Impacts of Heavy Metal Contamination on Soils and Textiles from Vehicular Emission on Major Roads in Ilorin, Nigeria

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Abstract: Urbanization, along with the development of roads, transportation systems, infrastructure, and other human activities, has led to soil contamination with heavy metals, particularly in areas with high traffic. This study examined the levels of certain harmful heavy metals in the soils of Ilorin metropolis, Kwara State, Nigeria. Surface soil samples were collected from major roads within the city, and the concentrations of lead (Pb), chromium (Cr), and cadmium (Cd) were analyzed using wet digestion and Atomic Absorption Spectrophotometry (AAS). The aim was to determine the levels of these heavy metals, the extent of soil pollution, and the ecological risks posed by these contaminants on human health and textiles. The results showed that chromium concentrations ranged from 0.10 ppm to 0.30 ppm, cadmium from 0.1 ppm to 0.2 ppm, and lead from 1.0 ppm to 2.3 ppm. The contamination factor for cadmium was classified as moderate, with an index range of 1-2, indicating moderate contamination. Correlation analysis revealed a moderate positive correlation (0.54) between cadmium and chromium, suggesting that these metals may come from similar pollution sources, such as vehicle emissions or industrial activities. In contrast, moderate negative correlations were observed between lead and cadmium (-0.22), and between lead and chromium (-0.49), indicating that the factors affecting lead contamination might be different from those influencing cadmium and chromium levels. The study highlights the importance of regularly assessing and monitoring the levels of heavy metals in urban traffic soils. This is important to safeguard the health and textiles of people living near areas with high concentrations of these metals, prevent environmental pollution, reduce the risk of soil contamination that can lead to food scarcity, and promote long-term ecological sustainability.

Keywords: Heavy metals, Soil contamination, Vehicular emissions, Textile degradation, Urbanization

Introduction

Urbanization is the process where the population in cities grows faster than in rural areas, leading to changes in economies, cultures, and landscapes as societies adjust to these shifts (United Nations, 2019). This demographic change has a profound effect not only on how we live but also on how cities develop. To accommodate the growing population, new infrastructure, industries, and services are built, which often disturb the soil in urban areas through compaction, sealing, and the removal of natural surfaces. These disturbances are seen in parks, roadsides, sports fields, water channels, waste sites, and mining areas (Tang et al., 2024).

With urbanization come challenges, which include; housing shortages, poor transportation networks, and significant environmental pollution. The rapid growth of cities leads to various health issues, such as diseases caused by pollution, poor nutrition, inadequate housing, and related illnesses. These problems directly affect the well-being of residents and place a heavy burden on both individual and community healthcare systems (World Health Organization, 2021).

In Nigeria, heavy metal contamination in urban traffic soils is becoming a major environmental concern. As urbanization and industrial activities increase, the soil in these areas are seeing higher levels of toxic metals, particularly in regions with heavy traffic and industrial emissions (Adewole et al., 2017). Pollutants like lead (Pb), cadmium (Cd), copper (Cu), zinc (Zn), and chromium (Cr) are commonly found, mainly due to vehicle exhaust, industrial processes, and waste disposal practices (Olutona et al., 2019).

In Ilorin metropolis, the concentration of heavy metals in urban soils varies based on factors like traffic volume, land use, and soil characteristics (Balogun et al., 2020). Areas with heavy traffic, such as major roads and commercial districts, tend to have higher levels of contamination compared to quieter residential or green spaces. Soil properties like organic matter content, pH, and clay mineral composition also play a significant role in how these metals are absorbed and move within the soil, further contributing to the variability of contamination across different areas (Adewole et al., 2017). Beyond the soil quality degradation, heavy metal pollution in Ilorin negatively impacts the ecosystem, human health and textile materials worn by people (Brysson et al., 2012).These toxic metals can also harm soil microbes, which are essential for nutrient cycling and maintaining soil fertility. This disruption can interfere with biogeochemical processes and reduce soil productivity (Adewole et al., 2017). Additionally, heavy metals can accumulate in food crops and livestock, posing a direct health risk to humans who consume contaminated agricultural products (Olutona et al., 2019).

Air pollution from traffic is a common issue in cities worldwide and is a growing concern in large urban areas. Air pollution is the state where the air gets polluted with high concentration of volatile chemicals which usually harm living beings and cause serous damage to non living things (Vaganathan et al., 2014). Motor vehicle emissions are major contributors to air and noise pollution, as well as to soil and water contamination, largely due to urbanization and rising car ownership (Iqbal et al., 2022). Traffic-related particulate matter, including both fine (PM2.5) and coarse (PM10) particles, come from sources such as road dust, tire and brake wear, and exhaust emissions. These particles can penetrate deep into the respiratory system and lead to respiratory and cardiovascular diseases (Gupta et al., 2021). Furthermore, emissions from vehicles also release greenhouse gases and pollutants like nitrogen oxides (NO_2), volatile organic compounds (VOCs), and carbon monoxide (CO), which contribute to ground-level ozone formation and smog (Liu et al., 2020) in form of aerosol dust that accumulates on textile materials worn by people in that environment which can in turn discolour or damage the appearance of the fabrics (Helmy et al., 2016). Ands by extension serves as triggers of respiratory or dermatological diseases to the wearer due to the allergic, irritant or toxic effects of the chemical components of the atmospheric dust on the textile materials worn by those in that environment (Kumar et al, 2021).

Traffic also contributes a lot to soil and water pollution through runoff and vehicle emissions that deposit toxic metals like lead, cadmium, and zinc into urban soils. These pollutants can accumulate in the food chain, posing serious health risks to humans and wildlife. Studies have shown that traffic congestion, with its stop-and-go traffic patterns, increases emission rates and worsens pollution levels. Despite the challenges of workload and model complexity, using a multi-matrix approach to assess this pollution can be helpful in tackling these issues (Zhang et al., 2019). Traffic-related pollution can only be fought off by several methods, these methods include: programs such as emission control policies, increasing the popularity of public and active transportation like carriages, bicycles among others and decisive planning of cities for sustainable transport instead of automobiles. Strategies such as planting of trees in the city and putting in other infrastructure like green roofs and streets can help in filtering air and soak up pollutants emitted by traffic systems, as stated by Escobedo et al. (2019).

As earlier noted, in the the environment heavy metal pollution mostly emanates from anthropological activities, according to the various researches conducted. Transport of heavy metals in urban soils and road dusts from tyre wear, street surface wear particles, brake lining wear particles, vehicle exhaust emission from traffic, industrial emission including power plants, metallurgy, coking coal combustion, auto repair and metal processing industries and chemical plants are typical examples (Smith and Owens, 2020). The presence of heavy metals in the urban traffic soils therefore has negative implications particularly with regards to human health, the environment and the ecosystem. As such, elaborate research and analysis need to be conducted to identify the causes and establish the degree of the pollution and then find a way to address the challenges.

It is earlier established that, there are various potential sources of heavy metals in urban traffic soils, with vehicle emissions being one of the most significant contributors. Automobiles, particularly those powered by diesel, emit particulate matter that contains heavy metals into the atmosphere. Studies by Hudda et al. (2019) and Zhang et al. (2020) highlight how these emissions, including metals like lead, cadmium, and copper from fuel, lubricants, and engine components, contribute to pollution. Additionally, metals such as zinc (Zn) and chromium (Cr) are also released into the environment from the wear and tear of tires and brake linings (Wang and Qin, 2019). When road surfaces wear down due to traffic, these heavy metals are suspended and spread, exacerbating soil contamination (Mahr et al., 2023).

Beyond the aforementioned, urban soils also accumulate heavy metals like lead, cadmium, chromium, mercury, and arsenic, turning them into harmful pollutants when present in large amounts (Ozturk et al., 2023). The sources of these contaminants include traffic emissions, industrial discharge, waste disposal, building materials, energy production, and mining activities (Zhu et al., 2024).

Lead (Pb) is a prime example of a dangerous pollutant. Historically, leaded gasoline used in cars has been a major source of global lead pollution, with thousands of tons released annually from road traffic. Lead contamination is found in soil, water, and air, originating from sources like petroleum, electronics, batteries, paint, and biocides (Aziz et al., 2024). This pollution is absorbed by soil, plants, and food, which can pose significant risks to human health. Lead is highly toxic and can damage the brain, lungs, and nervous system. It may cause developmental delays in children, memory and learning impairments, and even male infertility (Bjørklund et al., 2023). The extreme toxicity of lead affects microbes, plants, animals, and humans, leading to long-lasting and often irreversible damage

Chromium is a metal commonly used in industrial processes, but its presence in the environment can have serious consequences for both ecosystems and human health. The toxic and carcinogenic form of chromium, known as hexavalent chromium Cr (VI)), poses a threat to both land and water ecosystems. When soil becomes contaminated with Cr(VI), it can disrupt plant growth, alter the microbial communities in the soil, and negatively impact essential soil processes (Kotaś and Stasicka, 2021). In aquatic habitats, Cr(VI) can accumulate in sediments and water, harming aquatic life and disrupting ecosystem balance (González et al.,2019). For agricultural systems, chromium contamination can lower crop yields and raise concerns about food safety. Exposure to Cr (VI) through contaminated soil, water, and food can lead to short-term health effects such as gastrointestinal, skin, and respiratory problems, as well as long-term risks like cancer.

Cadmium (Cd), a rare metal found in Group II-B of the periodic table, is increasingly used in various industries, including semiconductor production, batteries, electroplating, and nuclear reactors. The contamination of soil and water with cadmium often results from industrial pollution, mining, burning fossil fuels, and sewage sludge (Guo et al., 2024). Research has shown that cadmium exposure can disrupt calcium metabolism and lead to the formation of kidney stones. It is also linked to bone pain, fractures, and kidney damage. Long-term exposure can affect several organs, including the liver, kidneys, lungs, and brain, and in severe cases, it can cause lung edema and even death (Anjum et al., 2024).

This study aims to assess the concentrations of three heavy metals—lead, cadmium, and chromium—found in soils from different locations around Ilorin. It will evaluate the level of pollution these metals cause in urban traffic soils and investigate the potential ecological risks they pose to soil quality, textile materials and the broader Ilorin ecosystem. By addressing these objectives, the research will add to our understanding of heavy metal contamination in urban environments, Ilorin, and provide valuable insights for local communities and environmental agencies. Ultimately, it aims to raise awareness about the environmental and health risks associated with these pollutants.

3.0 Materials and Methods

3.1 Description of Study Area

The study is focused on Ilorin metropolis, which serves as the capital of Kwara State in North central of Nigeria. The research will be conducted at two major roads in each of the four Local Government Areas (LGAs) of Ilorin: Ilorin West, Ilorin East, Ilorin South, and Asa. Ilorin is one of Nigeria's largest cities, playing a crucial role as a commercial, administrative, and educational hub for the region (Oguntoke, 2012). The city has a rich history of cultural diversity, with influences from several ethnic groups, including the Yoruba, Fulani, Nupe, and Hausa (Aderamo and Magaji, 2010).Economically, Ilorin thrives as a bustling commercial center. It is home to a variety of industries, including agriculture, trade, manufacturing, and services. The strategic location of the city along key transportation routes boosts its role in trade and commerce, contributing significantly to its growth and development

3.2 Description of Collection Sites

The study was conducted along major express roads in the Ilorin metropolis. Soil samples were gathered from two key roads in each of the four Local Government Areas of the city. Specifically, Coca-Cola Road and Oja Oba Road represent Ilorin West; Kwara State Polytechnic Road and Airport Road represent Ilorin East; University of Ilorin Road and Gaa-Akanbi Road represent Ilorin South; and Eiyenkorin Road and Ogbondoroko Road represent Asa Local Government Area. Additionally, a control soil sample was collected from Odo Ore Road, Ilorin South, a cite located far from anthropogenic activities, hence, less pollution.

Table 1: Study Sites with Their Coordinates

S/N	Study Area	LGA	Latitude	Longitude
1	Coca-Cola Road	Ilorin West	8.4617°N	4.5625°E
2	Oja oba Road	Ilorin West	8.4854°N	4.5805°E
3	Kwara state polytechnic road	Ilorin East	8.4836°N	4.5544°E
4	Airport Road	Ilorin East	8.4892°N	4.5559°E
5	University of Ilorin road	Ilorin south	8.4979°N	4.6845°E
6	Gaa-Akanbi Road	Ilorin South	8.4872°N	4.5737°E
7	Eiyenkorin Road	Asa	8.4876°N	4.6247°E
8	Ogbondoroko Road	Asa	8.4703°N	4.6231°E
9	Odo ore Road	Ilorin south	8.4923°N	4.5359°E

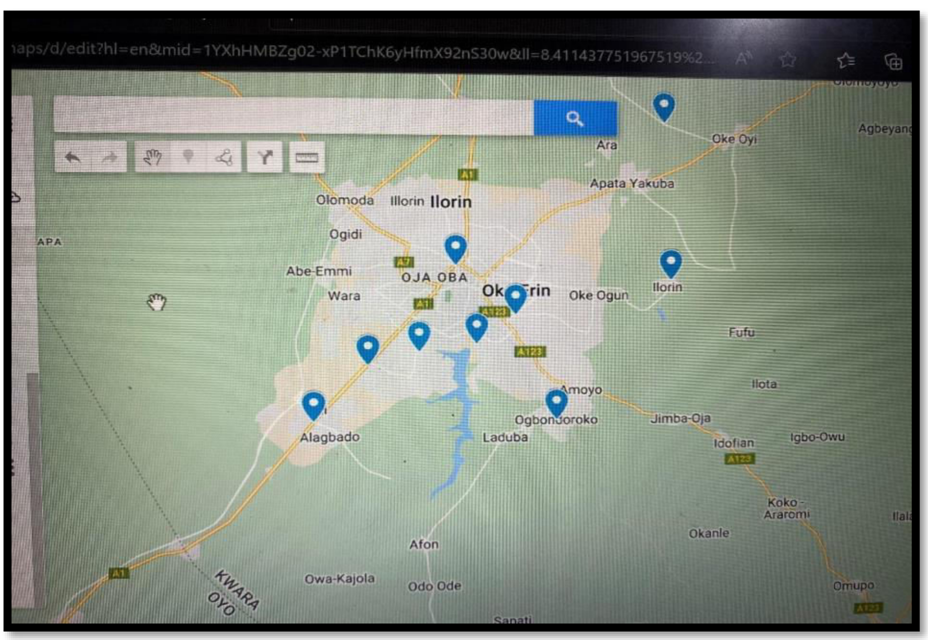

Figure 1: Map showing the Study Sites

3.3 Soil Sample Collection

A total of twenty-seven soil samples were collected for this research from nine different sites, along major traffic roads in the Local Government Areas of Ilorin metropolis, in triplicate, including the control. The control sample was taken from a less urbanized area, Odoore (off Egbejila Road), also in triplicate, which is characterized by fewer anthropogenic activities and minimal traffic. At each study site, 2kg of topsoil (10-20 cm depth) was collected using an auger from six different points, arranged in a zigzag pattern, to ensure a representative sample of each area. These sites, which represent major traffic roads in each Local Government Area, are detailed in Table 1 above.

3.4 Soil Preparation

The soil samples were air-dried at room temperature, ranging from 25°C to 35°C. Afterward, the samples were crushed using a clean, dry mortar and pestle. To ensure a uniform mixture for analysis, the soil was then sieved through a 6mm mesh. Each sample was subsequently transported to the laboratory for further analysis (Bao et al., 2021).

3.5 Laboratory Analysis

3.5.1 Heavy metal analysis

3.5.1.1 Digestion of soil samples

Weighing: A 1.0 g portion of the prepared soil sample was carefully weighed and placed in a Teflon digestion vessel. To the sample, 10 mL of a nitric acid (HNO_3) and hydrochloric acid (HCl) mixture in a 3:1 ratio (aqua regia) was added (USEPA, 1996). The vessel was then subjected to microwave digestion at 180°C for 20 minutes to ensure complete digestion of the sample (Hossain et al., 2017). After digestion, the sample was allowed to cool to room temperature. The resulting digestate was filtered using what man filter paper and then diluted to a final volume of 50 mL with deionized water.

3.5.1.2 Analysis by Atomic Absorption Spectrometry (AAS)

The atomic absorption spectrometer (AAS) was calibrated using standard solutions for the heavy metals to be analyzed (Pb, Cr, Cd). The prepared soil digestates were then analyzed for their heavy metal content using the AAS. The absorbance values obtained during the analysis were compared with the calibration curve to determine the concentrations of the heavy metals in the soil samples (Zheng et al., 2019).

Quality Control: To ensure accuracy and precision, quality control measures including the use of blanks, triplicates, and certified reference materials were incorporated into the analysis (Yang et al., 2021).

3.5.2.1 Pollution Index

The Pollution Load Index (PLI) of the soil in each site was estimated by the formular of Tomlinson et al. (1980) as stated below:

$PLI= (CF_1\times CF_2 \times CF_n)^{1/n}$

Where;

i. PLI signifies the Pollution Load Index.
ii. CF_i is the contamination factor for each metal, a given metal in the soil to the background concentration of that metal.
iii. $_n$ is the number of metals considered in the study
iv. The contamination factor (CF) for each metal is calculated using this formula;

$$CF = \frac{\text{Concentration of metal in soil}}{\text{Background concentration of metal}}$$

Recent studies have utilized the pollution load index to evaluate heavy metals contamination in urban soils. According to Solima and Zaki (2022), the PLI has effectively applied the degree of contamination in various urban environments.

3.5.2.2 Potential ecological risk index

The Potential Ecological Risk Index (PERI) was used to assess the ecological risk posed by heavy metal contamination in environmental samples. The concept of PERI was introduced by Hakanson in 1980. To calculate the PERI, the pollution coefficient (Pi) for each heavy metal is multiplied by its respective toxic-response coefficient (Ti), and the results are then summed for all the metals analyzed.

The PERI was calculated using the following formula:

$$E^r{}_i = T_i \cdot C_i$$

Where:

i. E_i^r is the potential ecological risk factor for a given heavy metal i.
ii. T_i is the toxic response factor for the given heavy metal i.
iii. C_i is the contamination factor for the given metal i.

The contamination factor ($^C{}_i$) is defined as:

$$C_i = \frac{C^s{}_i}{C_i^b}$$

Where:

i. C_i^s is measured concentration of heavy metal I in the soil sample.
ii. $C^b{}_i$ is the background concentration of the heavy metal i.

The overall potential ecological risk index (PERI) for all heavy metals is then calculated as the sum of the individual risk factor:

$RI = \sum_{i=1}^{n} \quad E_i^r$

Where:

iii. RI is the overall potential ecological risk index.

iv. E_i^r is the ecological risk factor for each heavy metal

v. n is the number of heavy metals considered.

3.6 Quality Control

Quality Control: Blank samples were included in the analysis to monitor and control potential contamination, helping to ensure the reliability of the results. Also, triplicate analyses and regular instrument calibration were carried out to further strengthen the quality assurance process.

3.6.1 Data Analysis

Descriptive statistics, including the calculation of means, were used to interpret the results, while inferential statistics helped to assess the relationships between heavy metal concentrations and various environmental factors. Exposure limits were applied to compare the concentrations of identified heavy metals with established regulatory or guideline values. Data analysis was conducted using Microsoft Excel and Python.

3.6.2 Interpretation and Reporting

The findings were interpreted in relation to environmental quality standards and guidelines. The potential implications for human health, ecological integrity, and land management practices were discussed. Based on these insights, recommendations for remediation and suggestions for further monitoring were also provided.

4.0. Results

This study presents the results of the data collected on heavy metal contamination in urban traffic soils across eight study sites and one control site, totaling nine sites in Ilorin, Nigeria. The study focused on three key heavy metals lead (Pb), cadmium (Cd), and chromium (Cr)—which are known for their toxicity, environmental impacts, and health risks. Fig 2. below illustrates the concentrations of chromium (Cr) at the various sites (1-8) and the control site (9). The concentrations ranged from 0.10 ppm to 0.30 ppm, with Oja-Oba Road showing the highest Cr concentration at 0.30 ppm. In contrast, Airport Road, Coca-Cola Road, Eiyenkorin Road, Ogbondoroko Road, and the control site, Odo Ore Road, all recorded the lowest concentration of Cr at 0.10 ppm. Gaa-Akanbi Road, Kwara Poly Road, and University of Ilorin Road had the same chromium concentration of 0.20 ppm, as shown in Figure 2 below.

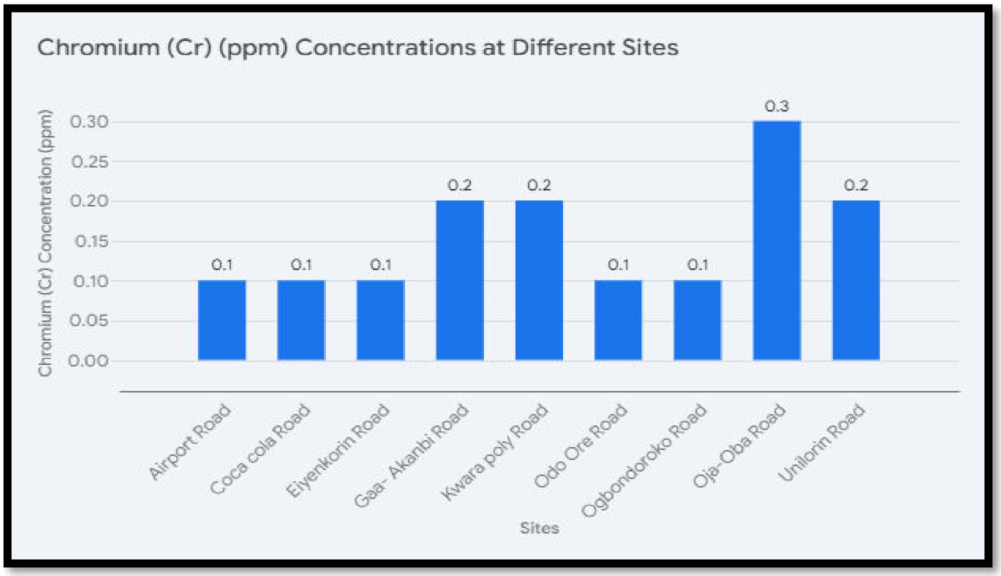

Fig 2: Concentrations of chromium (Cr) in the soil samples collected from the eight study sites and the control sites as shown in Table 1. WHO permissible limit: Cr=100; Cd=0.8; Pb=85; in part per million (ppm)

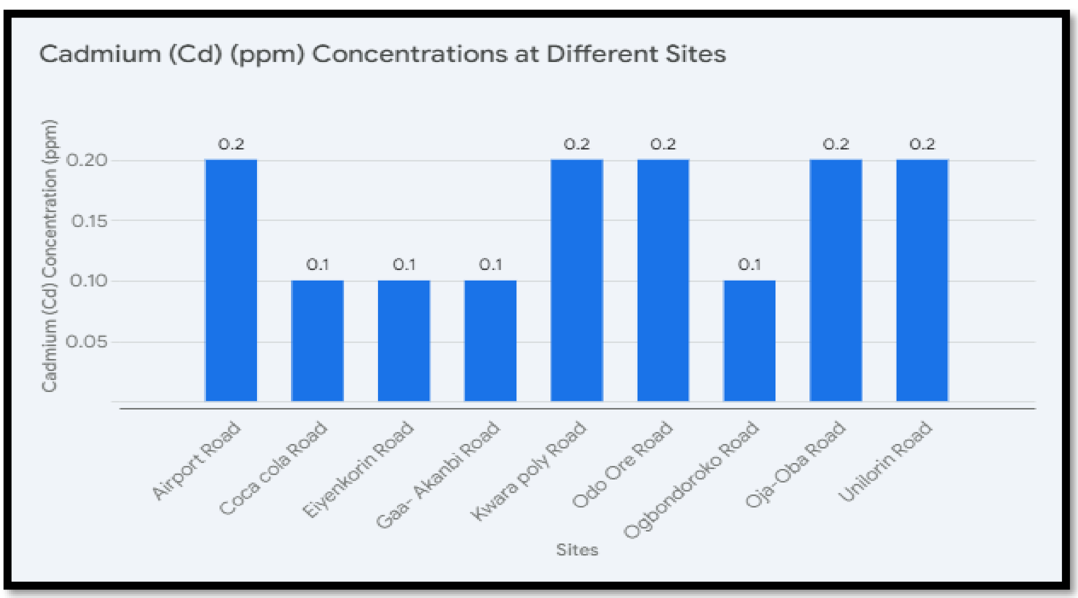

Fig 3. Concentrations of Cadmium (Cd) in the soil samples collected from the eight study sites and the control sites as shown in Table 1 WHO permissible limit: Cr=100; Cd=0.8; Pb=85; in part per million(ppm)

Fig 3, below shows the concentration of cadmium (Cd) at different sites 1-8, and the control site 9 in parts per million (ppm). The Cd concentration in the study sites ranged from 0.1 ppm -0.2 ppm. Four sites, namely; Cocacola road, Eiyenkorin road, Gaa-Akanbi and Ogbondoro recorded lower concentration (0.1 ppm) while the remaining four sites, including the control site recorded a higher Cd value (0.2 ppm), The control site recorded higher Cd value than sites 2,3,4 and 7(Fig 3).
Fig 4, below illustrates the lead (Pb) concentrations, measured in parts per million (ppm), across nine different study sites. The concentrations ranged from 1.0 ppm to 2.3 ppm, with Coca-Cola Road recording the lowest value and Airport Road having the highest concentration, as shown in the figure. The control site (Odo Ore) had the same lead concentration as sites 4 (Gaa-Akanbi) and 7 (Ogbondoroko), which was lower than the concentrations found at sites 1 (Airport Road) and 3 (University of Ilorin Road), with values of 2.3 ppm and 2.1 ppm, respectively. The lead concentration at the control site was higher than those at sites 2 (Coca-Cola Road), 5 (Kwara Poly Road), 8 (Oja-Oba Road), and University of Ilorin Road, as shown in Figure 4. The result indicates higher pollution in the seemingly low anthropogenic control area.

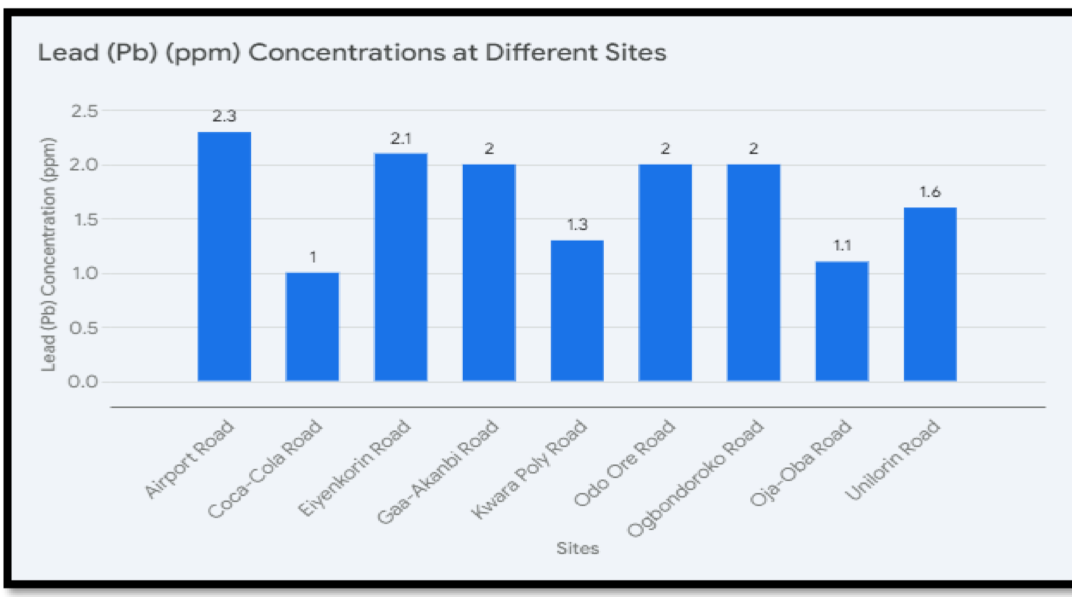

Fig 4. Concentrations of Cadmium (Cd) in the soil samples collected from the eight study sites and the control sites as shown in Table 1. WHO permissible limit: Cr=100; Cd=0.8; Pb=85; in part per million (ppm)

Table 2 below shows the contamination factors for the selected heavy metals—lead (Pb), cadmium (Cd), and chromium (Cr)—in soils from the study sites and the control site. The contamination factor for lead (Pb) ranged from 0.067 to 0.153, with the lowest value recorded at site 2 (Coca-Cola Road) and the highest at site 1 (Airport Road). The Pb contamination factor at the control site was higher than at most of the study sites, except for site 1 (Airport Road). Sites 4 (Gaa-Akanbi Road) and 7 (Ogbondoroko Road) recorded the same Pb contamination factor (0.133) as the control site. The Pb contamination factor was lower in the soils of sites 2, 5, and 8 compared to the control site, as shown in Table 2. For cadmium (Cd), the contamination factor ranged from 1 to 2. The control site recorded a higher Cd contamination factor than sites 2, 3, 4, and 5, as shown in Table 2. The contamination factor for chromium (Cr) in the studied soils ranged from 0.002 to 0.006. The control site had a lower or similar Cr contamination factor compared to all the other sites, except for sites 4, 5, 8, and 9, as shown in Table 2.

These results indicate varying levels of contamination at the study sites, with the control site generally showing moderate contamination levels for Pb and Cd, and relatively low contamination for Cr. The data shows varying levels of contamination by the three heavy metals across the study sites. Airport Road had the highest contamination of lead (Pb), while Coca-Cola Road had the lowest. Cadmium (Cd) contamination was fairly consistent at most sites, with many locations showing higher contamination levels for Cd. In contrast, chromium (Cr) contamination was generally low at all sites. The control site (Odo Ore Road) had contamination factors similar to several of the study sites, particularly for Pb and Cr, but displayed higher levels of Cd contamination. These findings highlight the significant influence of traffic and urbanization on the presence of heavy metals in the soil.

Table 2. Contamination Factor of Heavy Metals of Soil from the Study Sites

	Study site	Pb CF	Cd CF	Cr CF
1	Airport Road	0.153	2	0.002
2	Coca-Cola Road	0.067	1	0.002
3	Eiyenkorin Road	0.14	1	0.002
4	Gaa-Akanbi Road	0.133	1	0.004
5	Kwara Poly Road	0.087	2	0.004
6	Odo Ore Road (control site)	0.133	2	0.002
7	Ogbondoroko Road	0.133	1	0.002
8	Oja-Oba Road	0.073	2	0.006
9	Unilorin Road	0.107	2	0.004

Py ≤ 1 (No pollution), Py ≥ 1≤ 2 (Low pollution), Py ≥ 2 ≤ 3 (Moderate pollution),s Py≤ 3≥ 5 (Strong pollution) and Py ≥ 5(Very strong pollution) (Yang et al., 2011, 2014)

Fig 5, below illustrates the Heavy Metal Pollution Load Index (PLI) of the soils from the study sites. Airport Road and Odo Ore Road stand out as the most polluted sites, while Coca-Cola Road emerges as the least polluted. Cadmium (Cd) is identified as the most significant pollutant across all sites, with consistently high contamination factor (CF) values. Lead (Pb) also contributes significantly to the contamination at most locations, whereas chromium (Cr) seems to have a lesser impact, although its presence is still noticeable. Upon closer inspection of specific sites, Airport Road is heavily contaminated with both Pb and Cd; Odo Ore Road and Oja-Oba Road are particularly affected by high Cd levels while Gaa-Akanbi, Kwara Poly, and Unilorin Roads show a similar pattern of elevated Pb and Cd contamination. In contrast, Coca-Cola and Eiyenkorin Roads display relatively lower contamination levels overall.

These findings emphazize the significant pollution from cadmium and lead, which pose a serious threat to the environment in this region. The high PLI values at Airport Road and Odo Ore Road, coupled with the widespread presence of Cd and Pb, highlight the urgent need of addressing this problem. While Coca-Cola Road appears less affected, the overall data calls for a thorough investigation into the sources of this pollution. Remediation efforts should prioritize tackling these key pollutants and focus on the most impacted areas to protect both the environment and public health.

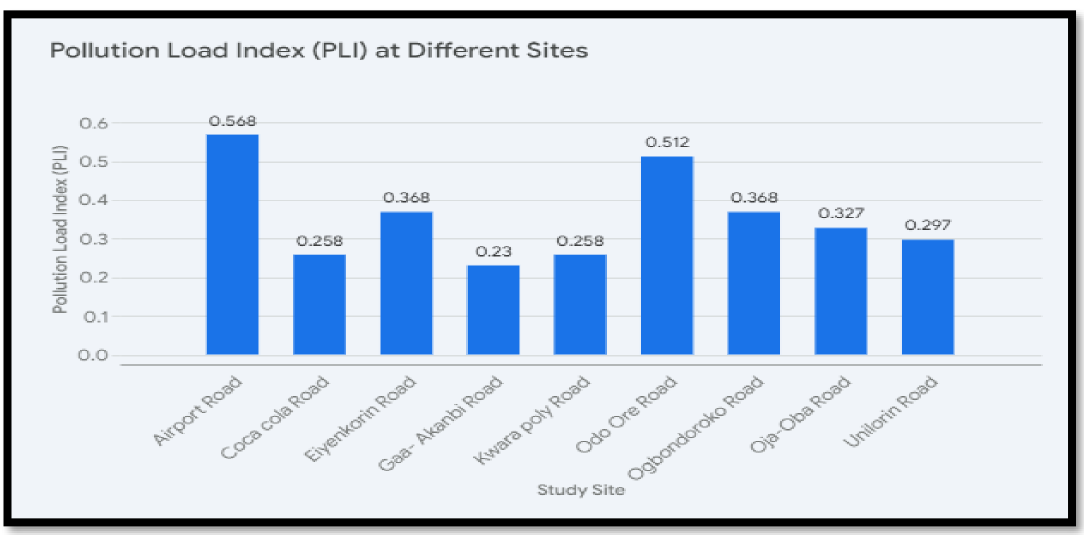

Fig 5: shows the concentrations Pollution Load Index (PLI) in the soil samples collected from the eight study sites and the control sites as shown in Table 1

Table 3 below shows the Potential Ecological Risk Indices (PERI) for each heavy metal at the eight study sites and the control site. The PERI for lead (Pb) across the sites ranged from 0.335 to 0.765, with the lowest value recorded at site 2 (Coca-Cola Road) and the highest at Airport Road. The control site had a PERI of 0.665, which was the same as sites 4 (Gaa-Akanbi) and 7 (Ogbondoroko), lower than sites 1 (Airport Road) and 3 (University of Ilorin Road), but higher than sites 2 (Coca-Cola Road), 5 (Kwara Poly Road), 8 (Oja-Oba Road), and 9 (Unilorin Road), as shown in Table 3. For cadmium (Cd), the PERI values ranged from 30 to 60. The control site had the highest Cd PERI value of 60, compared to sites 2, 3, 4, and 7, which all recorded a Cd PERI of 30, as shown in Table 3. The chromium (Cr) PERI values at the study sites and the control site ranged from 0.004 to 0.012. The control site had a lower or identical Cr PERI value of 0.004, which was the same as those at Airport Road, Coca-Cola Road, Eiyenkorin Road, Ogbondoroko Road, and the control site itself, as shown in Table 3.

These findings highlight the varying levels of ecological risk posed by the different heavy metals, with lead (Pb) and cadmium (Cd) representing more significant risks compared to chromium (Cr). Overall, the control site exhibited moderate levels of contamination, though specific sites, such as Airport Road and Coca-Cola Road, showed higher ecological risks from lead contamination.

Table 3. Potential Ecological Risk Index of Heavy Metal the Study Sites

S/N	Study Sites	Pb (PERI)	Cd (PERI)	Cr (PERI)
1	Airport Road	0.765	60	0.004
2	Coca-Cola Road	0.335	30	0.004
3	Eiyenkorin Road	0.7	30	0.004
4	Gaa-Akanbi Road	0.665	30	0.008
5	Kwara Poly Road	0.335	60	0.008
6	Odo Ore Road (Control site)	0.665	60	0.004
7	Ogbondoroko Road	0.665	30	0.004
8	Oja-Oba Road	0.365	60	0.012
9	Unilorin Road	0.535	60	0.008

RI≤ 150: low potential ecological risk Ri ≥ 150≤300: moderate potential ecological risk
Ri ≥300≤600: considerable potential ecological risk Ri ≥600: very high potential ecological risk Hakanson. (1980)

Table 4 below shows the relationships between the concentrations of cadmium (Cd), chromium (Cr), and lead (Pb) in the urban traffic soils of Ilorin. A key observation is the moderate positive correlation (0.54) between cadmium and chromium, indicating that these two metals tend to occur together in the soils. On the other hand, both lead and cadmium, as well as lead and chromium, show weak to moderate negative correlations (-0.22 and -0.49, respectively). This suggests that while cadmium and chromium may share similar influences or sources in the environment, lead appears to behave differently and may be affected by other factors in relation to both cadmium and chromium.

Table 4 Correlation coefficient between the heavy metals

	Pb ppm	Cd ppm	Cr ppm
Pb ppm	1	-0.22	-0.49
Cd ppm	-0.22	1	0.54
Cr ppm	-0.49	0.54	1

Discussion

The analysis of heavy metal contamination in Ilorin urban traffic soils, presented, paints a complex and concerning picture with important implications for environmental health. While chromium (Cr) levels remained consistently below the World Health Organization's permissible limit (Cr=100 ppm; Cd=0.8 ppm; Pb=85 ppm) across all sites (Figure 2), the elevated concentrations of cadmium (Cd) and lead (Pb) found at several locations are cause for significant environmental and health concerns (Figures 2-4). These higher levels of Cd and Pb suggest potential risks to both the ecosystem and public health that warrant further investigation and action.

Cadmium: Cadmium (Cd) emerged as the most widespread pollutant in the study, with the highest concentrations observed at Airport Road, Oja-Oba Road, Kwara Poly Road, Unilorin Road, and Odo Ore Road (Figure 3). The elevated levels of cadmium at these sites are likely linked to high traffic density, which increases emissions from vehicle exhausts, tire wear, and brake linings, as well as industrial activities that release cadmium as a byproduct of metal processing and manufacturing. Interestingly, significant levels of cadmium were also found at the control site, Odo Ore Road, which is less urbanized, suggesting that atmospheric deposition might be spreading the pollutant from more industrialized areas to less impacted regions. This finding is consistent with previous studies by Adewole et al. (2017) and Adeyemi et al. (2018), which similarly identified traffic and industrial activities as major sources of cadmium pollution in urban environments.

Lead (Pb) contamination is also widespread, with Airport Road showing the highest concentration of 2.30 ppm, surpassing the WHO recommended limit. This high level can be attributed to the heavy traffic in the area, leading to increased deposition of lead from fuel combustion, particularly from older vehicles that may still use leaded gasoline. Other sites, such as Eiyenkorin Road and Gaa-Akanbi Road, also show notable lead contamination, which could be influenced by traffic-related factors as well as industrial emissions. Interestingly, the control site, Odo Ore Road, which is less urbanized, still exhibits significant lead levels. This could be due to long-range atmospheric transport or historical contamination, resulting in the persistence of lead in the environment. These findings align with the research of Afolayan et al. (2020), who similarly identified widespread lead contamination in urban soils, particularly in areas with heavy traffic.

The comparison with the control site further highlights the unexpected presence of significant heavy metal levels in an area with fewer direct pollution sources. At Odo Ore Road, cadmium levels were even higher than at some of the more urbanized sites, suggesting that less impacted areas can still suffer from background contamination, likely due to atmospheric deposition or the retention of pollutants in the soil. This observation is consistent with other studies, such as Olusola et al. (2020), which found that even areas considered less vulnerable to pollution can still exhibit significant contamination due to broader environmental influences.

The correlation analysis of the data revealed a moderate positive correlation (0.54) between cadmium (Cd) and chromium (Cr), indicating that these two metals tend to occur together in the soil samples. This co-occurrence suggests that they may share common sources of pollution, such as emissions from vehicles and industries, or that they behave similarly in the environment, being deposited and retained under comparable conditions. In contrast, the moderate negative correlations between lead (Pb) and cadmium (-0.22) and between lead and chromium (-0.49) suggest that the factors influencing the presence of lead may differ from those affecting cadmium and chromium. This implies that various pollution sources and environmental processes interact in complex ways, emphasizing the importance of site-specific analysis and tailored remediation strategies.

In summary, the analysis of heavy metal contamination across the different sites in Ilorin, including the control site, reveals patterns that align with global research on urban pollution. The widespread presence of cadmium and lead, particularly in high-traffic and industrial areas, underscores the well-established impact of vehicular and industrial emissions. The findings at the control site further highlight the significance of considering both direct and indirect sources of pollution, as well as natural environmental factors, in understanding the full extent of contamination. The correlation analysis emphasizes the need for targeted remediation efforts that address multiple pollutants at once. This integrated approach, supported by existing literature, underscores the importance of comprehensive environmental monitoring and remediation efforts, as advocated by other researchers in the field

Conclusion

The investigation into heavy metal contamination in Ilorin's urban traffic soils has revealed a complex and concerning scenario. Elevated levels of lead (Pb), cadmium (Cd), and chromium (Cr) were detected across the eight studied sites, including the control site, Odo Ore Road, raising significant concerns about potential environmental and health risk for residents and people plying those routes. Among these contaminants, cadmium emerged as the most critical pollutant, with consistently high concentrations and an elevated ecological risk across all locations. In contrast, lead contamination showed notable spatial variability, with Airport Road identified as a hotspot of concern. Although chromium was less prevalent overall, it still contributed to the pollution burden, particularly at Oja-Oba Road.

The findings from this study highlight the urgent need for targeted interventions to mitigate heavy metal pollution in Ilorin. Remediation efforts should prioritize cadmium due to its widespread presence and significant ecological risk. Additionally, addressing localized lead contamination hotspots, such as at Airport Road, will be essential. Further research is needed to pinpoint the specific sources of these pollutants, which would allow for the development of tailored pollution control measures specific to the unique characteristics of each site.

This study therefore serves as a call to action for key stakeholders such as government agencies, environmental organizations, and local communities to come together and address the issue of heavy metal contamination in Ilorin. By implementing comprehensive remediation efforts, pollution control strategies, and regular monitoring of soil quality, alongside raising public awareness, Ilorin can reduce the environmental and health risks associated with heavy metal pollution. This collaborative approach will help create a safer, healthier urban environment for the city's residents.

Recommendations

Based on the thorough assessment of heavy metal contamination in Ilorin's urban traffic soils, it is clear that a multi-faceted and adaptive approach is necessary to effectively address the environmental and health risks posed by these pollutants. The following recommendations are aimed at both immediate action and long-term strategies for sustainable soil management:

i. The necessity for the development of a long-term soil management plan that integrates remediation, monitoring, and prevention strategies.

ii. Public awareness and education with a broad and inclusive campaign can be created to raise awareness about the dangers of heavy metal exposure in order to protect public health.
iii. Regulatory framework should be strengthened to setclear guidelines and standards for soil quality control in urban areas and provide a framework for ongoing monitoring
iv. Colour and tensile quality of textile materials affected by metal air pollutants can be improved through mordants such as turmeric, cochineal and madder by exhaustion method
v. Stricter controls on waste disposal practices are essential to prevent the illegal dumping of hazardous materials that contribute to contamination.
vi. Promoting cleaner technologies and practices in industrial processes and transportation can reduce future emissions and minimize environmental damage.
Implementing these recommendations, will not only address the immediate concerns of heavy metal contamination, but also pave the way for a cleaner, healthier urban environment for both current and future generations.

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