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Assessment of Heavy Metals, Physicochemical Parameters and Bacterial Load (TPC/TCC) in Soils from Selected Areas of Mubi Local Government Areas, Adamawa State, Nigeria

[1*] Evelyn Kattan Titus, [1]Sunday Peter Zira, [1] Priscilla Alexander

[1]Department of Pure and Applied Chemistry, Adamawa State University, Mubi, Nigeria

***Correspondence email:** evelynkaytee@gmail.com

ABSTRACT

This study assessed the physicochemical and microbial properties of soil in selected locations within Mubi metropolis, Adamawa State, Nigeria. The study was carried out in Barama, Yelwa, Wuro Patuji, and Wuro /Gude, with the aim of determining the physicochemical characteristics, heavy metal concentrations, microbial quality, and associated environmental and public health implications of the soil natural resources. Soil samples exhibited a uniform sandy clay loam texture across the study locations. The soils generally showed moderate fertility, with appreciable organic matter, available phosphorus, potassium, and cation exchange capacity, although relatively low total nitrogen was observed. Soil heavy metal concentrations were generally low and within applicable reference values, indicating minimal heavy-metal contamination. However, the detection of microbial indicators suggested possible fecal contamination of some soil samples. Overall, the findings indicate that the soils are generally suitable for agricultural activities. Regular environmental monitoring, improved sanitation, proper waste management, and sustainable agricultural practices are recommended to minimize environmental and public health risks associated with the soils in Mubi metropolis.

Keywords: Soil pollution, physicochemical properties, Heavy metal, Total coliform, Mubi

INTRODUCTION

Soil is a dynamic, ecologically complex, and diverse component of the environment, formed through the interaction of biological, climatic, and geological processes. It plays a vital role in sustaining life and meeting basic human needs, including food production, water regulation, and the maintenance of a habitable environment (Okakpu et al., 2024; Adamu et al., 2017; Iya et al., 2026). Soil consists of organic matter, minerals, gases, liquids, and living organisms that collectively support essential ecological processes (Garandi et al., 2021). Beyond these functions, soil serves as an important reservoir for contaminants because of its capacity to bind and retain various chemical substances (Adamu et al., 2017; Ugbosu et al., 2025). However, its ability to retain or release contaminants depends largely on its physicochemical properties, which influence the mobility and potential environmental effects of pollutants (Ameh et al., 2026; Olagbemiro et al., 2025).

Environmental pollution occurs when substances or forms of energy are introduced into the environment at levels that may cause adverse effects (Edwin et al., 2022). Human activities, including industrial operations, agriculture, traffic, domestic activities, mining, and the disposal of industrial wastes and sewage sludge, are major sources of environmental contaminants. The indiscriminate release of these wastes can increase the concentrations of heavy metals in the environment, sometimes beyond levels associated with natural geological sources (Inobeme et al., 2014; Nwakife et al., 2022; Joy et al., 2024; Gakurnan et al., 2023). In urban and peri-urban environments, waste dumps and scrap-metal dumpsites frequently occupy vacant plots of land, particularly along major roads and streets. Such activities can introduce contaminants into the soil and alter its physical and chemical characteristics, potentially compromising soil quality and conditions necessary for healthy plant growth (Ikeh et al., 2024).

Among the contaminants associated with environmental pollution, heavy metals are of particular concern because of their persistence and potential to accumulate in soil. Heavy metals originating from solid municipal waste may interact with soil components, accumulate over time, and subsequently enter the food chain (Ikeh et al., 2024). Other sources include metal smelting and refining, scrap-metal processing, plastic and rubber industries, consumer products, and the burning of waste containing metallic elements. During combustion, some metals may become volatilized and subsequently be transported through the atmosphere before being deposited on soil and vegetation (Salam, 2010). Once deposited, their behaviour in the soil depends on several factors, including the physicochemical properties of the soil and the chemical forms of the metals. These factors can influence the availability of metals for plant uptake and their subsequent transfer through the food chain. For instance, soil pH and salinity affect metal uptake by plants, while chloride complexation in materials such as leachate can enhance the uptake of cadmium and lead (Eseyin et al., 2019). Consequently, heavy-metal contamination of soil has become a growing environmental concern because of its potential implications for ecological integrity and human health (Nwakife et al., 2022).

The environmental significance of heavy metals is further increased by the possibility of human exposure through direct ingestion of contaminated soil, dermal contact, and inhalation of contaminated particles (Odika et al., 2023; Badamasi et al., 2022).

Soil also serves as a medium through which heavy metals can be transferred to other environmental compartments and living organisms (Adedeji et al., 2019). However, the extent of contamination and the associated risks depend not only on the concentrations of

metals present but also on their mobility and bioavailability. Understanding the relationships between soil contaminants and physicochemical properties is therefore important for assessing environmental quality and developing appropriate soil management strategies (Hassan and Abubakar, 2018). The long-term exploitation of soil resources for various purposes has contributed to soil degradation, highlighting the importance of understanding the factors that influence soil health (Garandi et al., 2021).

Land-use patterns and agricultural practices are important considerations in assessing soil quality because they influence soil health, ecosystem functions, and long-term productivity. Changes in land use can affect soil nutrient status, vegetation cover, erosion rates, and the accumulation of contaminants. The assessment of soil ecosystem functions and their contributions to food availability and sustainability therefore underscores the importance of effective soil resource management (Bwatanglang et al., 2018). In this regard, the evaluation of soil physicochemical properties and heavy-metal concentrations provides useful information about soil conditions and the potential effects of human activities. Important heavy metals commonly investigated include zinc (Zn), lead (Pb), copper (Cu), iron (Fe), cadmium (Cd), and manganese (Mn). While zinc, copper, and iron are essential micronutrients required in appropriate quantities for biological functions, excessive concentrations may be harmful. Lead and cadmium, in particular, are toxic metals that can pose risks to human health and ecological systems when present at elevated concentrations (Alloway, 2019; Tchounwou et al., 2022). Furthermore, essential nutrients such as nitrates, sulphates, potassium, calcium, and sodium play significant roles in soil fertility and plant growth. However, excessive concentrations particularly of nitrates and sulphates can lead to environmental issues such as eutrophication of water bodies and contamination of groundwater. Elevated nitrate levels in drinking water have also been linked to health conditions such as methemoglobinemia, especially in infants (WHO, 2023).

In Mubi North Local Government Area, deforestation and other land-use changes have been associated with environmental concerns, including accelerated soil erosion, deterioration of soil nutrient status, alterations in hydrological regimes, sedimentation of wetlands, and loss of biodiversity (Garandi et al., 2021). Agricultural practices involving fertilizers and pesticides may also contribute to the introduction of chemical residues into the soil. Similarly, inappropriate waste disposal and other human activities may affect the physicochemical characteristics of soils in residential and other developed areas. These pressures underscore the importance of examining soil quality in locations experiencing different patterns of land use and human activity. Soil degradation in forested landscapes can further contribute to reduced soil fertility, increased erosion, and biodiversity loss, with adverse consequences for forest resilience and productivity (Joseph et al., 2025; Saidu et al., 2026).

Previous studies have investigated heavy-metal contamination in soils across different settings in Mubi and its surrounding areas. Williams et al. (2018) examined heavy-metal concentrations in soil and plant samples along the Mubi–Gombi road, while Bwatanglang (2019) assessed heavy-metal pollution in farmland soils in Mubi and its potential health implications for farmers. More recently, Chindapi et al. (2026) investigated heavy-metal pollution in soils and lettuce obtained from irrigated dumpsites in Mubi North, highlighting concerns about contamination and the potential transfer of metals into the food chain. These studies demonstrate the relevance of assessing soil contamination in relation to specific land uses and human activities. However, the present study examines selected locations within Mubi metropolis, namely Barama, Yelwa, Wuro Patuji, and Wuro Gude, providing an

opportunity to compare soil quality across these locations and contribute additional information on the environmental condition of the study area.

Against this background, the present study focuses on selected locations within Mubi metropolis, namely Barama, Yelwa, Wuro Patuji, and Wuro Gude. These locations represent different patterns of human activities, including residential settlements, agricultural areas, and varying waste disposal and sanitation conditions. Comparing soil characteristics across these locations provides an opportunity to investigate differences in soil quality and assess the potential influence of local environmental activities on the properties of the soil.

The justification for this study lies in the need to generate scientific data on the soil quality of the selected locations within Mubi metropolis. Assessing relevant physicochemical properties, microbial contamination and heavy-metal concentrations, in accordance with the study's analytical objectives, will provide information on the condition of the soils and help identify potential environmental concerns associated with human activities. Such information is important for establishing baseline data for future soil quality assessments, supporting environmental monitoring, and informing appropriate soil management practices. The study will therefore contribute to the understanding of soil conditions across the selected locations and provide evidence that may support environmental protection and the sustainable use of soil resources.

MATERIALS AND METHODS

Sample Collection, and Processing

The collection of samples was done aseptically using auger apparatus. Soil samples were collected by using a sterile soil auger to make a depth of topsoil. The soil samples for analysis were collected into fresh unused black polythene bags. The samples were transported within 2 hours of collection to the laboratory of Chemistry Department, Adamawa State University, Mubi (Emmanuel, 2023).

Sample Pre-treatment

The dry soil samples were pulverized with the aid of ceramic mortar and pestle to reduce the particle size of the soil and to obtain a homogeneous mixture of the soil. The pulverized soils were sieved using a 2 mm sieve initially, and then further pulverized and sieved with a 0.5 mm sieve (Adamu et al., 2017).

Digestion of Soil Samples and Heavy Metal Analysis for Soil

Five hundred milligram (500mg) of the soil samples were weighed into conical flasks and 20 mL of aqua regia (comprising 15mL HCl and 5mL HNO_3) were added. The mixture was digested until the volume was reduced to about 5mL and about 20mL distilled water was added. The mixture was filtered through a Whattman No 42 filter paper into a 50mL volumetric flask and diluted to volume with distilled water. Subsequently, analysis for metals were done using Atomic Absorption Spectrophotometer instrument as stated in the operational manual. The analyses were carried out in duplicate and the mean value reported (Emmanuel, 2023).

PHYSICOCHEMICAL ANALYSIS OF SOIL

Determination of the Soil pH

This is done by the use of pH meter which is calibrated using buffer 4 and buffer 7.10 g of the sample was weighed and pour into 250 ml beaker and 100 ml of water was added and stirred for about 30 minutes for 2 hours. The pH electrode was dipped into the beaker

containing the sample and water and was left to stay for 5 minutes before taking the reading (Chukwuemeka et al., 2017).

Determination of Sand, Silt, and Clay

A separate portion of the collected soil samples from the designated farmlands was prepared by removing any visible debris or stones from the soil samples and air-drying them at room temperature. Clumps and large aggregates were gently crushed and sieved using a 2 mm sieve. An appropriate amount of soil sample 100 grams was weighed into a beaker, and distilled water was added to the soil sample in the beaker to fully saturate it and mix thoroughly to ensure proper dispersion. The soil-water mixture was transferred into a measuring sedimentation cylinder, filling it up to 1000 mL. The soil-water suspension was allowed to settle for 24 hours, in a stable environment without disturbance, after which the height of each of the sedimentation zones (sand, silt, and clay) was measured using a ruler. The percentage of each particle size fraction was calculated (sand, silt, and clay) using Stokes' Law (Yusuf et al., 2024).

Soil Texture

Soil texture was determined from the percentages of sand, silt, and clay obtained by the hydrometer method. The values were plotted on the USDA Soil Texture Triangle to classify the soil into textural classes such as sand, loamy sand, sandy loam, loam, clay loam, sandy clay loam, clay, and others (Lazarus et al., 2026). Soil texture was reported as the textural class rather than a numerical value.

Electrical Conductivity

The soil sample weighing 20.00 g was transferred into a beaker. 20.00 cm^3 of distilled water was added and this was allowed to stand for 30 minutes. It was then stirred with a glass rod at intervals. The conductivity meter probe was inserted into the suspension and the electrical conductivity was measured. The probe of the conductivity meter was rinsed before and after immersion (Nwakife et al., 2022).

Determination of Soil Organic Matter

The Walkely Black method was used to determine the percentage of organic matter in all samples of soil. A 10g of soil was weighed into a crucible and heated the soil sample in a muffle furnace at 550°C for 4 hours to combust the organic matter. After combustion, the crucible was cooled in a desiccator to room temperature. The crucible and the remaining residue (ash) were weighed using an analytical balance. OM content was calculated as the difference between the initial weight of the soil sample and the weight of the remaining ash (Yusuf et al., 2024).

Cation Exchange Capacity (CEC)

Cation Exchange Capacity (CEC) was determined using the 1 N ammonium acetate saturation method at pH 7.0. Soil samples were saturated with ammonium acetate, washed with ethanol to remove excess solution, and the adsorbed ammonium ions were displaced using 1 N potassium chloride (KCl). The displaced ammonium was determined by the Kjeldahl distillation method. CEC was expressed as cmol(+) kg^{-1} soil (Lazarus et al., 2026).

Total Nitrogen in Soil by Regular Macro-Kjeldahl Method

10.00 g of soil sample was placed into a dried 500 cm^3 Macro-Kjeldahl flask, 20.00 cm^3 of distilled water was added and the flask was swirled for few minutes. This was allowed to stand for 30 minutes. 1.00 g of K_2SO_4 mixture catalyst and 10.00 g of K_2SO_4 were added then followed by 30.00 cm^3 of conc. H_2SO_4 through an automatic pipette. The flask was heated cautiously at low heat on the digestion stand. When the water was removed and frothing was

ceased, the heat was increased until the digest cleared. The mixture was boiled for 5 hours while the heating was regulated so that the H_2SO_4 condensed to about the middle of the way up the neck of the flask. The flask was allowed to cool and 100.00 $cm^3$of water was slowly added to the flask. The digest was carefully transferred into another Macro-Kjeldahl flask. The sand particles in the original digestion flask were retained to avoid severe bumping during Kjeldahl distillation. The sand residue was washed four times, with 50.00 cm^3 of distilled water and the aliquot was then transferred into the same flask. 50.00 cm^3 of H_3BO_3 indicator solution was put into a 500 cm^3 Erlenmeyer flask which was then placed under the condenser of the distillation apparatus. 750 cm^3 of Kjeldahl flask was attached to the distillation apparatus and 150.00 cm^3 of 10 M NaOH was poured through the distillation flask by opening the funnel stopcock. The condenser was kept cool to prevent suck-back by allowing sufficient cold water to flow through and the heat was regulated to minimize frothing. 150.00 cm^3 of the distillate was collected and the distillation was stopped. NH4-N in the distillate was then determined by titrating 0.50 M standard HCl using a 25 cm^3 burette graduated at 0.10cm^3 interval. The colour change at the end was from green to pink. The percentage of the Nitrogen content in soil was calculated (Nwakife et al., 2022).

Determination of Available phosphate (AP)

AP was determined using portions of the prepared soil samples which were weighed into a beaker. A 0.5M of $NaHCO_3$ extraction solution was added to the beaker and stirred gently. The soil-extraction solution mixture was allowed for 30 minutes to extract the AP which was filtered using a filter paper. The concentration of AP in the filtered extract was measured using colorimetry (Yusuf et al., 2024).

Determination of Sulphate

Available sulphate was determined using the turbidimetric method (APHA, 2017). Ten grams (10 g) of soil were extracted with calcium phosphate extracting solution, and barium chloride crystals were added to develop turbidity due to the formation of barium sulphate. The absorbance was measured at 420 nm using a UV-Visible spectrophotometer. Sulphate concentration was obtained from a standard calibration curve and expressed as mg kg^{-1} (ppm) of dry soil (Lazarus et al., 2026).

Determination of Nitrates

Nitrates were determined according to the method described by Gauthama et al., (2020).

Determination of Potassium

The macronutrients analyses of the soil samples were done using the method of Nwadiaro et al, (2015). A weight of 0.2g of soil sample was weighed into a crucible and digested with 50ml 1N HCl, filtered and made up with distilled water. Standard solutions of the metals (K) was prepared for calibration. The resulting absorbance of the potassium was determined from the calibration graph and concentration recorded as mg/kg of metal using atomic absorption spectrophotometer.

Bacteria enumeration method

Coliform count and total plate count were performed using serial dilution and pour plate methods. Dilution was carried out using buffered peptone water (BPW) with a sample ratio to BPW of 1: 9. The egg samples and BPW were homogenized using stomacher at 230 rpm for 2 minutes. The Coliform plating was carried out using Brilliance Agar media and incubation was carried out at 37°C for 24 hours. Coliform bacteria were shown with pink colonies on Brilliance Agar media. Plating for TPC calculation is done using Plate Count Agar (PCA) media and incubation was carried out at the temperature of 34–36^{0}C for 48 hours (Isnawaida et al., 2021).

RESULTS AND DISCUSSION

Results

Table 1: Physical Properties of Soil Samples

Parameter	Barama (Mean ± SD)	Yelwa (Mean ± SD)	Wuro Gude (Mean ± SD)	Wuro Patuji (Mean ± SD)
Sand (%)	51.00 ± 0.178	50.00 ± 0.214	46.00 ± 0.289	48.00 ± 0.152
Silt (%)	21.00 ± 0.253	23.00 ± 0.211	22.00 ± 0.125	23.00 ± 0.206
Clay (%)	28.00 ± 0.108	27.00 ± 0.159	32.00 ± 0.114	29.00 ± 0.302
Texture Class	SCL	SCL	SCL	SCL

Note: Values are presented as mean ± standard deviation (SD). SCL = Sandy Clay Loam, a USDA soil textural class determined from the relative proportions of sand, silt, and clay. Soil texture classification was based on the USDA soil textural triangle.

Table 2: Chemical Properties of Soil Samples

Parameter	Barama (Mean ± SD)	Yelwa (Mean ± SD)	Wuro Gude (Mean ± SD)	Wuro Patuji (Mean ± SD)	FAO Limit
pH	7.91 ± 0.261	7.79 ± 0.125	7.97 ± 0.342	8.13 ± 0.229	6.0-8.5
Organic Matter (%)	4.56 ± 0.384	4.63 ± 0.229	6.64 ± 0.153	5.71 ± 0.183	>3
Total Nitrogen (%)	0.095 ± 0.110	0.093 ± 0.134	0.12 ± 0.293	0.096 ± 0.302	0.1-0.2
Available Phosphorus (%)	12.96 ± 0.220	11.93 ± 0.356	14.17 ± 0.119	12.07 ± 0.212	10-20
CEC (cmol/kg)	11.34 ± 0.212	12.35 ± 0.158	16.56 ± 0.206	14.68 ± 0.315	10-20
Potassium (%)	0.27 ± 0.301	0.29 ± 0.227	0.34 ± 0.198	0.31 ± 0.149	0.2-0.5
Sulphates (mg/kg)	0.76 ± 0.244	0.62 ± 0.117	0.82 ± 0.230	0.83 0.273	<100
Nitrates (mg/kg)	0.43 ± 0.320	0.53 ± 0.129	0.84 ± 0.229	0.86 ± 0.194	<50

Table 3: Heavy Metal Composition of Soil Samples

Heavy Metal	Barama (Mean ± SD)	Yelwa (Mean ± SD)	Wuro Gude (Mean ± SD)	Wuro Patuji (Mean ± SD)	FAO Limit
Zinc (mg/kg)	16.35 ± 0.119	14.26 ± 0.214	18.77 ± 0.314	21.57 ± 0.242	300
Lead (mg/kg)	0.57 ± 0.247	0.42 ± 0.137	0.66 ± 0.153	0.62 ± 0.197	100
Cadmium (mg/kg)	0.077 ± 0.113	0.076 ± 0.244	0.082 ± 0.146	0.0079 ± 0.237	3
Copper (mg/kg)	1.93 ± 0.219	1.94 ± 0.312	1.98 ± 0.151	2.13 ± 0.221	100
Iron (mg/kg)	17.23 ± 0.123	16.34 ± 0.113	22.35 ± 0.188	21.56 ± 0.315	-
Manganese (mg/kg)	18.86 ± 0.224	14.26 ± 0.273	18.78 ± 0.191	21.58 ± 0.182	200

Table 4: Microbial Analysis of Soil Samples

Location	Total Plate Count (CFU/100 g)	E. coli (CFU/100 g)	Salmonella spp (CFU/100 g)	Total Coliform (CFU/100 g)
Barama	$3.82 \times 10^3 \pm 0.197$	43.00 ± 0.301	6.00 ± 0.122	$2.86 \times 10^2 \pm 0.257$
Yelwa	$3.48 \times 10^4 \pm 0.311$	60.00 ± 0.131	7.00 ± 0.164	$2.92 \times 10^3 \pm 0.331$
Wuro Patuji	$4.48 \times 10^3 \pm 0.119$	85.00 ± 0.247	15.00 ± 0.288	$3.22 \times 10^2 \pm 0.187$
Wuro Gude	$6.13 \times 10^3 \pm 0.193$	98.00 ± 0.136	16.00 ± 0.194	$4.62 \times 10^2 \pm 0.213$

Discussion

Table 1 shows the physical characteristics of soil samples obtained from Barama, Yelwa, Wuro Gude, and Wuro Patuji, including sand, silt, clay fractions, and textural classification. The sand fraction ranges from 46% to 51%**,** with Barama having the highest proportion (51%) and Wuro Gude the lowest (46%), while silt ranges from 21% to 23% and clay from 27% to 32%**.** The relatively balanced distribution of these soils separates results in a uniform sandy clay loam (SCL) texture across all locations. This textural class reflects a soil system with moderate water retention capacity and good aeration. Sandy clay loam soils typically combine the drainage advantage of sandy soils with the nutrient-holding capacity of clay, making them suitable for agricultural activities. The slightly higher clay content observed in Wuro Gude (32%) suggests improved water retention but may also reduce permeability compared to other locations.

From an agronomic perspective, soil texture plays a critical role in determining water infiltration, nutrient availability, and root penetration. High sand content enhances drainage but may lead to nutrient leaching, whereas increased clay content improves nutrient retention but can restrict aeration. The observed balance in this study indicates favorable conditions for plant growth, although slight variations may influence crop performance across locations. In ecological terms, soil texture affects microbial habitat and organic matter stabilization. Sandy clay loam soils support diverse microbial populations due to their balanced pore spaces. For plants, such soils promote root development and nutrient uptake, while for soil fauna, they provide a stable environment for biological activity. The results obtained are consistent with findings by Brady and Weil (2016), who described sandy clay loam as an ideal agricultural soil due to its balanced physical properties. Similarly, Lal and Shukla (2004) reported that soils with similar texture exhibit moderate permeability and high productivity potential. In addition, Ojanuga (2006) observed that many Nigerian soils fall within this textural class, supporting agricultural suitability.

Table 2 shows the chemical properties of soil samples collected from Barama, Yelwa, Wuro Gude, and Wuro Patuji in Mubi metropolis. These parameters including pH, organic matter, total nitrogen, available phosphorus, cation exchange capacity (CEC), potassium, sulphates, and nitrates are critical indicators of soil fertility, nutrient availability, and environmental quality. The soil pH across the study area ranged from 7.79 ± 0.125 (Yelwa) **to** 8.13 ± 0.229 (Wuro Patuji), indicating slightly alkaline conditions. These values fall within the FAO permissible range of 6.0–8.5, suggesting that the soils are generally suitable for agricultural activities. Slight alkalinity in soil can influence nutrient solubility and microbial activity. For instance, at higher pH levels, micronutrients such as iron and zinc tend to become less available to plants, potentially leading to deficiencies despite their presence in soil (Brady

&Weil, 2017). Prolonged cultivation in alkaline soils may therefore require soil amendments to maintain optimal nutrient uptake.

This finding aligns with the work of Kihara*et al*. (2020)**,** who reported pH values between 7.5 and 8.2 in agricultural soils in northern Nigeria. Similarly, Akan *et al*. (2013) observed slightly alkaline soils in Maiduguri, attributing it to low rainfall and high evaporation rates typical of semi-arid regions. From an environmental perspective, slightly alkaline soils may reduce heavy metal mobility, thereby limiting their uptake by plants; however, long-term imbalance may still affect soil biodiversity and crop productivity.

The organic matter content ranged from 4.56 ± 0.384% (Barama) **to** 6.64 ± 0.153% (Wuro Gude), all exceeding the FAO minimum threshold of 3%**,** indicating relatively fertile soils. High organic matter content enhances soil resilience and supports sustainable agriculture by increasing the availability of essential nutrients. The relatively higher value recorded in Wuro Gude may be attributed to organic waste accumulation, plant residues, or limited soil disturbance. Similar findings were reported by Odedina *et al*. (2018)**,** who recorded organic matter values between 4.0% and 6.8% in cultivated soils. However, Ezeaku *et al.,* (2015) reported lower values (1.5–2.8%) in degraded soils, highlighting the importance of organic enrichment. In the long term, adequate organic matter supports plant growth and reduces erosion risks, while its depletion can lead to poor soil fertility and reduced agricultural productivity.

Total nitrogen content ranged from 0.093 ± 0.134% (Yelwa) **to** 0.12 ± 0.293% (Wuro Gude)**.** While some values fall within the FAO recommended range (0.1–0.2%)**,** others are slightly below the threshold, indicating moderate nitrogen deficiency in certain locations. Nitrogen is essential for plant growth as it is a key component of proteins, enzymes, and chlorophyll. Low nitrogen levels can result in poor crop yield and stunted growth (Havlin *et al*., 2020). Comparable studies by Bello *et al*. (2021) reported nitrogen values of 0.08–0.15% in semi-arid soils, indicating similar fertility status. Sadiq *et al*. (2019) also observed marginal nitrogen deficiency in northern Nigerian soils, attributing it to continuous cropping without adequate fertilization. In contrast, Adesodun*et al*. (2005) recorded higher nitrogen levels (0.15–0.25%) in soils enriched with organic manure. Long-term nitrogen deficiency can reduce soil productivity and necessitate the use of fertilizers, which, if poorly managed, may contribute to environmental pollution through leaching into groundwater.

Available phosphorus ranged from 11.93 ± 0.356% (Yelwa) to 14.17 ± 0.119% (Wuro Gude)**,** falling within the FAO recommended range of 10–20%**.**This observation is consistent with Akinrinde and Obigbesan (2006), who reported phosphorus levels within optimal ranges in cultivated soils. Similarly, Lawal *et al*. (2014) observed moderate phosphorus availability in northern Nigerian soils. However, Olowolafe (2012) reported phosphorus deficiency in heavily weathered soils due to fixation by iron and aluminum oxides.

CEC values ranged from 11.34 ± 0.212 cmol/kg (Barama) **to** 16.56 ± 0.206 cmol/kg (Wuro Gude)**,** all within the FAO recommended range (10–20 cmol/kg)**.**CEC is a measure of the soil's ability to retain and exchange cations such as calcium, magnesium, and potassium. Higher CEC values indicate better nutrient retention and soil fertility (Brady & Weil, 2017). The values observed in this study suggest moderate fertility status, capable of supporting agricultural activities. Ojanuga (2006) also reported comparable values in savannah soils. Conversely, Esu (2010) observed lower CEC values (<10 cmol/kg) in sandy soils with poor nutrient retention.

Potassium concentrations ranged from 0.27 ± 0.301% (Barama) to 0.34 ± 0.198% (Wuro Gude)**,** within the FAO recommended range (0.2–0.5%)**.** Potassium plays a critical role in enzyme activation, water regulation, and disease resistance in plants (Marschner, 2012). Adequate potassium levels enhance crop quality and stress tolerance. However, Ayoola and Adeniyan (2008) reported potassium depletion in intensively farmed lands due to continuous cropping.

Sulphate concentrations ranged from 0.62 ± 0.117 mg/kg (Yelwa) **to** 0.83 ± 0.273 mg/kg (Wuro Patuji), far below the FAO limit of <100 mg/kg, indicating no sulphate-related pollution.Sulphur is essential for protein synthesis and enzyme function in plants. However, excessive sulphate levels can lead to soil acidification and toxicity (Tisdale *et al*., 1993).The low values recorded in this study are consistent with Ekanem *et al*. (2015), who reported minimal sulphate concentrations in uncontaminated soils. Similarly**,** Bolan *et al*. (2014**)** observed low sulphate levels in rural soils. In contrast, Bier & Singh, (2018), reported elevated sulphate levels in industrial areas due to pollution.

Nitrate levels ranged from 0.43 ± 0.320 mg/kg (Barama) **to** 0.86 ± 0.194 mg/kg (Wuro Patuji), well below the FAO limit of <50 mg/kg**.** Nitrates are essential for plant nutrition but can pose environmental and health risks when present in high concentrations, particularly through groundwater contamination (WHO, 2017). The low nitrate levels observed suggest minimal risk of nitrate pollution. However, Gupta *et al*. (2000) reported elevated nitrate levels in heavily fertilized agricultural lands.

Table 3shows the heavy metal composition of soil samples collected from Barama, Yelwa, Wuro Gude, and Wuro Patuji in Mubi metropolis. The metals analyzed include zinc (Zn), lead (Pb), cadmium (Cd), copper (Cu), iron (Fe), and manganese (Mn). These metals are important indicators of soil quality because, although some are essential micronutrients, their elevated concentrations can pose serious environmental and public health risks due to toxicity and bioaccumulation.

The concentration of zinc ranged from 14.26 ± 0.214 mg/kg (Yelwa) to21.57 ± 0.242 mg/kg (Wuro Patuji), which is well below the FAO permissible limit of 50 mg/kg. This indicates that zinc levels in the study area are within safe limits and are unlikely to pose environmental or health risks.Zinc is an essential micronutrient required for enzyme activation, protein synthesis, and plant growth; however, excessive concentrations can lead to phytotoxicity and reduced microbial activity in soil (Alloway, 2013). The moderate levels observed suggest adequate availability for plant uptake without toxicity. This result is consistent with Akan *et al*. (2013), who reported zinc concentrations ranging from 12 to 25 mg/kg in soils from northeastern Nigeria. In contrast, Wuana and Okieimen (2011) and Wuana and Okieimen (2011) reported elevated zinc levels (>60 mg/kg) in industrially impacted soils, highlighting the influence of anthropogenic activities.

Lead concentrations ranged from 0.42 ± 0.137 mg/kg (Yelwa) **to** 0.66 ± 0.153 mg/kg (Wuro Gude), which is significantly lower than the FAO limit of 100 mg/kg**.** Lead is a non-essential and highly toxic metal with no known biological function. Even at low concentrations, it can accumulate in soils and enter the food chain, posing risks to human health such as neurological disorders and developmental issues (WHO, 2017). The low levels observed in this study suggest minimal anthropogenic contamination. This agrees with Iwegbue *et al*. (2013), who reported lead concentrations below 1 mg/kg in uncontaminated soils. However,

Adriano (2001) reported significantly higher values in urban and industrial environments due to vehicular emissions and waste disposal.

Cadmium levels ranged from 0.076 ± 0.244 mg/kg (Yelwa) **to** 0.082 ± 0.146 mg/kg (Wuro Gude), with the lowest value of 0.0079 ± 0.237 mg/kg recorded in Wuro Patuji, all far below the FAO permissible limit of 3 mg/kg**.** Cadmium is highly toxic even at low concentrations and is known for its persistence in the environment. It can accumulate in plant tissues and cause kidney damage, bone demineralization, and other health issues in humans (Alloway, 2013). The low concentrations recorded align with Adefemi and Awokunmi (2010), who reported cadmium levels below 0.1 mg/kg in uncontaminated soils. Similarly, Olowoyo *et al*. (2012) observed minimal cadmium contamination in rural soils. In contrast, Nicholson *et al*. (2003) reported higher cadmium levels in soils receiving long-term phosphate fertilizer application.

Copper concentrations ranged from 1.93 ± 0.219 mg/kg (Barama) to 2.13 ± 0.221 mg/kg (Wuro Patuji), which is significantly below the FAO limit of 100 mg/kg. Copper is an essential micronutrient involved in photosynthesis and enzyme activity, but excessive levels can lead to toxicity, affecting plant root growth and microbial processes (Kabata-Pendias, 2011). However, Adriano (2001) reported elevated copper levels in soils impacted by industrial waste and mining activities.

Iron concentrations ranged from 16.34 ± 0.113 mg/kg (Yelwa) to 22.35 ± 0.188 mg/kg (Wuro Gude). Although no specific FAO limit is provided, iron is naturally abundant in soils and is generally not considered toxic unless present in extremely high concentrations. Iron plays a vital role in chlorophyll synthesis and electron transport in plants. However, excessive iron can lead to soil acidity and toxicity, particularly in waterlogged conditions (Kabata-Pendias, 2011). The values observed are consistent with Essien *et al*. (2009)**,** who reported iron concentrations between 15 and 30 mg/kg in Nigerian soils. Similarly, Alloway (2013) noted that iron is typically abundant in tropical soils due to weathering processes. In contrast, Fagbote and Olanipekun (2010) reported higher iron levels in contaminated sites.

Manganese concentrations ranged from 14.26 ± 0.273 mg/kg (Yelwa) to 21.58 ± 0.182 mg/kg (Wuro Patuji), which is well below the FAO permissible limit of 200 mg/kg**.**Manganese is an essential micronutrient involved in photosynthesis and enzyme activation. However, excessive manganese can be toxic to plants, causing chlorosis and reduced growth (Alloway, 2013). The results are in agreement with Akan *et al*. (2013), who reported manganese levels below 50 mg/kg in uncontaminated soils. Similarly, Ogundele *et al*. (2015) observed moderate manganese concentrations in agricultural soils. In contrast, Kabata-Pendias (2011) reported elevated manganese levels in polluted environments.

The heavy metal concentrations in soils from Mubi metropolis are generally low and within permissible limits, suggesting minimal contamination and low environmental risk. From this studies, the distribution of metals suggest that their presence is largely influenced by natural geological processes rather than anthropogenic activities. However, despite the current safety status, continuous monitoring is essential due to the bioaccumulative nature of heavy metals, which may lead to long-term ecological and health impacts if concentrations increase over time.

Table 4 shows the microbial characteristics of soil samples collected from Barama, Yelwa, Wuro Gude, and Wuro Patuji in Mubi metropolis. The parameters analyzed include Total

Plate Count (TPC), coliform bacteria**,** *Escherichia coli***,** and *Salmonella* spp., which are widely used indicators of soil health, contamination status, and potential public health risks. Microbial quality is a critical component of soil assessment because it reflects both biological activity and environmental contamination, especially from anthropogenic sources such as waste disposal, sewage infiltration, and agricultural practices (Pepper *et al*., 2015).

The total plate count across the study locations showed considerable variation, indicating differences in microbial load and biological activity within the soils. High TPC values generally reflect active microbial populations, which are beneficial for nutrient cycling, organic matter decomposition, and soil fertility (Brady & Weil, 2017). However, excessively high counts may also indicate organic pollution or contamination, particularly from untreated waste or animal droppings. The elevated microbial counts observed in some locations, especially in areas with higher organic matter (such as Wuro Gude), may be linked to increased availability of nutrients that support microbial proliferation. This agrees with Ogunmwonyi *et al*. (2008)**,** who reported high microbial loads in soils enriched with organic residues.

Coliform bacteria were detected across the study locations, indicating fecal contamination or environmental pollution**.** Coliforms are commonly used as indicator organisms because their presence suggests contamination by human or animal waste, which may also introduce pathogenic microorganisms (WHO, 2017). The detection of coliforms in soil samples suggests poor sanitation practices and possible infiltration of waste materials into the soil. This finding is consistent with Edema *et al*. (2001)**,** who reported widespread coliform contamination in soils near residential and agricultural areas. Similarly, Adefemi and Awokunmi (2009) observed elevated coliform counts in soils impacted by open waste disposal. In contrast, Okonko *et al*. (2008) reported lower coliform levels in protected environments with proper sanitation systems.

The presence of *Escherichia coli* in the soil samples is particularly significant, as it is a specific indicator of fecal contamination**.** *E. coli* originates from the intestinal tract of warm-blooded animals and humans, and its presence in soil indicates recent contamination by fecal matter (WHO, 2017). This raises concerns about the safety of agricultural produce grown in such soils, especially leafy vegetables that may be consumed raw. The findings align with Olowe *et al*. (2015), who reported *E. coli* contamination in agricultural soils exposed to wastewater irrigation. Similarly, Fawole and Oso (2004) documented the occurrence of *E. coli* in soils affected by poor sanitation. However, Obire *et al*. (2008) reported minimal *E. coli* presence in controlled agricultural soils.

From a public health perspective, prolonged exposure to *E. coli* can lead to infections such as diarrhea, urinary tract infections, and other gastrointestinal disorders, particularly in vulnerable populations.

The detection of *Salmonella* spp. in soil samples indicates a level of microbial contamination, as these organisms are pathogenic and associated with foodborne illnesses. *Salmonella* can persist in soil for extended periods and may contaminate crops through direct contact or irrigation with contaminated water (Pepper *et al*., 2015). Its presence suggests poor hygiene, improper waste disposal, or contamination from animal sources. This observation is consistent with Avery *et al*. (2014), who reported the survival of *Salmonella* in agricultural soils. Similarly, Islam *et al*. (2004) found *Salmonella* contamination in soils used for

vegetable cultivation. In contrast, Gerba and Smith (2005) reported low prevalence of *Salmonella* in well-managed soils with proper sanitation practices.

Conclusion

The evaluation of the chemical properties of water and soil samples from Barama, Yelwa, Wuro Patuji, and Wuro Gude revealed varying levels of suitability for domestic and agricultural use. The soils demonstrated relatively stable and favorable chemical properties. The pH was generally neutral to moderately alkaline, while organic matter, available phosphorus, potassium, and CEC indicated moderate fertility and good nutrient-retention capacity. However, the relatively low total nitrogen suggests that nitrogen may be a limiting nutrient for optimum crop productivity. Heavy-metal concentrations in the soils were generally low and within applicable reference values, indicating minimal heavy-metal contamination.

This study contributes to existing knowledge on the physicochemical and microbial quality of soil in semi-arid urban environments, using Mubi metropolis, Adamawa State, Nigeria, as a case study. It provides baseline data on the physical, chemical, microbial, nutrient, and heavy-metal characteristics of soil from Barama, Yelwa, Wuro Patuji, and Wuro Gude, thereby providing useful information for future environmental monitoring and comparative studies.

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