below the maximum permissible limits for drinking water, the presence and significant spatial variation of toxic metals like Lead, Zinc, and Chromium are a cause for concern. This confirms that atmospheric deposition is introducing these metals into the water cycle, with Station C (Lead) and Station B (Chromium) being particular hotspots, likely due to specific but unidentified local industrial or urban activities.

The microbial analysis conclusively shows that the rainwater in Minna is microbiologically unsafe for consumption without treatment. The high Total Bacteria and Total Coliform Counts across all stations indicate widespread fecal contamination, likely originating from animals, birds, and environmental debris, rendering the water a potential vehicle for waterborne diseases.

Recommendations

- i. Investigations should be conducted around stations with elevated parameters (like Station 1) to identify and mitigate specific pollution sources, such as uncontrolled dust from construction sites or industrial emissions.
- ii. Households, especially in areas with high TDS and alkalinity, should employ first-flush diversion devices to discard the initial volume of rainfall, which carries the highest load of dissolved contaminants from the atmosphere and roof surfaces.
- iii. A robust and continuous atmospheric and rainwater quality monitoring program for heavy metals should be established to track trends and provide early warning of increasing pollution levels.
- iv. Rainwater must be disinfected before any potable use, Effective and accessible methods including boiling, chlorination, or using ultraviolet (UV) light purification system.

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