IMPACT OF URBANIZATION ON SOIL QUALITY AND HEAVY METAL CONCENTRATIONS IN SELECTED AREAS OF ILORIN WEST LOCAL GOVERNMENT AREA

BY

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Abstract

Soil quality is strongly influenced by land-use practices, which modify nutrient status, organic matter dynamics, and contamination levels. While urbanization, modernization, and population growth drive economic development, they also adversely affect soil systems through pollutant accumulation and physicochemical alteration. This study assessed the spatial variability of soil quality indicators such as pH, electrical conductivity (EC), organic matter, moisture content, available phosphorus, total nitrogen, and selected heavy metals (Pb, Cd, Cr, Cu, and Ni) across traffic-congested, residential, industrial, and undisturbed land-use types in Ilorin West Local Government Area, Kwara State, Nigeria. Results indicated relatively stable pH values (6.2–6.5) across sites, while electrical conductivity was markedly elevated in residential (53.33 dS m^{-1}) and industrial soils (20.00 dS m^{-1}), suggesting substantial anthropogenic ionic inputs. Organic matter content was highest in undisturbed soils (1.44%) and lowest in industrial soils (0.14%). Industrial soils recorded the highest concentrations of Pb, Cr, and Cu, whereas elevated Cd and Ni concentrations occurred in undisturbed soils, suggesting possible geogenic or legacy influences. Principal component analysis identified two dominant components explaining 78.1% of the total variance, distinguishing between fertility-related factors and heavy-metal contamination. These findings demonstrate the strong influence of urban land use on soil quality and highlight the need for routine monitoring and land-use-specific management strategies in rapidly urbanizing environments.

Keywords: Soil quality; urban land use; heavy metals; electrical conductivity; principal component analysis

Introduction

Rapid population growth, expanding cities, and increasing industrial activities are widely recognized as major drivers of economic development. However, these same processes are placing growing pressure on natural systems, particularly soils, which play a critical role in environmental stability and human wellbeing ((Ben-Uwabor *et al*., 2023; Jagaba *et al*., 2024). As urban areas expand, soils are increasingly exposed to various forms of contamination. In many cities, urban soils act as repositories for pollutants originating from industrial emissions, traffic-related activities, and poor waste management practices. Over time, these inputs accumulate and alter the natural composition and function of the soil (Gomes da Silva & Gouveia, 2019; United Nations, 2020). Among the most concerning pollutants found in urban soils are heavy metals such as lead (Pb), cadmium (Cd), chromium (Cr), copper (Cu), and nickel (Ni). These elements are especially problematic because they do not degrade over time and can persist in the environment for long periods. Their tendency to accumulate in soil and enter the food chain raises serious concerns for both ecosystem health and human safety. Exposure to elevated levels of heavy metals can affect plant growth, reduce soil fertility, and pose significant health risks to humans through direct contact, inhalation of dust, or consumption of contaminated food (Jomova *et al*., 2024; Monib *et al*., 2024). Soil quality, in this context, refers to the ability of soil to perform essential functions within an ecosystem. This includes supporting plant growth, maintaining biological productivity, regulating environmental processes, and sustaining the health of living organisms. In urban settings, however, soil quality is often compromised. Activities such as construction, road development, and other forms of land-use change can lead to soil sealing, compaction, and nutrient imbalances. In addition, the continuous deposition of pollutants further degrades soil conditions, reducing its capacity to function effectively (Dumanski & Pieri, 2000).

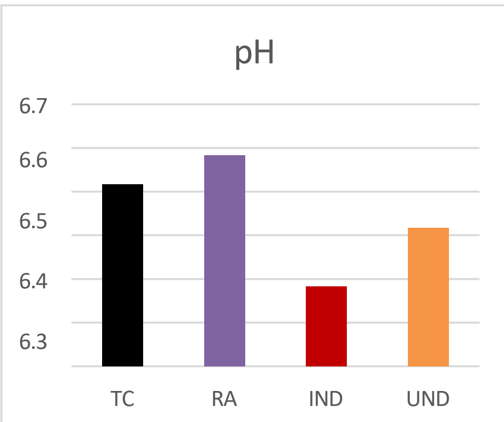
In Nigeria, the challenges associated with urban soil degradation are becoming more pronounced due to the rapid pace of urbanization. As cities grow, natural landscapes are transformed into built environments, often without adequate environmental safeguards. This transformation has a direct impact on the topsoil layer, typically the upper 0–20 cm, which is the most biologically active part of the soil ((Abba *et al*., 2024; Umar, 2023). This layer is crucial for plant growth and is also the zone where human exposure to contaminants is most likely to occur, whether through agriculture, gardening, or other forms of land use (FAO, 2021; Obidike-Ugwu *et al*., 2023). Given these concerns, there is a need to better understand how urbanization influences soil properties and contamination levels in specific local contexts. This study focuses on Ilorin West Local Government Area in Kwara State, Nigeria, where urban growth has been particularly rapid. By examining variations in soil physicochemical characteristics and the concentration of heavy metals across different land-use types, the research aims to provide insights into the extent of soil degradation and its potential implications.

Methodology

The study was carried out in Ilorin West Local Government Area of Kwara State, Nigeria, a region characterized by a tropical savanna climate with clearly defined wet and dry seasons (Weather and Climate, 2024). This climatic pattern plays a significant role in influencing soil properties, including moisture content, organic matter decomposition, and the mobility of contaminants. The area is marked by diverse land-use patterns, encompassing residential settlements, industrial zones, major transportation corridors with heavy traffic, and relatively undisturbed locations that serve as control sites. These varying land-use types provide a useful framework for evaluating the impact of human activities on soil quality and contamination levels ((Ben-Uwabor *et al*., 2023; FAO, 2021). To ensure a comprehensive assessment, soil samples were systematically collected from four distinct land-use categories: traffic-congested areas, residential neighborhoods, industrial sites, and undisturbed locations. Sampling was conducted at a depth of 0–20 cm, which corresponds to the topsoil layer. This layer is widely recognized as the most biologically active zone of the soil profile and is particularly susceptible to contamination from anthropogenic sources such as vehicular emissions, industrial discharges, and domestic waste. Consequently, it is commonly used in environmental studies focusing on soil pollution and ecological risk assessment. Following collection, the soil samples were subjected to standard preparation procedures to ensure consistency and accuracy in analysis. The samples were first air-dried at room temperature to remove moisture, after which they were sieved using a 2 mm mesh to eliminate coarse particles and debris. This step ensured uniform particle size distribution, which is essential for reliable laboratory analysis. The prepared samples were then digested using concentrated nitric acid, a process that facilitates the extraction of heavy metals from the soil matrix. The resulting solutions were analyzed for heavy metal concentrations using flame atomic absorption spectrophotometry, a widely accepted analytical technique known for its precision and sensitivity in detecting trace metal concentrations. To evaluate differences in heavy metal concentrations across the various land-use types, statistical analyses were performed (Agilent Technologies, 2021). One-way analysis of variance (ANOVA) was employed to determine whether significant differences existed among the sampling locations. In addition, Pearson correlation analysis was used to examine the relationships between different heavy metals, providing insight into possible common sources or similar environmental behavior. Principal component analysis (PCA) was further applied to reduce the complexity of the dataset and identify potential sources of contamination by grouping related variables. Overall, the combination of systematic sampling, rigorous laboratory procedures, and robust statistical analyses provided a reliable framework for assessing the influence of land-use practices on soil contamination in the study area ((IBM Corp., 2011; Markos *et al*., 2019).

Results

Mean values of soil physicochemical properties and heavy metal concentrations varied across the four land-use types (traffic-congested, residential, industrial, and undisturbed), as illustrated in Figures 1.1–1.6. Soil pH showed limited spatial variability, ranging from 6.2 to 6.5 across all sites (Fig. 1.1a), indicating slightly acidic conditions. Electrical conductivity (EC) exhibited pronounced variation among land-use types (Fig. 1.1b). Residential soils recorded the highest mean EC value (53.33 dS m^{-1}), followed by industrial soils (20.00 dS m^{-1}), while traffic-congested (10.00 dS m^{-1}) and undisturbed soils (6.67 dS m^{-1}) showed comparatively lower values.



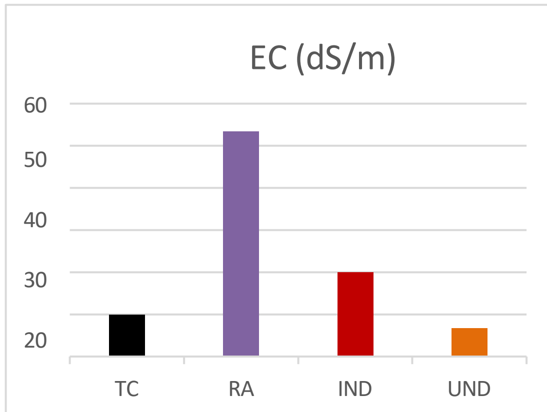
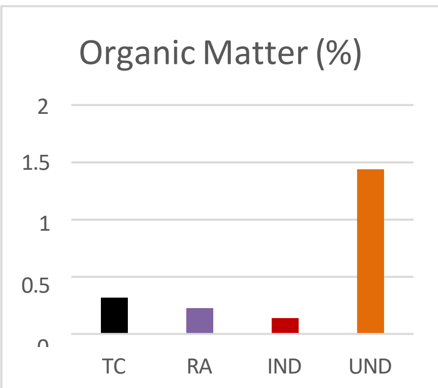


Fig. 1.1a **Fig. 1.1b**

Source: Authors' Computation (2025)

Figure 1.a1 and 1.1b: Descriptive statistic of pH and Electrical conductivity (dS/m) across all sites

Organic matter content differed markedly among sites (Fig. 1.2a). The undisturbed site recorded the highest mean organic matter value (1.44%), whereas lower contents were observed in traffic-congested (0.32%), residential (0.23%), and industrial soils (0.14%). Moisture content followed a different pattern (Fig. 1.2b), with residential soils showing the highest mean value (3.04%), followed by industrial (1.16%), traffic-congested (0.53%), and undisturbed soils (0.12%).



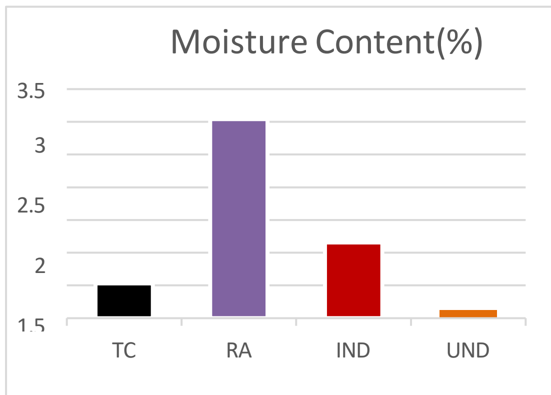


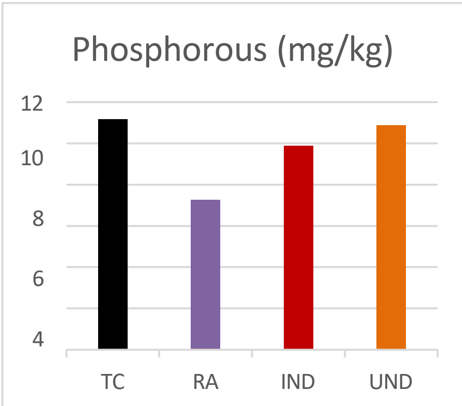
Fig 1.2a **Fig 1.2b**

Source: Authors' Computation (2025).

Figure 1.2a and 1.2b: Descriptive statistic of organic matter (%) and moisture content (%) across all sites

Macronutrient concentrations varied moderately across land-use types. Available phosphorus was highest in traffic-congested soils (11.18 mg kg^{-1}) and undisturbed soils (10.89 mg kg^{-1}), compared with industrial (9.89 mg kg^{-1}) and residential soils (7.26 mg kg^{-1}) (Fig. 1.3a). Total nitrogen was relatively higher in industrial (0.165%) and residential soils (0.163%) than in traffic-congested and undisturbed soils (both approximately 0.148%) (Fig. 1.3b).

ISSN 2756-4444



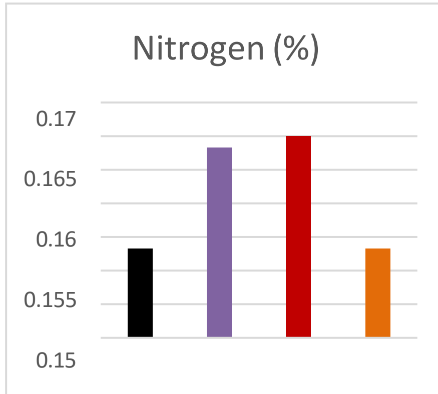


Fig 1.3a **Fig 1.3b**

Source: Authors' Computation (2025)

Figure 1.3a and 1.3b: Descriptive statistic of phosphorous (mg/kg) and nitrogen (%) across all sites

Heavy metal concentrations showed clear land-use-related differences. Lead (Pb) concentrations were highest in industrial soils (68.00 mg kg^{-1}), followed by residential (50.50 mg kg^{-1}), traffic-congested (37.00 mg kg^{-1}), and undisturbed soils (35.92 mg kg^{-1}) (Fig. 1.4a). Cadmium (Cd) displayed an inverse trend, with the highest mean concentration recorded in undisturbed soils (18.58 mg kg^{-1}), compared with much lower values in industrial (2.25 mg kg^{-1}), traffic-congested (2.00 mg kg^{-1}), and residential soils (1.83 mg kg^{-1}) (Fig. 1.4b). Chromium (Cr) concentrations were markedly elevated in industrial soils (208.83 mg kg^{-1}), exceeding levels observed in undisturbed (117.67 mg kg^{-1}), residential (98.50 mg kg^{-1}), and traffic-congested soils (94.67 mg kg^{-1}) (Fig. 1.5a). Nickel (Ni) concentrations ranged from 41.87 mg kg^{-1} in residential soils to 70.00 mg kg^{-1} in undisturbed soils, with intermediate values in traffic-congested (51.67 mg kg^{-1}) and industrial soils (47.00 mg kg^{-1}) (Fig. 1.5b). Copper (Cu) showed the highest degree of enrichment among the measured metals, with industrial soils recording a mean concentration of 246.33 mg kg^{-1}, compared with residential (75.83 mg kg^{-1}), traffic-congested (55.17 mg kg^{-1}), and undisturbed soils (47.00 mg kg^{-1}) (Fig. 1.6).

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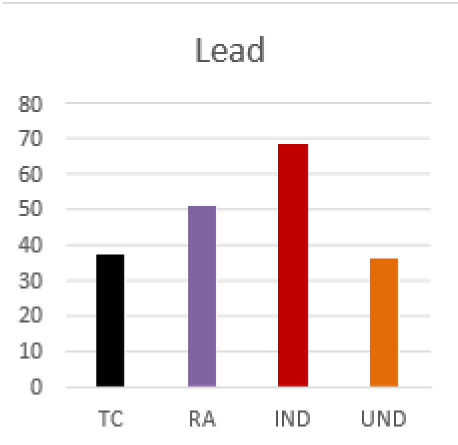


Fig 1.4a

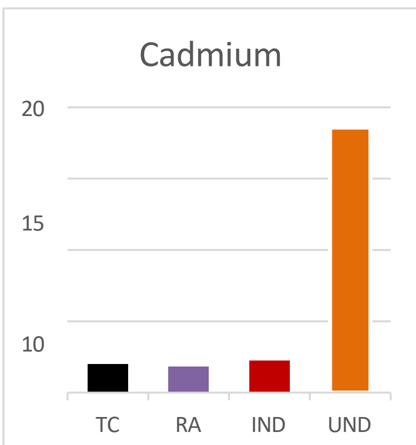
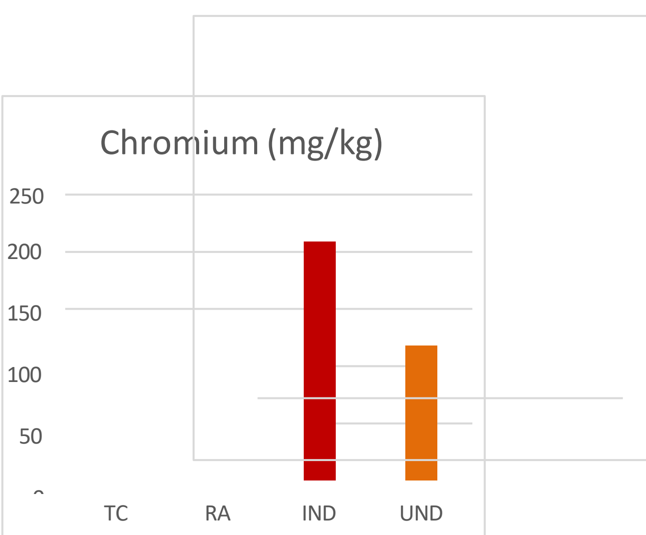


Fig 1.4b

Source: Authors' Computation (2025)

Figure 1.4a and 1.4b: Descriptive statistic of Lead (mg/kg) and Cadmium (mg/kg) across all sites



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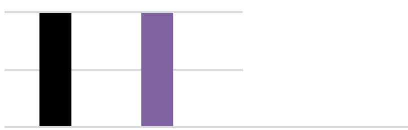

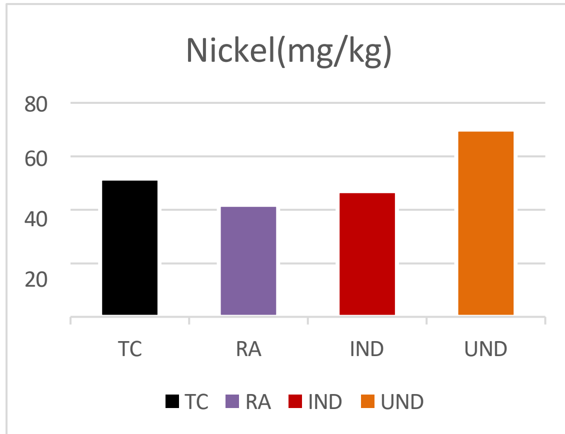

Fig 1.5a **Fig 1.5b**

Source: Authors' Computation (2025)

Figure 1.5a and 1.5b: Descriptive statistic of Chromium (mg/kg) and Nickel (mg/kg) across all sites

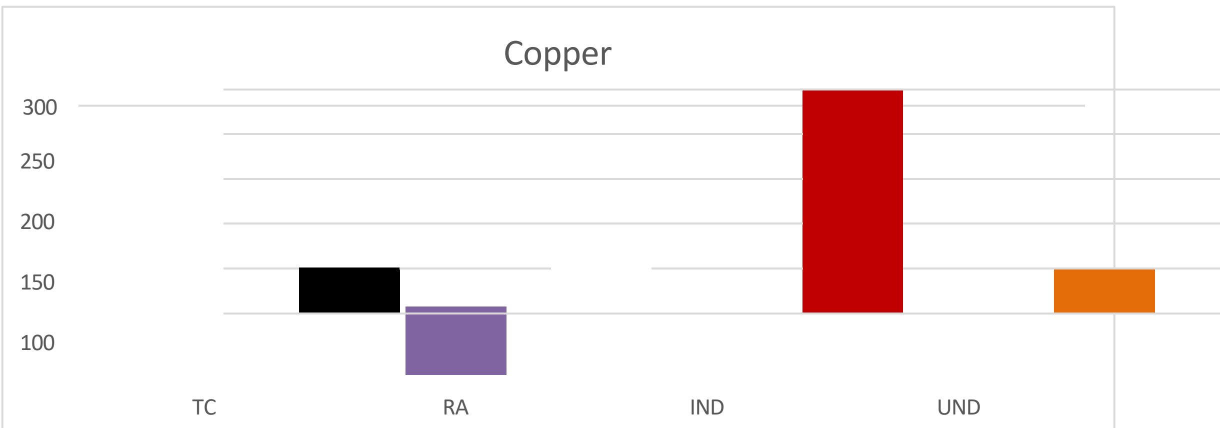

Figure 1.6: Descriptive statistics of Copper

Table 1: **Correlation matrix of heavy metals across all sampling sites**

Variable	Cu	Zn	Pb	Cd	Ni
Cu	1.000	0.993	0.987	0.991	0.996
Zn	0.993	1.000	0.977	0.992	0.988
Pb	0.987	0.977	1.000	0.970	0.979
Cd	0.991	0.992	0.970	1.000	0.980
Ni	0.996	0.988	0.979	0.980	1.000

Source: Authors' Computation (2025)

Table2: Eigenvalues and variance explained by principal components

Component	Eigenvalue	Variance Explained (%)	Cumulative Variance (%)
PC1	5.56	55.3	55.3
PC2	2.28	22.8	78.1
PC3	1.12	11.2	89.3
PC4	0.74	7.4	90.7

Source: Authors' computation (2025).

Table 3: Principal Component Analysis (PCA) component loadings

Parameter	PC1	PC2
Phosphorus	0.42	0.31
Organic matter	0.68	0.25
Electrical conductivity	−0.47	0.38
pH	0.12	−0.05
Lead (Pb)	−0.15	0.62
Cadmium (Cd)	−0.38	0.56
Chromium (Cr)	−0.45	0.45
Copper (Cu)	0.73	−0.14
Nickel (Ni)	0.61	−0.22
Nitrogen (N)	0.66	−0.38
Moisture content	−0.44	0.41

Discussion

Comparison of the measured heavy-metal concentrations with international guideline values provides clearer insight into the potential environmental and health implications of the observed contamination patterns. World Health Organization–referenced soil guideline values suggest target concentrations for uncontaminated soils of approximately 85 mg kg^{-1} for Pb, 0.8 mg kg^{-1} for Cd, 100 mg kg^{-1} for Cr, 36 mg kg^{-1} for Cu, and 35 mg kg^{-1} for Ni (WHO, 1996). When the results of the present study are evaluated against these benchmarks, several metals exceed recommended limits, indicating varying degrees of contamination risk. Lead concentrations across all land-use types (35.92–68.00 mg kg^{-1}) remain below the WHO guideline threshold, suggesting moderate Pb contamination relative to international standards. Similar Pb ranges have been reported in other Nigerian urban soils and are commonly attributed to vehicular emissions, historical use of leaded fuels, and diffuse urban sources rather than acute industrial pollution (Ben-Uwabor *et al*., 2023; Okafor *et al*., 2025).

In contrast, cadmium concentrations are substantially elevated, particularly in the undisturbed site (18.58 mg kg^{-1}), far exceeding the recommended soil limit of 0.8 mg kg^{-1}. Such extreme Cd enrichment has been linked in previous studies to geogenic sources, phosphate-rich parent materials, or legacy contamination that predates current land-use patterns (Keerthan *et al*., 2023; Monib *et al*., 2024). Chromium concentrations in industrial soils (208.83 mg kg^{-1}) exceed the WHO guideline value of 100 mg kg^{-1}, indicating potential ecological and environmental risk associated with industrial activities. Elevated Cr levels in urban and industrial soils have been widely associated with metal processing, waste disposal, and vehicular sources (Jagaba *et al*., 2024; Kahangwa, 2022). Similarly, copper concentrations in industrial soils (246.33 mg kg^{-1}) greatly exceed the recommended limit of 36 mg kg^{-1}, highlighting significant Cu accumulation likely related to industrial discharge, abrasion of vehicle components, and improper waste handling (Ben-Uwabor *et al*., 2023; Okafor *et al*., 2025). Nickel concentrations in undisturbed (70.00 mg kg^{-1}) and traffic-congested soils (51.67 mg kg^{-1}) also exceed the guideline value of 35 mg kg^{-1}, suggesting a combination of natural background enrichment and anthropogenic inputs, a pattern reported in other tropical soils (Keerthan *et al*., 2023). Soil physicochemical conditions further influence the environmental behavior of these metals. The slightly acidic pH recorded across all land-use types may enhance metal solubility and mobility, thereby increasing bioavailability and potential exposure risks (Khaled & Sayed, 2023). Elevated electrical conductivity in residential and industrial soils reflects increased ionic strength, which can promote metal transport in soil solution (Shannon *et al*., 2020). In addition, reduced organic matter content in urban soils limits the capacity of soils to immobilize metals through complexation, potentially exacerbating contamination effects under disturbed land-use conditions (Ding *et al*., 2022). Overall, the results demonstrate that while Pb contamination remains within acceptable limits, Cd, Cr, Cu, and Ni concentrations in several land-use types exceed international guideline values, underscoring the need for targeted soil monitoring, risk assessment, and management interventions, particularly in industrial and peri-urban zones.

Conclusion

Urbanization has significantly influenced soil quality and the distribution of heavy metals in Ilorin West Local Government Area. Rapid expansion of infrastructure, increased population density, and intensified human activities have contributed to notable changes in the physical and chemical characteristics of soils across different land-use types. In particular, industrial and residential areas show clear signs of anthropogenic impact, largely due to activities such as manufacturing, waste disposal, vehicular emissions, and domestic practices. These factors have contributed to elevated levels of heavy metals and other contaminants, thereby altering the natural composition of the soil. Industrial zones are especially affected, as they often serve as focal points for the release of pollutants from production processes, effluents, and improper waste management practices. Similarly, residential areas, though less intense than industrial zones, still contribute to soil contamination through household waste, construction activities, and traffic-related emissions. The cumulative effect of these activities leads to increased concentrations of heavy metals, which may pose risks to environmental quality and human health. In contrast, relatively undisturbed sites tend to maintain better soil fertility and more stable ecological conditions. These areas are less impacted by direct human interference and therefore preserve more of their natural soil characteristics, including higher organic matter content and balanced nutrient composition. However, the presence of certain heavy metals in these locations may still occur due to geogenic factors, such as the natural weathering of parent rock materials, or from historical (legacy) contamination that predates current land-use patterns. Given these observations, there is a clear need for routine soil monitoring to track changes in soil quality over time and identify emerging contamination risks. Additionally, implementing land-use-specific management strategies is essential to mitigate the adverse effects of urbanization. Such strategies may include stricter environmental regulations, improved waste management systems, and sustainable land-use planning. Together, these measures can help protect soil health and ensure environmental sustainability in rapidly urbanizing regions.

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