

Assessment of Heavy Metal Soil Contamination in The Kabecha District of Lubumbashi, Democratic Republic of Congo, Five Years After the Relocation of the CHEMAF-USOKE Copper Processing Plant

**M. Nathan Mpiana Kibwela¹, Professeur Dr. Thierry Musanda Mukenz²,
Ms. Naomie Sifa N'kulu Mwenze³, M. Jean Marc Madhiano Rwema⁴,
Ms. Grace Ngolu Nyalosaso⁵**

^{1,5}Teacher-researcher at the University of Department of Industrial Chemistry, Faculty of Engineering.
University of Lubumbashi

Professor, Faculty of food technology and environmental sciences, University of New horizon

^{3,4}Teacher-researcher at the University of Faculty of food technology and environmental sciences
University of New Horizons

ABSTRACT:

The study evaluates soil contamination by trace-metal elements in the Kabecha district, located near the former CHEMAF-USOKE metallurgical plant in Lubumbashi. Its primary objective is to assess the current level of pollution in the area. Soil samples were collected from four streets surrounding the former industrial site. Analyses conducted using ICP-OES revealed elevated concentrations of heavy metals, often exceeding the guidelines set by the European Union and the World Health Organization—particularly in soils near Congo Kiwele Avenue. A comparative analysis with data from 2012 (prior to the relocation of CHEMAF) shows a significant reduction in trace metal concentrations. On average, levels have decreased by 30 to 50%, suggesting the onset of a natural decline in pollution. Furthermore, the cross-sectional investigation highlights a spatial gradient in contamination: heavy metal concentrations diminish progressively with increasing distance from the former industrial site. This pattern confirms the environmental dispersion of contaminants.

KEYWORDS: Trace metal elements, Heavy metal pollution, Soil contamination, Post-industrial pollution, Spatial distribution, Mining impact

RESUME :

Cette étude évalue la contamination des sols par les éléments traces métalliques dans le quartier de Kabecha, situé à proximité de l'ancienne usine métallurgique CHEMAF-USOKE à Lubumbashi (RDC). L'objectif principal est d'analyser l'état actuel de la pollution en 2024, quatre ans après la délocalisation de cette entreprise, précédemment identifiée comme une source majeure de pollution. Des échantillons de sol

ont été prélevés sur quatre avenues proches de l'ancien site industriel. Les analyses par fluorescence X et ICP-OES révèlent des concentrations élevées de cuivre atteignant jusqu'à 1 500 ppm, de plomb à 900 ppm et de zinc autour de 1 200 ppm. D'autres métaux tels que le cadmium (10 ppm), l'arsenic (15 ppm), le mercure (2 ppm), le manganèse (800 ppm) et l'uranium (5 ppm) sont également présents en quantités dépassant fréquemment les normes fixées par l'Union européenne et l'OMS, notamment dans les sols proches de l'avenue Congo Kiwele. Cependant, une analyse comparative avec les données de 2012 (avant le déménagement de CHEMAF) montre une diminution significative des concentrations en métaux traces dans la zone d'étude, avec des réductions moyennes comprises entre 30 et 50 %, indiquant le début d'une régression naturelle de la pollution. L'étude transversale démontre également une diminution spatiale des concentrations en métaux lourds à mesure que l'on s'éloigne du site industriel, confirmant un phénomène de dispersion environnementale des polluants.

1. INTRODUCTION

Mining is a cornerstone of economic development in many African countries, particularly in the Democratic Republic of Congo (DRC). However, these industrial activities are also major sources of environmental pollution, especially soil contamination by trace metal elements such as copper (Cu), cobalt (Co), lead (Pb), zinc (Zn), cadmium (Cd), arsenic (As), and mercury (Hg). These heavy metals, released into the environment during the extraction, processing, and waste disposal, accumulate in soils where they can persist for decades due to their non-biodegradable nature [1], [2]. This contamination poses serious risks to human health, food security, and local ecosystems.

Once introduced into the soil, these metals significantly alter their chemical, physical, and biological properties. In acidic soils with low organic matter, common in southern DRC, the mobility and bioavailability of trace metal elements are increased, heightening the risk of heavy metals transfer to plants and groundwater [3].

Similar cases of chronic soil pollution have been documented globally. In Kabwe, Zambia, for instance, soils in this former lead mining town contain concentrations exceeding 10,000 ppm, exposing children to dangerously high levels of heavy metals over time [4]. In China, around the Zhuzhou metallurgical complexes, extremely high levels of cadmium, lead, and zinc have been found in agricultural soils, threatening regional food security [5]. These examples underscore the global challenge of managing contaminated soils in a post-industrial context.

Several studies have highlighted the environmental consequences of mining in southern DRC, particularly soil contamination by trace metal elements. Other scholars, including Nathan Mpiana, Jean-Marc Madihano, and Professor Thierry Musanda, have documented significant levels of heavy metal pollution in the Penga-Penga district of Lubumbashi, located near active and former mining operations. Their research revealed elevated concentrations of copper (Cu), cobalt (Co), lead (Pb), and cadmium (Cd) in residential soils, often exceeding international safety thresholds. These findings underscore the persistent impact of industrial activities on urban soil quality and public health. Such studies reinforce the urgent need for long-term monitoring and remediation strategies to mitigate the risks posed by legacy pollution in mining-affected communities.

In 2012, Professor Banza conducted a pivotal investigation into soil pollution surrounding the CHEMAF-SOKWE site in Lubumbashi, Democratic Republic of Congo. His findings, published in a report titled "Report on the Chemical Pollution Survey in the Tshamilemba and Kabecha Neighborhoods of the City of Lubumbashi" [7], revealed alarming levels of levels of copper (Cu), cobalt (Co), lead (Pb), zinc (Zn),

and cadmium (Cd) in the soils of Tshamilemba and Kabecha neighborhoods near the CHEMAF-SOKWE site. Copper and cobalt were especially prominent due to the area's proximity to hydrometallurgical operations. Lead and cadmium levels exceeded international safety thresholds in many household gardens. Zinc was also present in significant concentrations, contributing to the overall trace metal burden.

These metals pose serious risks to human health, particularly through food grown in contaminated soil and exposure to dust. The report emphasized the need for environmental monitoring and public health interventions in these communities. The study also showed that most household gardens in these neighborhoods contained elevated concentrations of heavy metals, posing significant risks to public health and food safety. These results underscored the environmental impact of industrial activities on urban communities and highlighted the urgent need for remediation and regulatory oversight.

Although some improvements have been observed in certain areas, the persistence of high pollutant levels demands sustained attention. Developing effective monitoring, remediation, and sustainable soil management strategies is crucial, particularly in the mining regions of southern DRC, where demographic and industrial pressures continue to intensify.

Due to growing concerns over environmental pollution and urban encroachment, CHEMAF shut down its copper processing plant located in the Usoke residential neighborhood of Lubumbashi in 2012. The decision was driven by mounting environmental pressure from academic research, public health concerns arising from the plant's proximity to homes and schools, and a strategic relocation by the operator to a more industrially zoned area.

Our study investigates the evolution of soil pollution in the post-industrial period following the shutdown. The findings reveal the severity and long-term impact of contamination caused by mining activities, particularly when mineral exploitation occurs in a disorganized and poorly regulated manner.

2. MATERIALS AND METHODS

2.1 Study area

The Kabecha district is situated within the central industrial zone, near the former metallurgical facilities of the CHEMAF-USOKE company. These plants were historically involved in the production of copper concentrates, cobalt hydroxide, and sulfuric acid. The location of the study area is illustrated in Figure 1.



Figure 1: Geographic location of the KABECHA district

2.2 Sampling

Soil sampling was carried out using the random method, around the perimeter of the CHEMAF-USOKE company and in the adjacent plots of land. After collection, the samples were placed in plastic bags and labeled. Multiple samples were collected at each sampling point to create a composite sample. All the samples were packaged and coded. The composite sample was obtained by applying the cone and quartering homogenization method. Figure 2 illustrates the soil sampling process.

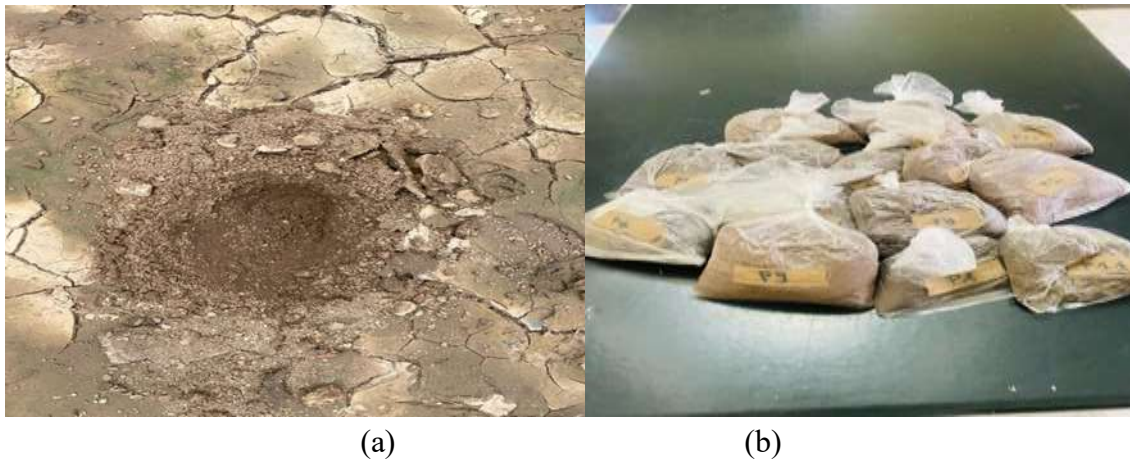


Figure 2: Photograph of sample collection: a) drilling the sample hole and b) collecting the samples

2.3 Determination of soil moisture content

Soil samples were dried in an oven at 105°C for 24 hours to determine their moisture content. The moisture percentage was calculated using the following equation:

$$\% \text{ Humidity} = \frac{P1 - P2}{P1} * 100 \quad (1)$$

P1 is the mass (g) before drying, and P2 is the mass (g) after drying.

2.4 Chemical analysis of trace metal elements concentration

Chemical analyses were conducted at Robinson International Afrique (RIA) laboratory in Lubumbashi using a Perkin Elmer Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES) spectrometer. The focus was on trace metal known that can be harmful to pose health risks, including cadmium (Cd), copper (Cu), lead (Pb), and zinc (Zn).

3. RESULTS AND DISCUSSION

As the objective of this article is to examine the spatial and temporal evolution of soil contamination by trace metals, the results are presented in the form of comparative tables and graphical representations. The discussion emphasizes both cross-sectional and longitudinal analyses of trace metal pollution in the study area.

3.1 Determination of humidity

Soil moisture plays a key role in the dynamics of trace metal elements in soils. Indirectly, it enhances microbial activity, which promotes the biodegradation of organic acids and chelating agents. These substances can increase the mobility and bioavailability of trace metals, facilitating their uptake by plant roots and their transfer into the food chain. Directly, soil moisture influences geochemical processes such as the precipitation and solubilization of metal ions. However, excessive moisture can reduce soil aeration, leading to anaerobic conditions that may alter redox potential and affect metal speciation. Therefore, soil

moisture is a critical parameter in assessing soil pollution. The results of the moisture content analysis are represented in Tables 1 and 2.

Table 1: Humidity rate results for the first avenue (Congo kiwele)

Humidity (%)		
Samples	Test 1	Test 2
P1	15.69	14.8
P2	15.18	15.21
P3	16.91	17.95
P4	16.32	15.37
P5	11.79	12.13
P6	20.32	18.35
P7	12.47	12.3
Average	15.52	15.16

After sample collection, the soil was oven-dried at 105 °C for 24 hours to determine its moisture content. The results showed that moisture levels ranged from 15.16 % to 15.52 % on Congo Kiwele Avenue and from 13.57 % to 13.93 % on Tulipier Avenue. These relatively high values are consistent with sampling conducted during the rainy season. As previously discussed, soil moisture significantly influences the solubility and mobility of trace metal elements in soils, thereby enhancing their bioavailability and potential uptakes by plants.

Table 2: Humidity rate results for Second Avenue (Tulipier)

Humidity (%)		
Samples	Test 1	Test 2
P1	14.39	14.79
P2	10.15	10.88
P3	12.46	12.35
P4	18.42	17.1
P5	11.91	11.63
P6	13.34	11.8
P7	17.14	16.45
Average	13.97	13.57

3.2 Evaluation of trace metal elements in soils

Trace metal concentration in the soil samples was determined using an inductively optical emission spectrometer (ICP-OES) at the Robinson laboratory in Lubumbashi. The analytical results of the analysis are presented in Tables 3 and 4, organized by sampling location. Specifically, data from the second avenue (Tulipier), starting at the Chemaf fence, are detailed in Tables 5 and 6.

In addition to the spatial (cross-sectional) analysis based on the distance from the road to the Chemaf fence, a temporal comparison was conducted to assess changes in trace metal pollution over time. For this

purpose, the 2024 results were compared with previously published data. The outcomes of this temporal analysis are presented in Table 7 and illustrated in Figures 3 and 4.

Table 3: Concentration of trace metal elements in the first avenue (Congo kiwele)

Elements	Cd (ppm)	Cu (ppm)	Mn (ppm)	Pb (ppm)	Zn (ppm)
P1	0.881	1060	751.4	218.8	313.2
P2	0.269	1066	717	133.3	306.7
P3	1,466	992.1	596.1	108.3	392
P4	0.909	918.2	475.2	151.4	308.1
P5	0.975	1012.6	476.05	182.5	342.9
P6	0.975	1107	476.9	206.4	383.5
P7	1.35	1091	450.79	183.7	357.1
Reference values, according to AFNOR NF U 44-041	2	100	90	100	300

As shown in Table 3, the concentrations of all trace metal elements in the soil samples from Congo Kiwele avenue exceed the acceptable limit values defined by the AFNOR NF U 44-041 standard, except for cadmium (Cd), which matches the reference value. The highest concentrations were recorded for copper (1107 ppm), followed by manganese (751.4 ppm), zinc (392 ppm), and lead (218.8 ppm). Notably, the copper concentrations are approximately eleven (11) times higher than the AFNOR NF U 44-041 Threshold, indicating significant contamination. This elevated copper level is likely attributable to the proximity of the Chemaf plant, which processes copper ores and produces concentrates. Except for cadmium, all measured trace metal concentrations exceed the regulatory limits and are consistent with findings from previous studies conducted in southeastern Congo, where soils have been impacted by mining activities [6]. Among the sampling points, point 7 exhibited the highest copper concentration.

To contextualize our findings, we compared them with those reported by Prof Banza [7] for the same area. The comparative results, presented in Table 4, show that the concentration reported by the author [7] was significantly higher than those observed in our 2024 analysis.

Table 4: Concentration of trace metal elements on Congo Kiwele Avenue

Elements	CD (ppm)	Cu (ppm)	Mn (ppm)	Pb (ppm)	Zn (ppm)
P1	0.445	1004	344.6	595.1	199.1
P2	0.135	1008	467.9	216.1	225.3
P3	0.738	846.2	392.3	168.3	288.5
P4	0.459	837.8	399.7	163.7	285.3
P5	0.488	401.2	450.9	209.9	276.3
P6	0.488	721.1	339.8	163.6	209.3
P7	0.68	1041	760.3	331.4	252

Reference values, according to AFNOR NF U 44-041	2	100		100	300

In contrast, the results obtained in this study significantly outperform those reported by researchers [8,9].

Table 5: Results of the samples from Tulip Avenue

Elements	Cd (ppm)	Cu (ppm)	Mn (ppm)	Pb (ppm)	Zn (ppm)
P1	0.881	1060	751.4	595.1	313.2
P2	0.269	1066	717	316.1	306.7
P3	1,466	992.1	596.1	318.3	392
P4	0.909	918.2	475.2	313.7	308.1
P5	0.975	1012.6	476.05	309.9	342.9
P6	0.975	1107	476.9	263.6	383.5
P7	1.35	1091	450.79	331.4	357.1
Average	0.98	1035.27	563.35	349.73	343.36
Banza et al, 2012	1.84	1867		627	405.5
Reference values, according to AFNOR NF U 44-041	2	100	90	100	300

Soil analysis conducted along Second Avenue adjacent to the Chemaf factories (tulip tree area) revealed elevated concentrations of copper (Cu), manganese (Mn), and lead (Pb), exceeding the threshold values established by international environmental standards. Notably, mercury and copper levels were particularly high, while cadmium was relatively low. Zinc appeared to comply with the French regulatory limit of 300 ppm. In contrast, lead levels significantly exceeded the permissible limit defined in European and French regulations [10].

Table 6: Comparison of the results of the Tulip Avenue with previous work

Elements	CD (ppm)	Cu (ppm)	Mn (ppm)	Pb (ppm)	Zn (ppm)
P1	0.445	1004	344.6	218.8	199.1
P2	0.135	1008	467.9	133.3	225.3
P3	0.738	846.2	392.3	108.3	288.5
P4	0.459	837.8	399.7	151.4	285.3
P5	0.488	401.2	450.9	182.5	276.3
P6	0.488	721.1	339.8	206.4	209.3

P7	0.68	1041	476.9	183.7	252
Average	0.49	837.04	410.30	169.20	247.97
Banza et al, 2012	1.84	1867		627	405.5
Reference values, according to AFNOR NF U 44-041	2	100	90	100	300

The concentrations of copper, cadmium, lead, and zinc measured in soil samples collected along Tulip Avenue (located two blocks from the Chemaf fence) were compared with those reported in previous studies conducted on the same site. Our results indicate significantly lower concentrations of these metals compared to those reported by Banza [7]. Furthermore, the values reported in his publication [7] also exceed those documented in subsequent studies by Yang [11] and Kahangwa [12].

3.3 Study of the evolution of pollution by trace-metal elements over time

Table 7: Evolution of the concentration of trace metal elements over time on Tulipier Avenue

Elements	Cd (ppm)	Cu (ppm)	Pb (ppm)	Zn (ppm)
Tulip tree (2024)	0.49	837.04	169.2	247.97
Banza et al., 2012	1.84	1867	627	405.5
Reference values, according to AFNOR NF U 44-041	2.00	100.00	100.00	300.00

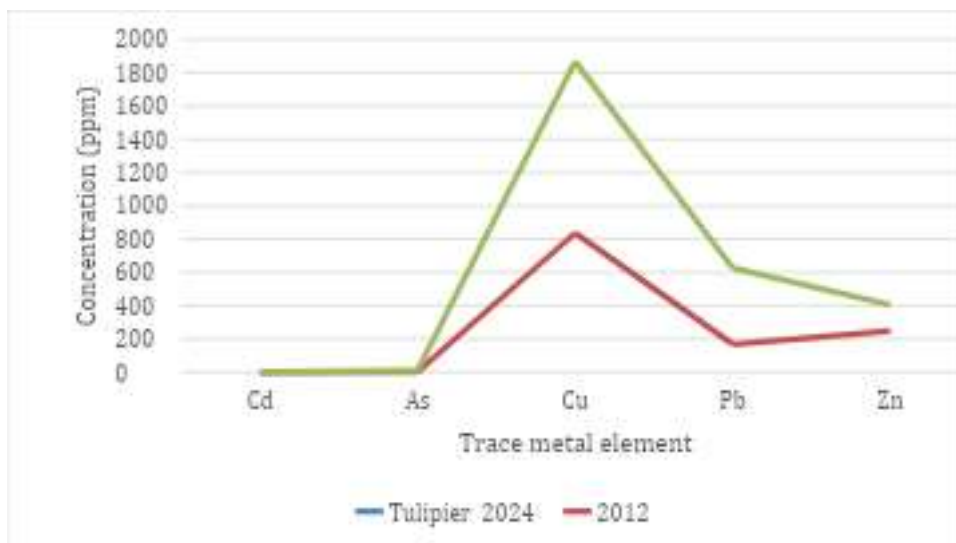


Figure 3: Study of the evolution of trace metal pollution over time

Table 8: Evolution of the concentration of trace metal elements over time on Congo Kiwele Avenue

Elements	Cd (ppm)	Cu (ppm)	Pb (ppm)	Zn (ppm)
	Ppm	Ppm	Ppm	Ppm
Kiwele (2024)	0.98	1035.27	349.73	343.36
Banza et al., 2012	1.84	1867	627	405.5
Reference values, according to AFNOR NF U 44-041	2.00	100.00	100.00	300.00

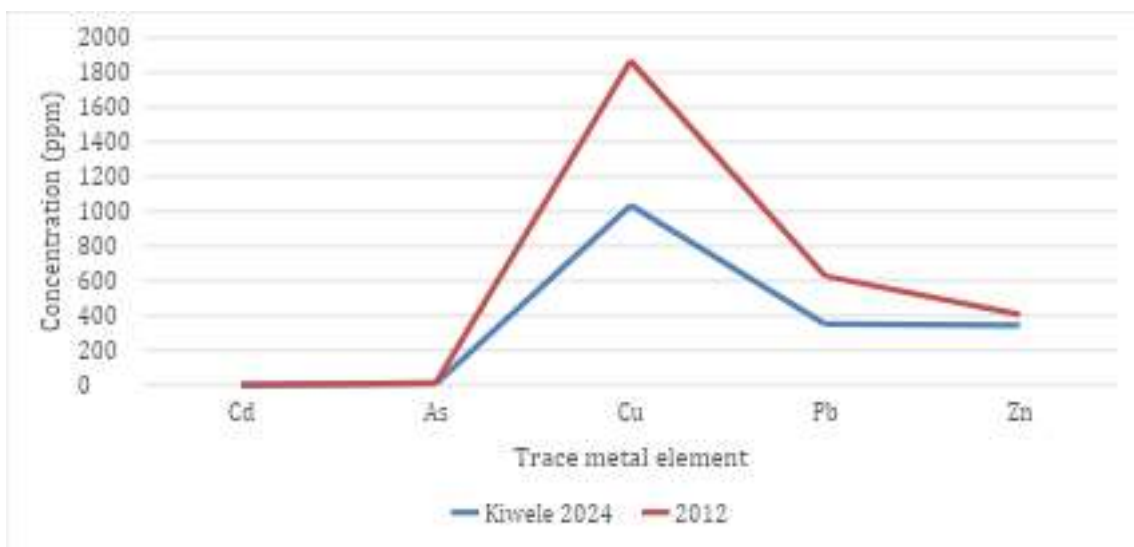


Figure 4: Study of the evolution of the concentration of trace metal elements over time on Congo Kiwele Avenue

The temporal evolution of soil contamination by trace metal elements (TME) in the Kabecha district is assessed by comparing recent data (2024) with those published by Banza [7] in 2012. The results reveal a marked decline in the concentrations of heavy metals such as copper (Cu), lead (Pb), zinc (Zn), and cadmium (Cd) over these twelve years. For instance, on Congo Kiwele Avenue, copper concentrations decreased from 1867 ppm in 2012 to 1035 ppm in 2024, representing a 44.6 % reduction. Similar downward trends were observed for lead (from 627 to 349.7 ppm) and cadmium (from 1.84 to 0.98 ppm). This decline is likely attributable to the relocation of the CHEMAF-USOKE metallurgical plant, a major emitter of metal pollutants, which ceased operations in the area several years prior. Since then, no significant anthropogenic inputs have been recorded, allowing for partial natural attenuation of the contamination. This process may involve mechanisms such as leaching by rainwater, dilution, stabilization of metals into less bioavailable forms, and phytoremediation by local vegetation.

Despite this apparent improvement, heavy metal concentrations remain well above international environmental thresholds. For example, the AFNOR NF U 44-041 standard sets the maximum copper content at 100 ppm, whereas values exceeding 1000 ppm persist in several locations. Elevated levels of lead and zinc are also still present, indicating ongoing chronic pollution and posing a continued risk to human health and the environment, particularly in areas close to the former industrial site.

These findings are consistent with observations from other post-industrial contexts. In Kabwe, Zambia, Yabe et al. (2011) reported persistent soil lead concentrations exceeding 10,000 ppm. Similarly, Zhang [5] documented sustained cadmium and lead contamination of Zhuzhou agricultural soils in China, while Mpundu [13] highlighted the bioaccumulation of TMEs in vegetables cultivated in Lubumbashi, raising concerns about food chain contamination.

3.4 Cross-sectional study of the evolution of trace metal pollution

The cross-sectional study investigates trace metal contamination along four avenues, Congo Kiwele, Tulipier, Lualaba, and Mpanda avenues, located at varying distances from the Chemaf industrial site. The primary objective is to assess the spatial dispersion of heavy metals in surface soils, hypothesized to occur predominantly via aeolian (wind-driven) transport mechanisms. The analytical results are summarized in Table 9 and illustrated in Figure 5.

Table 9: Cross-sectional study of the evolution of the concentration of trace metal elements

Elements	Cd (ppm)	Cu (ppm)	Mn (ppm)	Pb (ppm)	Zn (ppm)
Congo Kiwele Avenue	0.98	1035.27	563.35	349.73	343.36
Tulipier Avenue	0.49	837.04	410.30	169.20	247.97
Lualaba Avenue	0.25	737.93	231.67	164.86	200.28
Mpanda Avenue	0.01	638.81	53.05	160.53	152.59
Reference values, according to AFNOR NF U 44-041	2.00	100.00	90.00	100.00	300.00



Figure 5: Cross-sectional study of trace metal pollution in the study area

A consistent decline in metal concentration is observed with increasing distance from the chemical site. For instance, copper, the most abundant trace metal detected, shows a marked decrease from 1035.27 ppm on Kiwele Avenue to 638.81 ppm on Mpanda Avenue. Similar decreasing trends are evident for other metals, including manganese, lead, uranium, mercury, arsenic, and cadmium. Specifically, the manganese concentrations drop from 563.35 ppm on Congo Kiwele to 410.3 ppm on Lualaba, and further to 53 ppm

on Mpanda Avenue. Lead concentrations follow a comparable pattern: 349.73 ppm on Congo Kiwele Avenue, 169.2 ppm on Tulipier, 164.68 ppm on Lualaba, and 160.53 ppm on Mpanda Avenue. Regression analysis of concentration data yields negative slopes (angular coefficients), confirming a statistically significant inverse relationship between metal concentration and distance from the pollution source. This spatial trend supports the hypothesis of wind-mediated dispersion of trace metals from the Chemaf site, with deposition intensity diminishing progressively with distance.

3.5 Discussion

Analytical results reveal a significant accumulation of trace metal elements with concentrations substantially exceeding the thresholds established by the AFNOR NF U 44-041 standard. These elevated levels indicate chronic contamination of industrial origin. The geochemical signature of the soils analyzed is characteristic of environments impacted by metallurgical activities, where pollutant dispersion is primarily driven by particulate emissions, untreated effluents, and solid residues (tailings and slags). Comparable studies conducted in Kabwe (Zambia) and La Oroya (Peru) have reported similarly high concentrations of Cu and Pb in urban soils adjacent to mining and smelting operations, particularly in areas lacking effective containment or remediation infrastructures [14],[15].

The spatial distribution of trace metal elements exhibits a decreasing concentration gradient with distance from the CHEMAF-USOKE site. This pattern reflects diffuse dispersion influenced by prevailing wind direction, topographic slope, and soil permeability. The observed distribution aligns with a particulate advection-sedimentation transport model, further by vertical leaching processes during the rainy season. The cross-sectional analysis confirms this dynamic: the maximum values of Cu (1035 ppm) and Pb (349 ppm) are recorded on Congo Kiwele Avenue, near the former industrial site, and progressively decline toward Mpanda Avenue. This spatial trend is well-documented in the literature [16,17], underscoring the relevance of integrating geographic Information systems (GIS) with atmospheric dispersion models such as AERMOD for predictive pollution mapping.

From a chemical mobility perspective, the soil moisture content measured (13–15 %) during the rainy season increases, enhancing the risk of solubilization and migration of TMEs. Moist conditions favor the formation of organometallic complexes or chelate, especially in the presence of biodegradable organic matter, thereby increasing the phytoavailability of metals [18]. This risk is exacerbated by the sandy-loam texture of the soils, which exhibit limited cation exchange capacity and poor metal retention. These factors contribute to the vertical mobility of, posing a threat to shallow groundwater resources, as demonstrated by Schneider (2020) on lead leaching in urban environments.

Temporal analysis, based on comparison with data published by Banza [7], indicates a partial decline in trace metal elements concentrations following the relocation of industrial activities. This reduction may be attributed to the cessation of direct anthropogenic inputs, as well as to natural attenuation processes such as dilution, degradation, or adsorption on stable mineral phases. However, this attenuation remains slow and incomplete, particularly for low-mobility metals like lead and copper. Moreover, the absence of passive containment strategies such as vegetative stabilization or capillary barriers heightens the risk of recontamination during extreme weather events (runoff, flooding).

Finally, the persistent presence of heavy metals in surface horizons poses a serious threat to food security and public health due to the potential for bioaccumulation in crops cultivated in these peri-urban areas. The concentrations of Cu, Zn, and Pb exceed the phytotoxic thresholds defined by Kabata [2], potentially inhibiting plant growth, disrupting microbial soil communities, and the sustainability of urban agroecosystems. These findings corroborate earlier warnings by Mpundu [13] regarding contamination of

leafy vegetables grown in Lubumbashi. It is therefore imperative to implement eco-compatible remediation strategies, such as assisted phytoremediation or soil amendment with stabilizing biochars, as demonstrated successfully in recent studies. [19].

4. CONCLUSION

This study underscores the persistent contamination of soils by trace metal elements in the Kabecha district, despite the relocation of CHEMAF-USOKE's industrial operations several years ago. While concentrations of heavy metals such as copper (Cu), lead (Pb), and zinc (Zn) have significantly declined compared to 2012 levels, they continue to exceed internationally recognized environmental thresholds—particularly in areas adjacent to the former industrial site. This residual contamination presents a serious ecological and public health concern, notably through the bioaccumulation of metals in food crops cultivated on these soils.

To address these risks, it is imperative to establish a long-term environmental monitoring program, supported by in-depth research on the bioavailability, speciation, and mobility of these metals within the local pedoclimatic context. Sustainable remediation strategies, including phytoremediation and soil amendment, should be prioritized. Concurrently, awareness campaigns targeting local communities are essential to communicate the health risks associated with agricultural use of contaminated soils. Strengthening the regulatory framework governing post-industrial land management is also critical to ensuring environmental safety and promoting sustainable development.

An integrated and multidisciplinary approach will not only protect public health but also support the ecological rehabilitation of soils in this environmentally sensitive urban area.

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