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Original Article

Analysis of Soil Pollution by Trace Metal Elements and Habitability Conditions in the Kanyamenshi Neighbourhood, Kipushi City (Haut-Katanga, DR Congo)

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ABSTRACT

The city of Kipushi has experienced accelerated, unregulated urbanisation, primarily driven by mining activities, leading to extensive environmental contamination. In particular, the spontaneous occupation of mining waste sites has intensified soil pollution by trace metal elements (TMEs). This study evaluates soil pollution management practices and their relationship to habitability conditions in the Kanyamenshi neighbourhood. Structured household surveys were administered to residents adjacent to Kipushi's tailings to document anti-pollution architectural and landscaping strategies, as well as socioeconomic profiles. Spatial distribution of TMEs in soils was mapped using geostatistical interpolation techniques within QGIS. Results demonstrate that adaptive architectural and landscaping practices correlate strongly with local contamination levels. In Kanyamenshi, 55.2% of respondents reported implementing remediation measures, including soil scrubbing (deep biological ground extraction, (DBGE) and complementary mitigation techniques. In Kichangalayi, 35% of households employed excavation-based interventions. Socioeconomic analysis revealed that educational attainment remains low, with 35% of residents having primary education and 45% secondary education. Spatial interpolation revealed that Cu-Co concentrations are markedly lower in the southern sector of the study area and significantly elevated toward the northeast. These findings highlight the emergence of both autonomous and community-driven environmental management practices in highly contaminated urban settings. The identification of key land stakeholders emerges as a strategic priority for enhancing the efficacy of soil pollution mitigation efforts and promoting sustainable urban development.

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INTRODUCTION

Urbanisation has become a major global trend over the past century. Since 2014, urban dwellers have accounted for 54% of the world's population (Useni, 2017), and by 2023, this figure had risen to 56%, representing approximately 4.4 billion people (World Bank, 2023). Africa has experienced particularly rapid urban growth, fueled by high demographic rates; in Sub-Saharan Africa, the population has increased by an average of nearly 2.8% annually since 1960 (Chaléard, 2010). Among African countries, the Democratic Republic of the Congo (DRC) stands out due to its vast size and one of the highest demographic growth rates globally (Pourtier, 2018; Simeon et al., 2024). Despite its potential, the DRC's development trajectory has been structurally unstable since independence (ANAPI, 2018), with rapid urbanisation often outpacing urban planning and infrastructure development (Marhegane et al., 2022).

Southern DRC is home to some of the largest copper and cobalt reserves worldwide (Leteinturier et al., 1999). The mining boom of the early 21st century triggered significant socio-economic benefits (Ettler, 2016) but also induced profound environmental transformations, including soil and water contamination, deforestation, and land degradation (Panagos et al., 2013). Poorly managed mining waste, especially abandoned sedimentation basins heavily contaminated with heavy metals (Narendrula et al., 2012), has been increasingly encroached upon by expanding urban settlements. In areas like Kipushi, such proximity between mining residues and residential spaces poses serious environmental health risks. Studies have documented elevated levels of trace metals (As, Cd, Co, Pb, and U) in biological samples from populations living near mining sites compared to those from non-mining regions, indicating a heightened risk of metal-related health disorders (Banza et al., 2009; Tembo et al., 2006).

Kipushi, located in Haut-Katanga Province, illustrates the nexus between mining expansion and unregulated urban growth. Following the entry of new mining companies after 2002 (Mwitwa et al., 2012), the town experienced explosive demographic growth. Limited land availability led to residential expansion into contaminated zones, including former tailings sites locally known as

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"wounded landscapes." The Kanyamenshi neighbourhood exemplifies this dynamic, where military and civilian populations, displaced by economic necessity and political upheavals post-1997, progressively settled on an abandoned tailing without adequate environmental remediation measures (Mpundu et al., 2014; Cabala et al., 2017).

While extensive research has focused on the characterisation of soil pollution in mining regions, there remains a paucity of studies addressing how local communities adapt their architectural and landscaping practices in response to environmental contamination, and the implications of these practices for habitability conditions.

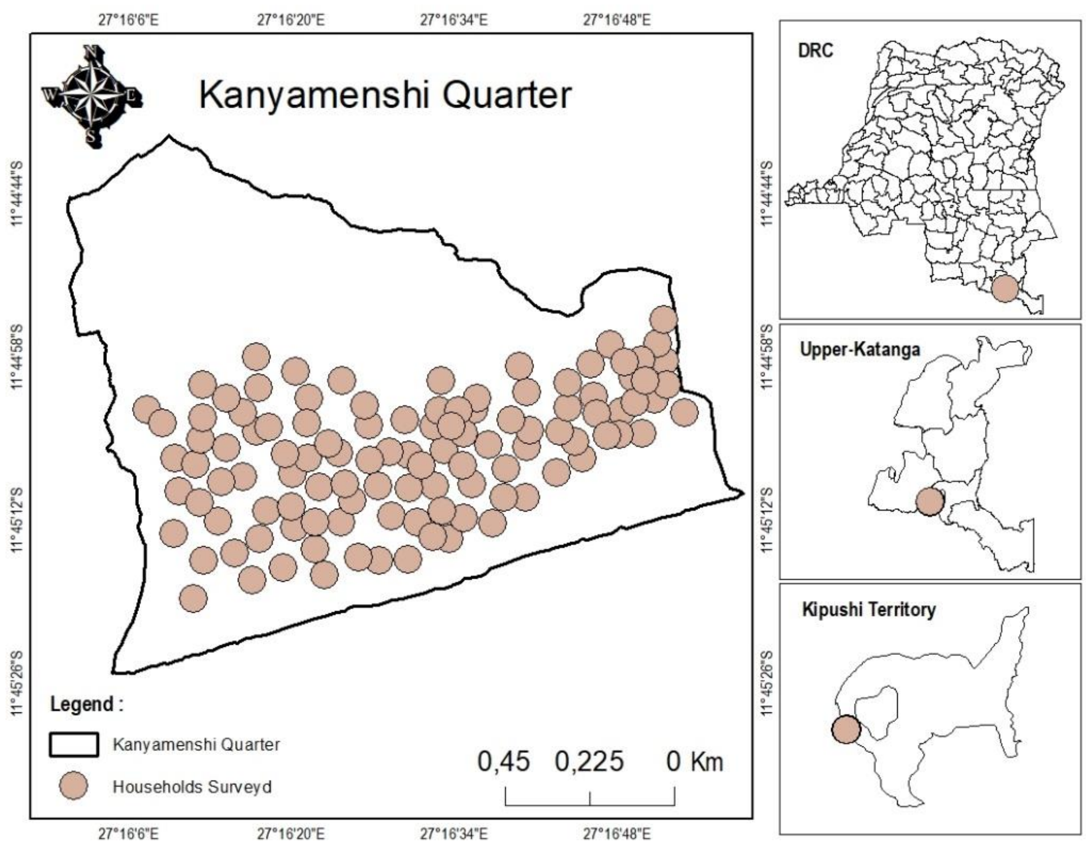
This study aims to investigate soil pollution management strategies related to trace metal contamination and assess their influence on the living conditions and habitability of the Kanyamenshi neighbourhood in Kipushi.

MATERIALS AND METHODS

Study Area

Kipushi is a small town located 30 km from Lubumbashi in the Katanga province of the DRC (Kitobo, 2009), at approximately 11˚ 46' South latitude and 27˚ 14' East longitude. Situated at 1,350 m altitude, Kipushi borders Zambia and was historically prosperous due to the state-owned mining company Gécamines. Today, Kipushi remains a mining hub, producing copper, zinc, and cobalt (Giz, 2018).

Figure 1: Location of the Study Area (Kipushi Town) is Situated Approximately 30 km from the City of Lubumbashi (DRC).



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Spatial Distribution of Trace Metal Elements in Soil

A random soil sampling method was used, considering contamination gradients and vegetation coverage (Kaya et al., 2019). Nine soil samples were collected using an auger, reaching depths of 50 cm to ensure sample homogeneity. The samples were analysed in the laboratory, and geographic coordinates of collection points were recorded using a GPS device to generate spatial distribution maps for copper and cobalt concentrations (De Smet, 2009). The concentration levels were determined using an atomic absorption spectrophotometer (PG Instruments AA500). Samples underwent wet digestion for analysis (O.R.S.T.O.M., 1982). A detailed preprocessing phase enabled the development of a spatially coherent and exploitable heavy metal distribution map using QGIS at a 1/10 scale (Mwanasomwe, 2022).

Characterisation of Architectural and Landscape Practices

A survey was conducted among households to gather information on their current architectural practices and the construction materials used (Lecourt, 1998). The study also aimed to present the characteristics of existing buildings in high-risk areas to assess their resilience to toxic metals, with a particular focus on construction materials and interior layouts (Breton et al., 2016). Specifically, we examined innovative and sustainable architectural solutions that have been successfully implemented in other regions facing similar challenges. Additionally, we inventoried all case studies of households that have successfully adapted their architecture and documented the lessons learned, such as excavations and the use of vegetation for housing (Kilela, 2022).

Socio-Demographic Profiling of Kanyamenshi Residents

A preliminary investigation was conducted to collect demographic data from local neighbourhood authorities. The population of the study area was estimated at approximately 2,080 inhabitants, including 310 adult males, 425 adult females, 678 male children, and 667 female children. These demographic figures were used to inform the sampling strategy, following the approach proposed by Kaleka (2021). Given the limited size of the study area and the decision to reduce the sampling unit to the level of individual plots, a systematic survey method (plot-by-plot) was employed to ensure an accurate representation of local conditions (MBumba, 2008; Kaleka, 2021). Data collection focused on key respondent characteristics, including education level, residential status (indigenous or non-indigenous), and household income. Information was gathered through an interview guide structured with closed-ended questions, in accordance with the methodological principles outlined by Quivy and Van Campenhoudt (1995). A total of 183 households were identified within the two blocks comprising the Kanyamenshi neighbourhood

Statistical Analysis

A Chi-square test of independence was applied, on the one hand, to analyse the variation in socio-economic profile elements of residents across the two blocks that make up the neighbourhood, and on the other hand, to examine the variation in architectural and landscape practices for pollution control across these two blocks. Laboratory analysis results, obtained from soil samples, were integrated into a Geographic Information System (GIS) to produce spatial distribution maps of pollutants. This approach combines precise scientific data with advanced spatial visualisation and analysis techniques to better understand pollutant distribution in the environment. The concentrations

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of trace metal elements (TMEs), mapped using QGIS, were also compared to regulatory standards.

Table 1: Standard Concentrations of Copper and Cobalt in the Soil of Grand Katanga.

Blocks	Copper (ppm)	Standard (ppm) (Cu)	Cobalt (ppm)	Standard (ppm) (Co)	Reference
Kanyamenshi	121 - 8100 ppm	200 ppm	15 - 27 ppm	20 ppm	(Mpinda, 2021)
Kichangalayi	13,461 - 28,000 ppm	200 ppm	27 - 59 ppm	20 ppm	—

RESULTS AND DISCUSSION

Spatial Distribution of Copper and Cobalt in Kanyamenshi

Table 2 illustrates the geographic distribution and intensity of cobalt and copper contamination in the Kanyamenshi neighbourhood, highlighting the most contaminated areas and the trends observed in the distribution of these metals.

Table 2: Geographical Distribution and Intensity of Cobalt (Co) and Copper (Cu) Contamination in the Kanyamenshi Neighbourhood

Metal	Class	Concentration Range (%)	Color	Shape/Orientation	Main Location	Trend/Notes
Co (Cobalt)	1	0.001 – 0.002	Dark green	Ellipsoidal, westward	Kanyamenshi & Kichangalayi	Lowest concentrations
	2	0.0021 – 0.003	Light green	Ellipsoidal, westward	Mainly Kichangalayi	Low concentrations
	3	0.0031 – 0.004	Dark red	Ellipsoidal, extending further east	Mainly Kanyamenshi	Moderate concentrations
	4	0.0041 – 0.005	Light red	Centrifugal, northward	Northern Kichangalayi	High contamination
	5	0.0051 – 0.006	Bright red	Centrifugal	Kichangalayi	Highest contamination zone
Cu (Copper)	1	0.0126 – 0.57	Dark green	Ellipsoidal, southward	Kanyamenshi	Low concentrations
	2	0.571 – 1.13	Light green	Ellipsoidal, southward	Kanyamenshi (south flank)	Moderate concentrations
	3	1.14 – 1.69	Dark red	Ellipsoidal, southward	South Kanyamenshi, Kichangalayi	Moderate-high risk zone
	4	1.7 – 2.24	Light red	Centrifugal	East and west of Kichangalayi	High contamination risk
	5	2.25 – 2.8	Bright red	Centrifugal	Entirely in Kichangalayi	Very high contamination

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In the first part of the table, cobalt (Co) pollution extends from west to east. The first class (0.001 - 0.002%) shows low concentrations, represented in dark green, and is predominantly found in the Kanyamenshi and Kichangalayi blocks, located in the west. The second class (0.0021 - 0.003%) corresponds to moderate concentrations, in light green, with a strong presence in the Kichangalayi block. The third class (0.0031 - 0.004%) is characterised by higher cobalt levels, represented in dark red, extending into the Kanyamenshi block. The fourth class (0.0041 - 0.005%) indicates high cobalt concentrations, in light red, covering the northern part of the Kichangalayi block, thus representing a risk zone. Finally, the fifth class (0.0051 - 0.006%) corresponds to the highest concentrations, in bright red, and is primarily concentrated in the Kichangalayi block, highlighting an area of significant contamination. Cobalt pollution follows a distinct spatial progression, with increasing concentrations towards the east, particularly in Kichangalayi. In the second part of the table, copper (Cu) pollution extends from south to north. The first class of copper (0.0126 - 0.57%) reflects low concentrations, in dark green, and is exclusively found in Kanyamenshi. The fifth class (2.25 - 2.8%) shows very high copper concentrations, in bright red, and is entirely located in the Kichangalayi block, indicating a major risk zone. Thus, copper pollution also follows a spatial progression, with increasing concentrations from south to north and a particularly high risk in the Kichangalayi block.

Architectural and Landscaping Practices

Status of Landscaping Practices

Several landscaping practices have been identified in the city of Kipushi. Table 3 describes these various landscaping practices used to combat pollution caused by heavy metals (Cu-Co) due to mining discharge in the Kanyamenshi neighbourhood, in Kipushi.

Residents of Kanyamenshi predominantly use soil scrubbing for pollution mitigation, whereas those in Kichangalayi favour excavation methods. Some employ vegetation and organic matter to stabilise contaminated sites.

Table 3: Identification of Landscaping Practices for Pollution Control Due to Mining Discharges in Kipushi, in the Kanyamenshi and Kichangalayi Blocks of the Kanyamenshi Neighbourhood

Before_Implantation1_2_3 Kanyamenshi	**Before _Impl1_2_3 Kichangalayi Collective landscape practice**
clearing	Excav-1m
LC	Excav-50cm
Excavation-30cm	Excav-STS
	shaving termite
	Excavate the foundation
After_Impl1_2_3_4 Kanyamenshi	After_Impl1_2_3_4 Kichangalayi
Us-VEGET	Excavation to Stable Soil (STS)
	Us-VEGET
	leveling
	Us-OM
Collective architectural practices Landscaping	

(*Excav: Excavation; Us-VEGET: Using Vegetation; Us-OM: Using organic matter; LC: Land Conservation*).

The various practices are divided into two phases: before and after the implementation of the plots, according to the Kanyamenshi and Kichangalayi blocks. Before the implementation of the plots,

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some residents of Kanyamenshi resort to clearing, land conservation (LC) as architectural and landscaping practices, and then finish with a 30 cm excavation (Excav-30cm) to lay the foundation. In contrast, those occupying the Kichangalayi landscape resort to landscaping and architectural practices such as excavations, which are divided as follows: 1m excavation (Excav-1m), 50cm excavation (Excav-50cm), excavation to stable soil (Excav STS), shaving of termite mounds to contain pollutants, soil stabilisation (SOL-STB), and plot tracing-excavation-implementation (TEI).

After implementation in the Kanyamenshi landscape, the residents use vegetation (Us-VEGET), while those in the Kichangalayi landscape also use vegetation (Us-VEGET), plot levelling and organic matter (USGE-OM) to promote plant growth. We also note the existence of collective architectural and landscaping practices to combat pollution; these include excavations (Excav), the use of vegetation (Us-VEGET), and the use of organic matter (Us-OM).

Status of Architectural Practices on Buildings

Several architectural practices on buildings have been identified in the city of Kipushi. Table 3 describes these various architectural practices used to characterise buildings and combat pollution caused by heavy metals (Cu-Co) resulting from mining discharges in the Kanyamenshi neighbourhood, which consists of the Kanyamenshi and Kichangalayi blocks in Kipushi.

Table 4: Identification of Architectural Practices at the Building Level in the Polluted Site Commonly Known as Kanyamenshi in Kipushi

Arch Practice Before_Impl1_2_3Kanyamenshi	**Arch Practice Before_Impl1_2_3Kichangalayi**
ABF	ABF
FBF	FBF
After_Impl1_2_3_4 Kanyamenshi	**After_Impl1_2_3_4 Kichangalayi**
AB	AB
FB	AB
clay plaster	clay plaster
corrugated sheets (CS)	Metal sheets (MS)

(*ABF: Adobe Brick Foundation; FBF: Fired Brick Foundation; AB: Adobe Brick; FB: Fired Brick*).

The architectural practices characterised at the building level in the two blocks, Kanyamenshi and Kichangalayi, were described before the implementation. It is observed that in both blocks, some residents use foundation laying based on adobe bricks (ABF) and foundation laying based on fired bricks (FBF). After implementation, in both blocks, the residents also resort to wall construction using adobe bricks (AB), wall construction using fired bricks (FB), plot levelling, the use of clay plaster (CL), and the use of corrugated sheets (MS)

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Table 5: Comparative Study Between the Environmental Status and Landscaping Architectural Practices Before Implementation in Polluted and Non-Polluted Areas by Heavy Metals in Kichangalayi (Kipushi).

		Architectural practices of landscape Before _Implementation 1					
		Land conservation (LC)	clearing	EXCAV-1m	EXCAV-50Cm	Excav-STS	Total
State of Bloc	Kanyamenshi(effective)	8	112	0	0	0	**120**
	Kichangalayi(effective)	0	0	20	12	31	**63**
Total		**8**	**112**	**20**	**12**	**31**	**183**
Value of Chi-deux (%)							***183.000[a]***
P (%)							***0.000***

State of bloc		Architectural practices of landscape Before _ Implementation 2				Total
		Excavation-30cm	NA	shaving of termite	tracing-excavation-implementation	
(effective)	Kanyamenshi	112	8	0	0	**120**
	Kichangalayi (effective)	0	0	2	61	**63**
Total		**112**	**8**	**2**	**61**	**183**
Value of Chi-deux (%)						***183.000[a]***
P (%)						***0.000***

(*Excav: Excavation; Us-VEGET: Using Vegetation; Us-OM: Using organic matter; LC: Land Conservation*).

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Once again, the Pearson chi-square test set at 5% was chosen for the comparison of these qualitative data. Indeed, there is a very strong link between the 'environmental status of the blocks' and 'architectural and landscaping practices before implementation' (cf. Table 5). This is evident from the Pearson chi-square test for these two variables, which is 0.000%, indicating a strong significance between the two variables. This is also true for the second table, where the Pearson chi-square test is 0.000%, reflecting a strong link between the two variables.

In fact, in Table 5, the result shows that the architectural practice (clearing or deforestation) was more commonly used in the plots located in Kanyamenshi, as opposed to Kichangalayi, where approximately 112 households or plots living in an unpolluted environment resorted to this landscaping practice of clearing; approximately 8 households correspond to unmodified plots considered as conserved plots (Land conservation (LC). These plots correspond to undervalued spaces. It is also observed that a large portion of the occupants living in a polluted environment during this phase of landscaping resorted to excavations (EXCAV), described according to their depths in terms of contamination. About 31 people used excavation to reach stable soil (Excav-STS), about 12 people excavated to 50 cm (EXCAV-50cm), and about 20 people excavated to 1m (EXCAV-1m). The next table clearly shows that the majority, at least 112 occupants (households) of the population living in Kanyamenshi, after clearing their plots, immediately began tracking and digging around 30 cm (teracing-30cm) at the landscape level. In contrast, 61 households in Kichangalayi, due to high concentrations of heavy metals, resorted to tracing-digging-implementation without specifying the depth. Thus, approximately 2 households from the polluted zone shaved termite mounds to contain the pollution. The (NA) refers to plots where nothing was done.

Environmental Status and Architectural Practices on Buildings During the Execution Phase

Table 6: Comparative Study Between the Environmental Status of Blocks and Architectural Practices on Buildings During Execution at Kichangalayi and Kanyamenshi Blocks Polluted by Heavy Metals in Kipushi

		Architectural Practices on Buildings Before Implementation			
		ABF	FBF	NA	**Total**
State of Env_bloc	Kanyamenshi (effective)	45	67	8	**120**
	Kichangalayi (effective)	18	45	0	**63**
Total		**63**	**112**	**8**	**183**
Value of Chi-deux (%)					***6,798[a]***
P (%)					***0.033***

(*ABF: Adobe Brick Foundation; FBF: Fired Brick Foundation; NA: Not Available*).

According to the Pearson chi-square test (5%), a comparison is made between the environmental status of the blocks and architectural practices on buildings during the execution phase. The chi-square test value of 0.033% indicates a medium-level link between the two variables, suggesting a moderate connection between the “environmental status of the blocks” and the “architectural practices on buildings during the execution phase”. The table shows that approximately 67 households in

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Kanyamenshi used fired bricks (FBF) for their foundation, with a similar number in Kichangalayi, where approximately 45 households also used fired bricks for the same purpose. Around 45 households in Kanyamenshi used adobe bricks (ABF) for their foundation, with approximately 18 households in Kichangalayi doing the same. Eight households correspond to undervalued plots in the non-polluted area, with no action taken during foundation implantation to combat metal pollution in either block, but particularly in Kichangalayi, where higher concentrations are found.

Environmental Status and Architectural Practices on Buildings After Implementation

Table 7: Comparative Study Between the Environmental Status of Blocks Kanyamenshi and Kichangalayi and Architectural and Landscaping Practices After Implementation in Polluted and Non-Polluted Areas at Kichangalayi (Kipushi)

		Architectural practices of landscape after implantations (Ap_Impl4)					
		NA	soil stabilization	Parcel terracing	Us-Veget	Us-OM	**Total**
State of blocs	Kanyamenshi (effective)	113	2	0	4	1	**120**
	Kichangalayi (effective)	3	31	1	10	18	**63**
Total		**116**	**33**	**1**	**14**	**19**	**183**
Value of Chi-deux (%)							**134,117[a]**
P (%)							**0.000**

(*Excav: Excavation; Us-VEGET: Using Vegetation; Us-OM; NA: Not Available)*

Table 6 compares the environmental status of the blocks (Kanyamenshi and Kichangalayi) and the architectural and landscaping practices after the implementation phase in the Kanyamenshi neighbourhood of Kipushi. The Pearson chi-square test was used, with a value of 0.000%, showing a very strong link between the two variables. The table reveals that no architectural landscaping practices were performed in Kanyamenshi after the implementation phase (NA). In contrast, in Kichangalayi, significant landscaping practices were observed, such as soil stabilisation, parcel terracing, use of vegetation (Usage-Veget), and use of organic matter (Us-OM) to reduce the mobility of heavy metals.

Environmental Status and Architectural Practices on Buildings in the Final Phase

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Table 8: Comparative Study Between Environmental Status and Architectural Practices on Buildings in the Final Phase at the Kanyamenshi Polluted Area by Heavy Metals

		Architectural Practices on Buildings after Implantation (Ap_Impl3)		
		Metal sheets	NA	**Total**
State env_bloc	Kanyamenshi (effective)	112	8	**120**
	Kichangalayi (effective)	63	0	**63**
Total		**175**	**8**	**183**
Valeur de Chi-deux (%)				***4,392***
P (%)				***0,036***

(NA: Not Available).

Table 8 compares the environmental status of the blocks (Kanyamenshi and Kichangalayi) and architectural practices on buildings during the final phase of execution. The Pearson chi-square test value of 0.036% indicates a weakly significant link between the two variables. Before finalisation, Kanyamenshi households raised walls using fired bricks and adobe materials. In the final phase, the table shows that Kanyamenshi had more buildings covered with corrugated metal sheets, compared to Kichangalayi. The NA category corresponds to undervalued plots.

Identification of Social Profile in Kanyamenshi Quarter, Kipushi

Synergy Between the Block Status and the Educational Level of Kanyamenshi Residents

Table 9: Social Profile: Comparison Between Block Status and Educational Level in Kanyamenshi Neighbourhood

		Education					
		LP	LS	LU	LP	NE	
Blocs	KANYAMENSHI	40	50	14	4	11	119
	KICHANGALAYI	20	31	1	0	12	64
Total		**60**	**81**	**15**	**4**	**23**	**183**
Value Chi- deux							***10,706[a]***
P (%)							***0,03***

(*Level: Primary, LS: Secondary, LU: University, LP: Professional, NE: No Education*)

The results of the chi-square test of independence were used to verify the comparisons between two qualitative variables. The Pearson chi-square test, with a 5% significance level, was chosen to compare these two modalities. The Pearson chi-square value of 0.030% indicates a statistically significant relationship between the two variables, revealing a link between the social profile modalities, namely the education level of the inhabitants and the state of the blocks.

This relationship highlights the low level of awareness among the residents of the Kanyamenshi block, an area severely contaminated by heavy metals due to mining waste. It is observed that most households in the area have low educational levels, primarily distributed between primary education (LP), secondary education (LS), and no education (NE). In contrast, a small proportion of residents have higher educational levels, spread across university education (LU) and professional education (LF), as shown in Table 8.

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Regarding the link between the state of the blocks and the education level, the distribution shows that the social profile of the occupants is more pronounced in Kanyamenshi than in Kichangalayi. Most residents with primary (LP), secondary (LS), university (LU), and professional (LF) education live in Kanyamenshi, while those without education (NE) live in Kichangalayi, although the difference is less significant.

Indeed, about 40 households in Kanyamenshi have primary education, compared to 20 households in Kichangalayi. Additionally, 50 households in Kanyamenshi have secondary education, compared to 30 in Kichangalayi. Around 15 households in Kanyamenshi have a university education, compared to 3 in Kichangalayi. All professional-level households reside in Kanyamenshi, while 14 households without education live in Kichangalayi, compared to 11 in Kanyamenshi.

DISCUSSION

Methodological Approach

Architecture is often defined as a crossroads of expertise and knowledge from various disciplines (Bourget-Mauger, 2022). The growing interest in landscape issues is a current reality (Blanc et al., 2004). In this context, the landscape is viewed as a relationship between the sensory experience of the inhabitants and their living territories. This relationship requires analysis of the physical dimension of the environment (Berque, 2009). Our reflections and methodologies were applied to a neighbourhood divided into three blocks, chosen due to the landscape characteristics often attributed to it (contamination by heavy metals from mining waste). The enhancement of our results followed the establishment of a suitable and thorough methodology (surveys aiming to characterise different architectural practices in relation to the landscape as well as the built environment implemented in the region to fight against heavy metal pollution, both before and after installation). This enhancement involved characterising architectural and landscape practices, the spatial distribution of pollutants in the area, and identifying the social profile of those living in areas contaminated by trace metals. Our results reveal landscape architectural practices in both the heavily contaminated site and a less contaminated site. The spatial distribution of pollutants, such as copper (Cu) and cobalt (Co), was mapped using the most recent statistical methods, such as kriging (random soil sampling based on contamination gradients, with approximately nine soil samples taken from sites to perform suitable analyses and determine the spatial distribution of heavy metals). Additionally, the social profile was described using socio-economic data (education level, income, environmental status, and level of awareness). One main issue faced during our work is the communication of experiences. Indeed, following exploratory interviews with residents using a structured guide (Faburel et al., 2007), some interviewees experienced significant difficulties in discussing their efforts to combat pollutants due to the non-appropriation of the questionnaire (the questions related to a hierarchical description of landscape architectural practices). For others, embarrassment in discussing their social profile arose from low intellectual capacity and mistrust due to insecurity. Clearly stating one’s profession and income, as demonstrated by other studies (Balez, 2000; Grosjean and Thibaud, 2001; Blanc et al., 2004; Grésillon, 2010), reveals the challenge inhabitants face in talking about sensitive matters; discussing social profiles touches on personal intimacy. The researcher's solicitation, and especially that of the surveyor, could be interpreted as an intrusion. As a result, people were more willing to talk about visual experiences rather than other topics. Simultaneously, there was a tendency to focus on more common concepts, resulting in a certain "poverty" in the lexical fields, along with a bias toward discussing negative experiences. The limitations of the methodology were also noted in the study by Observatoire, espace et Société (2019),

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which addressed the limitations of qualitative surveys in urban environments.

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Our research results showed variability in these practices over time and across space. The various practices were divided into two phases: before and after the implementation of plots, depending on whether the site was contaminated by heavy metals or not. Architectural and landscape practices, such as excavation, termite mound scraping to contain pollutants, and soil stabilisation, were part of the process of treating polluted soil due to mining activities in Kipushi. The literature from Vranken (2013) also showed that the most common methods for decontaminating sites polluted by heavy metals involve soil excavation or chemical/physical treatment of soils. Physical methods involve displacing (excavation), covering, or solidifying contaminated soil (Kilela, 2022). Some authors emphasised the importance of combining several techniques, including excavation, soil treatment, and even phytoremediation (using plants to clean up a heavy metal-rich site). The link between phytoremediation and landscape design has already been emphasised by Kilela (2022) and Vranken (2013), whose studies show the use of plant species in certain neighbourhoods of Lubumbashi to contain pollutants. Our results corroborate those of Isotta & Fedérica (2020), which adopted a soil remediation method involving the excavation of the contaminated topsoil. The research by Xiaodi et al. (2020) also follows this same decontamination approach, involving more and more architecture professionals. The practice mainly focuses on three types of sites: industrial and infrastructure wastelands, mining wastelands, and dumps. Landscape strategies based on excavation and earthworks have been undertaken for decontamination by Dong et al. (2021) in his study on the effects of landscape characteristics on heavy metal distribution in roadside soils in a tropical area of southwest China. His findings clearly show effective pollution control measures for soil, such as soil excavation. On the other hand, Peter Latz (1991) proposed decontaminating by excavating the polluted soil and storing it in bunkers. Excavation is often the fastest method for site development, but the soil remains polluted. To date, excavation techniques, which involve removing the soil and dumping it elsewhere, remain the preferred method for landscape rehabilitation. While these techniques allow for immediate soil pollution remediation, they remain very costly (Egendorf et al., 2020). According to Origo (2012), in a study comparing decontamination costs per hectare, using data from the U.S. Atomic Energy Commission, he estimates the cost of decontamination through excavation and landfilling the same volume would range from $400,000 to $700,000, whereas phytoremediation for half a hectare of lead-contaminated soil to a depth of 50 centimeters ranges from $60,000 (around €43,400) to $100,000. Some authors, like Egendorf et al. (2020), argue that excavation techniques are not ideal due to the vast amount of mining waste produced and propose chemical remediation, which involves adding reagents to extract or inactivate soil pollutants (Tordoff et al., 2000; Conesa et al., 2006). These methods are quick and efficient at improving soil conditions and preventing the migration of contaminants, and they are better suited for remediating highly contaminated substrates (Khan and Jones, 2009 in Wang et al., 2017). However, these methods have significant disadvantages as they require substantial resources (high costs).

CONCLUSION

This research aimed to analyse soil pollution management by trace metals (ETMs) and its impact on the livability of the Kanyamenshi neighbourhood. It involved mapping the spatial distribution of copper (Cu) and cobalt (Co) in an affected landscape using kriging to better understand the extent and severity of contamination.

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Additionally, a socio-economic profile of the residents was conducted through surveys of households in Kipushi's spoil heap and surrounding areas. This approach allowed us to collect data on the socio-economic diversity of the residents, mostly characterised by low incomes, limited education levels, and varied family structures. The results reveal a spatial distribution marked by high Cu and Co contamination, extending from the south to the north of the Kanyamenshi neighbourhood, with ellipsoidal and centrifugal patterns. The pollution exhibits a gradient, ranging from weakly contaminated to highly polluted areas. Regarding architectural and landscape practices, these vary depending on the contamination gradient. In the Kanyamenshi block, residents prioritise debridement (DBGE) as a landscaping technique, while in the Kichangalayi block, excavation (Excav) is more commonly used to combat the high concentration of heavy metals. The study thus highlights the importance of local knowledge in the fight against ETM pollution and its potential to improve living conditions in the studied area. From a socio-economic perspective, the results of this work could help reduce exposure to heavy metals by raising awareness among residents about best landscaping practices. Moreover, this study enriches scientific production in landscape architecture by providing insights into the adaptation of landscaping practices to environmental challenges.
However, some difficulties were encountered during the research. On the one hand, the mistrust of respondents, due to insecurity, made it challenging to obtain precise information on their income levels. On the other hand, the identification of actors involved in land management in the neighbourhood could not be accomplished, thus limiting the analysis of local land dynamics. In the future, further studies should be conducted to better identify land actors and analyse potential conflicts related to land allocation in this area. Based on the results of this research, we recommend awareness Campaigns on Safe Landscaping Practices: Launch community-based awareness campaigns to educate residents on safe landscaping practices, such as debridement (DBGE) and excavation (Excav), tailored to the contamination gradient in the area. These campaigns should focus on reducing exposure to harmful metals while promoting more effective methods of environmental management.

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Declaration of Competing Interest

The authors declare that they have no conflicts of interest that might appear to influence the outcome of this paper.

Author's Contributions

Kalambulwa, N.A., drafted the article, Mwika I. I collected, processed the data, and drafted the methodology., Sambieni K.R., Tshitungu B.I., Mpanda M. M and Mumba T. U. read the draft and made corrections, and Cabala K.S. made the final revision.

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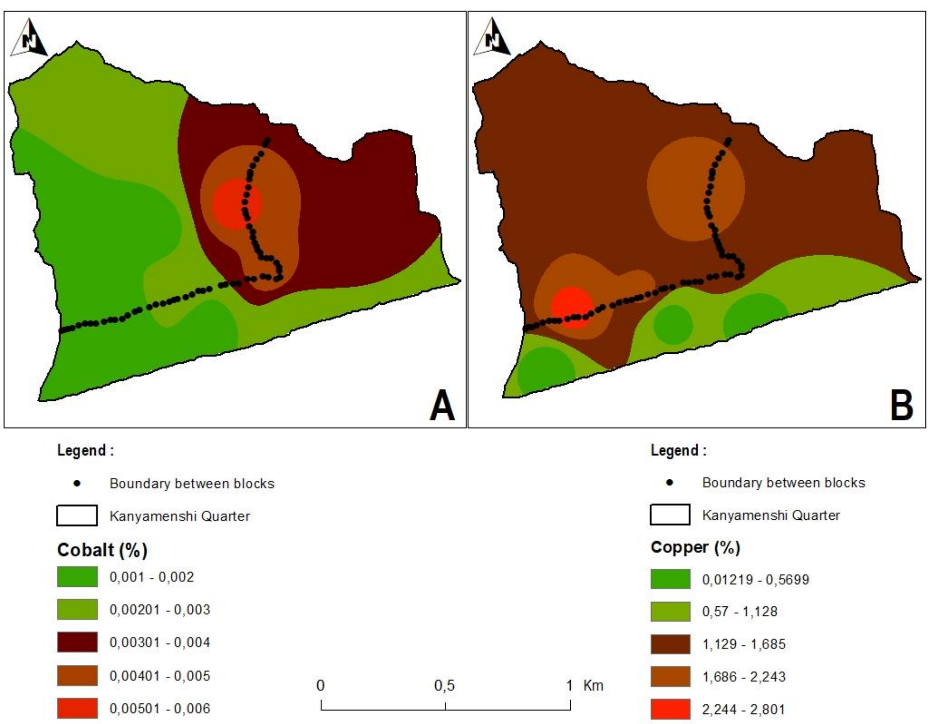
APPENDIX

Figure 2: Spatial Distribution of Trace Metal Pollutants in the Study Area at Kanyamenshi (A), For Co (B), For Cu.



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