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Seasonal profile of trace metal contamination (Hg, Cd, Pb and Al) and biological contamination of atmospheric air in the city of Kinshasa, Democratic Republic of the Congo

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ABSTRACT

Introduction
Unpleasant fumes, odours, reduced visibility, health issues from pollutants, and property damage caused by dust and corrosive gases are significant challenges in urban and industrial areas. Excessive pollution poses severe risks to health, rendering some areas uninhabitable and hindering socio-economic development.

Objective
This study aimed to assess the atmospheric air quality in Kinshasa, Democratic Republic of the Congo, by analysing chemical and biological pollution in dust collected at high-traffic intersections.

Methods
Sampling was conducted over 12 months in 2022, aligned with seasonal variations. Rainwater samples were collected in 500 ml plastic jars placed 5 m above ground, while dust samples were gathered from pre-selected rooftops. The concentrations of chemical pollutants in rainwater and dust were determined using molecular absorption spectrophotometry. Biological pollution was assessed by measuring organic matter in dust and cultivating diaspores from dust samples, with plant species identified using the APG III botanical classification.

Results
Chemical contamination of rainwater was observed with trace metals varying by site (e.g., Victoire: Hg = 0.43±0.03 mg/kg; Matadi Kibala: Hg = 0.07±0.04 mg/kg). Dust was also contaminated with trace metals (e.g., Victoire: Hg = 5.33±4 mg/kg; Kingasani: Hg = 5.33±4 mg/kg). Additionally, dust contained diaspores from 27 plant species across 16 botanical families, with higher concentrations during the dry season.

Conclusion
This study revealed poorer air quality in high-traffic areas in downtown Kinshasa compared to less urbanised sites like Mongata and Mbankana. Inhalation of dust and consumption of rainwater in these areas, especially during the dry season, pose health hazards, exposing residents to various diseases. Protective measures, such as mask-wearing, are crucial to safeguarding public health in areas with poor air quality.

INTRODUCTION

The preservation of atmospheric quality has become a global economic, legal, health, and environmental issue (Mondo et al., 2020). Atmospheric pollution affects the lives of millions of people worldwide, particularly in large industrial cities with intense motor vehicle traffic (World Health Organization [WHO], 1978). Air pollution is among the leading causes of preventable morbidity and mortality globally. Approximately 4.3 million annual deaths, primarily in developing countries, are linked to exposure to indoor air pollution, with an additional 3.7 million deaths attributable to ambient (outdoor) air pollution (Agence de l'Environnement et de la Maîtrise de l'Énergie [ADEME], 2015).

Even at relatively low levels, air pollution poses a significant health risk. Due to the number of people exposed, it causes substantial morbidity and mortality in all countries (WHO, 2014). According to WHO (2016), air pollution is responsible for nearly 200,000 deaths annually in Africa, with projections suggesting this figure could rise to 600,000 by 2050. Globally, 3 million people die each year due to air pollution, which has been established as a cause of lung and bladder cancer, heart disease, and vascular accidents (WHO, 1978).

In the Democratic Republic of the Congo (DRC), atmospheric pollution caused by intense human activity has long been a concern. Key sources include industrial activities and road transport in urban areas, while in rural areas, pollution arises from cooking fires, heating, lighting, mosquito control, and agricultural burning (WHO, 2016). Urban centres such as Kinshasa, Lubumbashi, and Kolwezi also face industrial pollution from mining and construction activities.

Research on air quality in the DRC remains sparse, with limited studies in Kinshasa and Kongo Central conducted by Musibono et al. (2009), WHO (2016), and Mondo et al. (2020). These studies highlight elevated levels of pollutants such as lead in urban air, with seasonal variations often overlooked (WHO, 2016; Mondo et al., 2020). Emissions from industrial and transportation activities represent a significant environmental challenge, particularly for populations near industrial facilities.

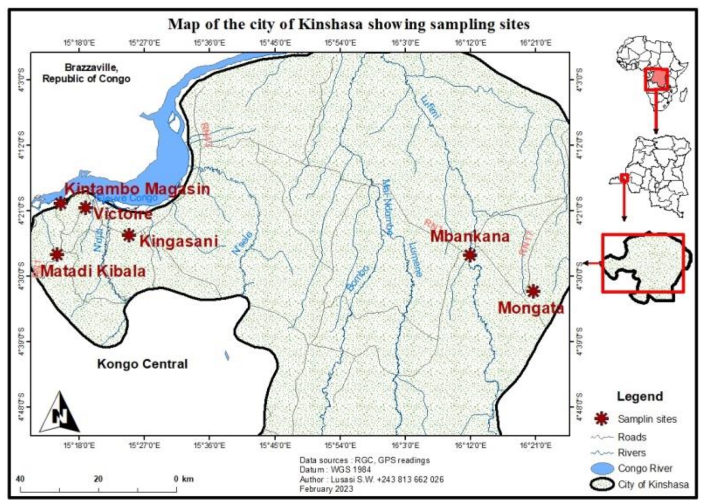
Regular monitoring of air quality across seasons is essential to inform decision-makers and implement measures to protect public health. This study aims to analyse the seasonal profile of chemical and biological contamination of atmospheric air in Kinshasa, DRC.

METHODS

Study Environments

This study was conducted in the city of Kinshasa, Democratic Republic of the Congo (DRC). The study focused on intersections with heavy automobile traffic, including Rond-Points Kintambo Magasin and Victoire, Kingasani, Matadi Kibala, Mbankana, and Mongata (see **Figure 1**).

Figure 1:
Map of the city of Kinshasa showing data sampling sites



Kinshasa was chosen because it is the largest city in the country, with a high population density exposed to diseases likely caused by air pollution. Mbankana and Mongata were selected as control sites due to their location in peri-urban areas with wild vegetation, despite being situated along National Road Number One. In contrast, the other sites were located in central Kinshasa, characterised by intense motor vehicle traffic and frequent human activity for various purposes.

Biological Material

The biological material for the study comprised plant species tested through the germination of diaspores contained in dust collected from selected sites.

Collection of Rainwater and Dust Samples

Sampling was carried out over 12 months in 2022, considering the different seasons. Rainwater samples were collected during the rainy season, specifically during the first three rains that signaled the end of the dry season. Plastic jars (500 ml) were placed 5 m above ground on metal stands at each sampling site. A total of six rainwater samples were collected per site.

Dust samples were collected from the roofs of pre-selected houses. After collection, the vials were labeled and stored in coolers protected from light at 4°C, in accordance with AFNOR standard NF 25667 (ISO 5667) guidelines, which specify sampling methods, reagents, transportation precautions, and more (AFNOR, 2004). Dust samples were then stored at room temperature prior to analysis.

Germination of Diaspores and Systematic Identification of Seedlings

The biological pollution of atmospheric air was assessed by measuring organic matter in dust samples and by germinating the diaspores present in the dust. Anemochory was verified by seeding dust samples in petri dishes to identify the types of diaspores carried by the wind. Dust samples from each site were placed in plastic jars and watered twice daily with a pipette until seedlings germinated (Mondo et al., 2020).

The experiment was performed in triplicate for each sample, accounting for seasonal variations. Germinated seedlings were transplanted to the experimental garden of the Life Sciences Department, Faculty of Science and Technology, to ensure growth before systematic identification. Plant species were identified following the botanical classification system outlined in APG III (1988). Additional samples of plant species were collected from house walls and roofs at the study sites for systematic identification at the INERA Herbarium in the Life Sciences Department, University of Kinshasa.

Analysis of Rainwater and Dust Samples

Toxicological Analyses

Trace metals (lead, aluminium, cadmium, and mercury), organic matter, carbon dioxide, and nitrogen were analyzed at the Laboratory of Soil Physics and Hydrology, General Commission for Energy/Regional Center for Nuclear Studies of Kinshasa (CGEA/CREN-K), using an ED-XRF Xepos III X-ray fluorescence spectrometer.

Preparation of Rainwater Samples

For heavy metal analysis, 1 ml of rainwater was placed in a 100 ml beaker with 30 ml of 10% HCl. The mixture was covered with a watch glass and gently heated for 30 minutes to achieve a homogeneous solution, which was then stored in a 100 ml volumetric flask prior to analysis (Mondo et al., 2020).

Dust Mineralisation

One gram of dust from each sample was placed in a 100 ml beaker with 30 ml of 10% HCl, covered with a watch glass, and gently heated for 30 minutes until a solution was obtained. Precipitates were separated for further analysis (Mondo et al., 2020).

Determination of Heavy Metals, Carbon Dioxide, and Nitrogen Dioxide

Pollutant concentrations in rainwater and dust samples were determined using molecular absorption spectrophotometry. This technique measures the concentration of a substance based on its absorption of characteristic radiation (Mondo et al., 2020).

Organic Matter Concentration

The organic matter content, indicative of biological pollution and anemochory, was measured by incineration at 550°C in a muffle furnace. The content was determined using the Dégrémont method with a DR2400 HACH spectrometer (HACH Method).

Hierarchical Ascending Classification (CAH)

Hierarchical Ascending Classification (CAH) was applied to analyze the similarity of sampling sites based on pollutant levels in water and dust samples. This method groups individuals based on similarity or affinity, constructing hierarchical classes through successive object agglomerations (Kouamélan, 1999; Mondo et al., 2020). CAH provided insights into variations in air quality across the study sites.

Data Analysis and Statistical Processing

Data were encoded in Excel 2013 and presented as tables and graphs. The Hartley test (1959) was used to assess variance homogeneity, as described by Dagnelie (1975). Variations between mean values of physico-chemical and toxicological parameters were analyzed using one-factor ANOVA (Scherrer, 1984) with Fisher's LSD test at a 95% confidence interval (Saville, 1990). Statistix software (version 10.8) was used for analysis, Origin 6.1 for graphing, and Past for similarity dendrogram classification. Study site maps were generated using ArcGIS 10.8, based on recorded geographical coordinates.

RESULTS AND DICUSSION

Variation in Parameters Measured in Dust Samples During the 2022 Rainy and Dry Seasons

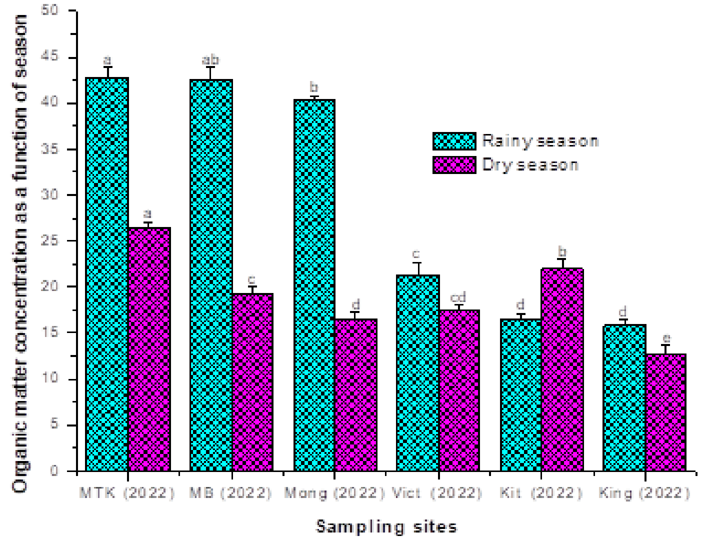
The variation in the parameters analyzed in dust samples collected at selected sites in the city of Kinshasa during the rainy and dry seasons of 2022 is presented below:

Organic Matter

The concentration of organic matter measured in dust samples varied across collection sites and between seasons, with higher concentrations observed in samples collected during the rainy season **(Figure 2)**. Analysis of variance (ANOVA) applied to the rainy-season data revealed a highly significant difference (F=289; p=0.0000) between means. The least significant difference (LSD) test critical value (2.4175) indicated that the highest concentrations were found at the Matadi Kibala (42.82 ± 0.98%), Mbankana (42.5 ± 1.35%), and Mongata (40.38 ± 0.44%) sites, while lower mean values were recorded at Kintambo Magasin (16.43 ± 0.72%) and Kingasani (15.82 ± 0.65%) sites.

During the dry season, ANOVA revealed a highly significant difference (F=58.2; p=0.0000) between mean organic matter concentrations. The LSD critical value (1.9056) indicated that samples from Matadi Kibala (26.36 ± 0.71%), followed by Kintambo Magasin (21.98 ± 1.04%) and Mbankana (19.28 ± 0.7%), had the highest organic matter content compared to other sites. These results far exceed those reported by Mondo et al. (2020), who analyzed dust samples collected at various crossroads in Kinshasa between October 2019 and July 2020. In their study, organic matter was present in all dust samples, with the highest concentration recorded at Rond-point Victoire (2.11%) and the lowest at Avenue Nguma in the Ngaliema commune (0.38%; Mondo et al., 2020). The high organic matter levels observed in the present study highlight the deteriorating state of atmospheric air quality in Kinshasa.

Figure 2:
Variation in organic matter concentration (%) in dust samples collected during the rainy season



Legend: MTK (2022) = Matadi Kibala (2022); MB (2022) = Mbankana (2022); Mong (2022) = Mongata (2022); Vict (2022) = Victoire (2022); Kit (2022) = Kintambo Magasin (2022); King (2022) = Kintambo Magasin (2022).

Mercury

In general, dust samples collected during the rainy season had higher average mercury levels than those collected during the dry season **(Figure 3)**. ANOVA applied to the mercury concentration data revealed no significant difference (F=0.02; p=0.9998) between the mean values, although the LSD critical value (12.794) indicated that samples from Kintambo Magasin (10.33 ± 0.00 mg/kg) had higher mean concentrations than those from other sites.

Similarly, analysis of the dry-season data revealed no significant difference (F=58.2; p=0.0000) between the means. The LSD test critical value (1.9056) showed that samples from Mongata (2.33 ± 0.00 mg/kg) exhibited higher concentrations compared to other sites.

Figure 3:
Variation in mercury concentration (mg/kg) in dust samples collected during the rainy season

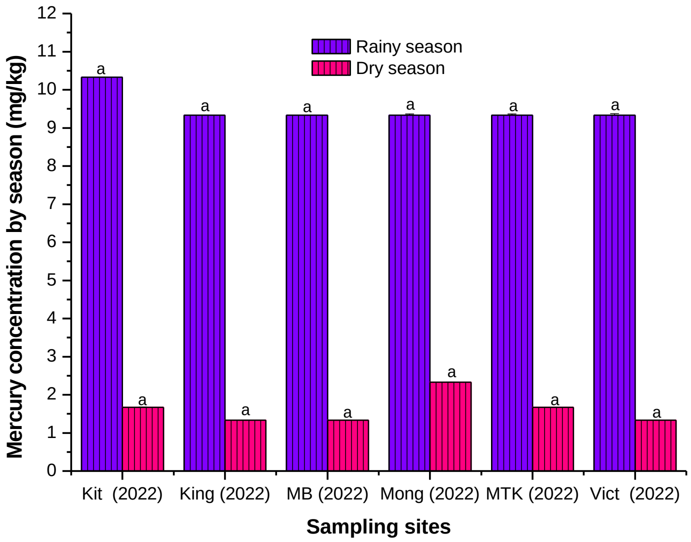
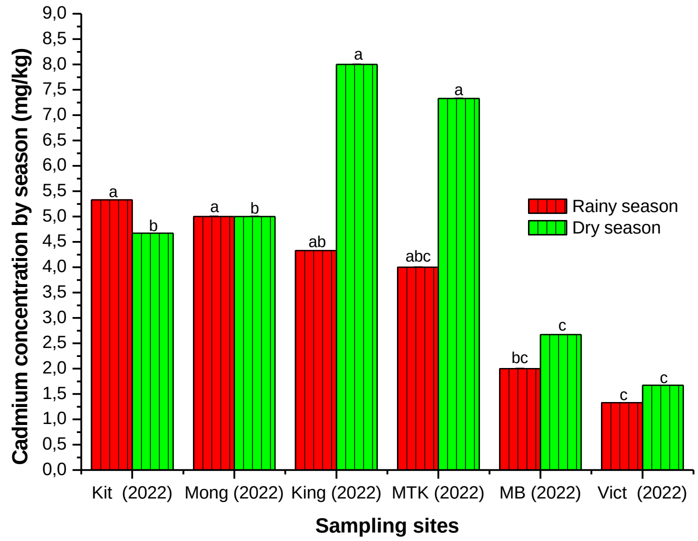


Figure 4:
Variation in Cadmium Concentration (mg/kg) in Dust Samples Collected During the Rainy Season



Cadmium

Dust samples collected during the dry season showed higher cadmium concentrations than those collected during the rainy season, with significant site-to-site variation **(Figure 4)**. ANOVA applied to rainy-season data showed no significant differences (F=2.82; p=0.0653), though the LSD critical value (2.994) indicated higher mean cadmium concentrations at Kingasani (8.00 ± 0.00 mg/kg) and Matadi Kibala (7.33 ± 0.00 mg/kg).

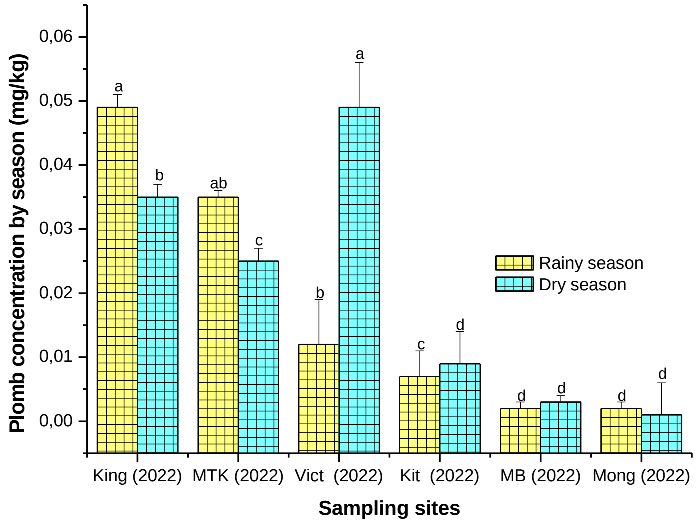
In contrast, analysis of dry-season data revealed a highly significant difference (F=25.8; p=0.0000) in cadmium concentrations between sites. The LSD critical value (1.511) indicated the highest concentrations in samples from Kingasani (5.33 ± 0.00 mg/kg), followed by Matadi Kibala (5.00 ± 0.00 mg/kg). According to Charpina et al. (2016), cadmium emissions primarily result from waste treatment processes, metal metallurgy, and, to a lesser extent, the combustion of coal, heavy fuel oil, and biomass. In Kinshasa, the inefficiency of household and industrial waste management, along with the prevalence of improvised waste dumps, exacerbates this issue. Open-air burning of waste at certain crossroads, without adequate safety measures, likely contributes to increased cadmium levels in the atmospheric air, as observed in this study.

Lead

Generally, the highest lead levels were observed in dust samples collected during the rainy season, with notable variation between sites **(Figure 5)**. A one-factor analysis of variance applied to the mean concentrations obtained during the dry season revealed a highly significant difference (F = 3.64; p = 0.0309) between concentrations at the different sites. The LSD test, with a critical value of 5.204, indicated that the sites of Kingasani (0.04 ± 0.00 mg/kg), Matadi Kibala (0.03 ± 0.00 mg/kg), and Victoire (0.012 ± 0.00 mg/kg) exhibited the highest concentrations.

Analysis of variance applied to the mean data for lead content in dust samples during the rainy season also showed a significant difference (F = 3.05; p = 0.0426). The LSD test, with a critical value of 6.949, revealed that the Victoire site (0.04 ± 0.00 mg/kg), followed by Kingasani (0.03 ± 0.00 mg/kg) and Matadi Kibala (0.02 ± 0.00 mg/kg), exhibited the highest concentrations. Historically, lead (Pb)—banned in gasoline since January 2000—remains present in the combustion of fossil fuels such as coal, fuel oils, and aviation fuels, as well as in the incineration of waste (Charpina et al., 2016). Additionally, lead persists in small quantities in brake pads, tires, and vehicle batteries. These findings confirm that the presence of lead in the atmospheric air of Kinshasa is linked to fossil fuel use.

Figure 5:
Variation in Lead Concentration (mg/kg) in Dust Samples Collected During the Rainy Season



Aluminum

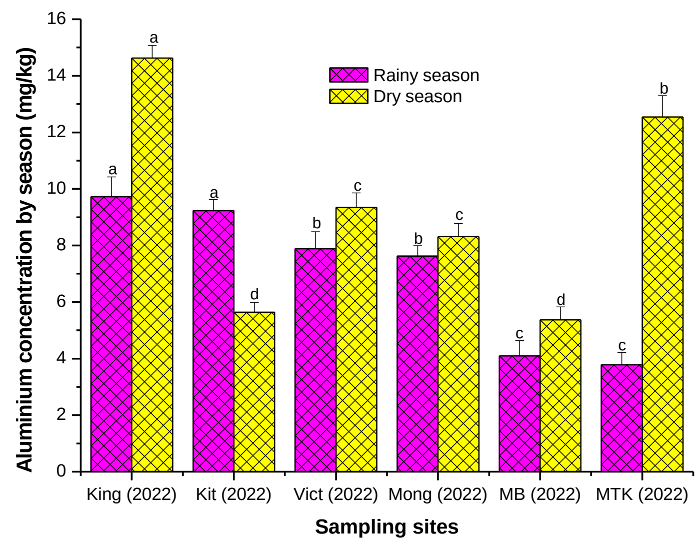
The concentrations of aluminum in dust samples varied depending on the season and the sampling site **(Figure 6)**, with higher concentrations observed during the dry season. A one-factor analysis of variance applied to the data evaluated during the rainy season revealed a highly significant difference ($F = 37.9$; $p = 0.0000$) between the average concentrations of the different sites. The LSD test (1.2722) showed that the Kingasani site, with 9.72 ± 0.7 mg/kg, had the highest average concentration, followed by Kintambo Magasin (9.22 ± 0.39 mg/kg). The lowest aluminum content was observed at the Matadi Kibala site (3.78 ± 0.42 mg/kg).

During the dry season, analysis of variance showed highly significant differences ($F = 89.2$; $p = 0.0000$; LSD = 1.2092) between the mean concentrations, with the highest levels observed at the Kingasani site (14.63 ± 0.44 mg/kg), followed by Matadi Kibala (12.54 ± 0.76 mg/kg). The lowest concentration was found at the Mbankana site (5.36 ± 0.46 mg/kg).

The results of the present study align with those reported by Mondo et al. (2020). Their study noted that dust collected at Rond-Point Victoire sites (Pb: 204.43 ± 4.49 ppb; Cd: 69.2 ± 2.69 ppb; and Al: 35.7 ± 3.32 ppb) and Kingasani (Pb: 193.74 ± 4.57 ppb; Cd: 64.84 ± 3.63 ppb; and Al: 34.08 ± 4.6 ppb) showed higher average concentrations of heavy metals compared to downtown sites. In contrast, trace element concentrations were lower at the Bombo-Lumene Reserve, considered a control site (Mondo et al., 2020).

Sites at major intersections in Kinshasa experience significant anthropogenic pressures, including heavy vehicle traffic (Mondo et al., 2020). Kinshasa faces dramatic population growth, second only to Cairo in Africa, and is burdened with imported, aging thermal vehicles decommissioned in developed countries (Fourn & Fayomi, 2006). Similar trends are observed in other sub-Saharan capitals (Demay, 2011). According to Musibono et al. (2009), these vehicles contribute significantly to air pollution through CO2 emissions and the wear and tear of tires, brakes, and road surfaces (Bihouix & Guillebon, 2010; Camara, 2014). The WHO (2016) reported that air pollution in African cities with populations exceeding 100,000 has increased by 8% over the past five years. Mondo et al. (2020) also highlighted the loss of green spaces in Kinshasa, which has contributed to deteriorating air quality.

Figure 6:
Variation in Aluminum Concentration (mg/kg) in Dust Samples Collected During the Rainy Season



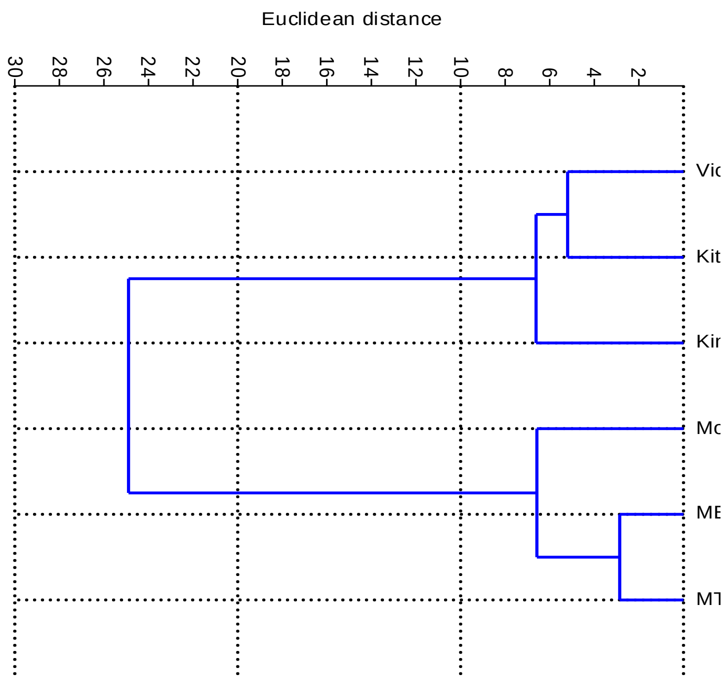
Similarity of Sampling Sites Based on the Concentrations of Parameters Measured in Dust

During the Rainy Season of 2022

The hierarchical ascending classification dendrogram, established based on the average concentrations of various elements measured in dust samples collected during the rainy season of 2022, highlights two significantly distinct main ecological entities ($R^2 = 0.9732$) along with subgroups

(Figure 7). The first entity consists of the Victoire, Kintambo Magasin, and Kingasani sites. Within this entity, the Victoire and Kintambo Magasin sites exhibit an affinity and form the first subgroup, while the Kingasani site constitutes a separate subgroup. The second entity comprises the Mongata, Mbankana, and Matadi Kibala sites, with a stronger affinity observed between the Mbankana and Matadi Kibala sites, which form a distinct subgroup, separate from the Mongata site.

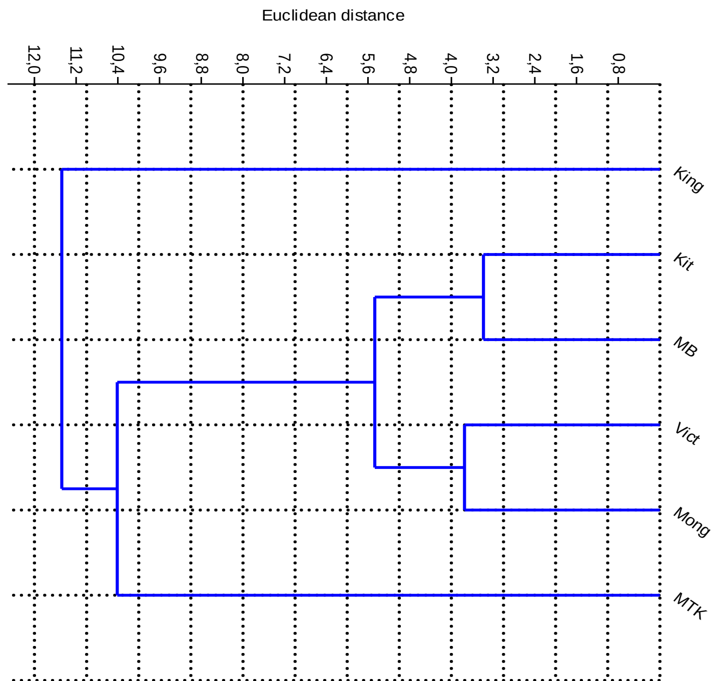
Figure 7:
Similarity diagram of sampling sites based on the concentrations of elements measured in the dust collected during the rainy season (MTK = Matadi Kibala; Mong = Mongata; MB = Mbankana; King = Kingasani; Vict = Victoire; Kit = Kintambo Magasin)



During the Dry Season of 2022

The average concentrations of the different parameters analyzed in dust samples collected during the dry season reveal the presence of two main groups subdivided into three significantly distinct subgroups ($R^2 = 0.9014$) (Figure 8). The Kingasani site forms a distinct entity separate from the Kintambo Magasin, Mbankana, Victoire, Mongata, and Matadi Kibala sites, which collectively form the second entity. This second entity is further divided into three subgroups: the Kintambo Magasin and Mbankana sites exhibit a strong affinity and form the first subgroup, the Victoire and Mongata sites constitute the second subgroup, and the Matadi Kibala site stands alone as the third subgroup.

Figure 8:
Similarity diagram of sampling sites based on the concentrations of elements measured in the dust collected during the dry season (MTK = Matadi Kibala; Mong = Mongata; MB = Mbankana; King = Kingasani; Vict = Victoire; Kit = Kintambo Magasin)



Variation of Parameters Measured in Rainwater Samples During 2022

The variation in the concentration of trace metal elements measured in water samples collected from different sites in Kinshasa reveals statistically significant differences across sites and parameters. The results presented in Figure 9 show the following:

1. **Mercury:** The highest mercury concentrations vary between sites. Analysis of variance (ANOVA) reveals a highly significant difference ($F = 11.2$, $p = 0.0003$) among sites. The critical value of LSD (0.1439) indicates that water samples from the Victoire site have the highest average mercury concentration (0.43 ± 0.03 mg/kg), followed by the Kintambo Magasin site (0.31 ± 0.01 mg/kg). The lowest concentration is observed at the Kingasani site (0.03 ± 0.03 mg/kg).
2. **Cadmium:** Cadmium concentrations also vary by site. ANOVA indicates a highly significant

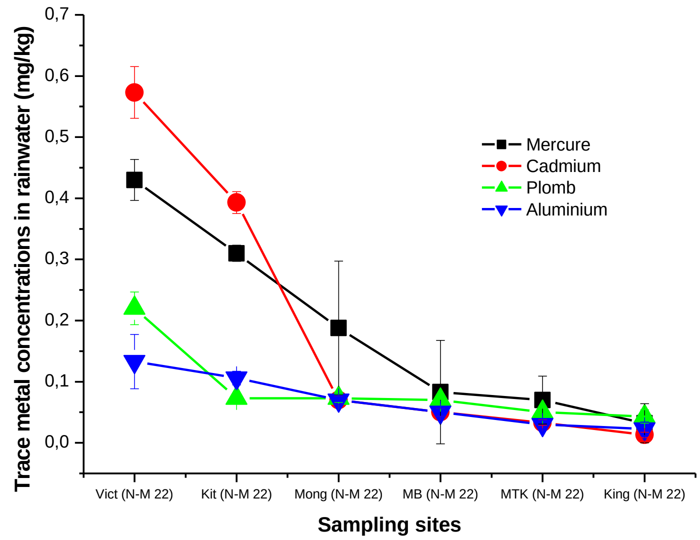
difference (F = 242, p = 0.0000). The LSD test (0.0467) shows that samples from the Victoire site (0.57 ± 0.04 mg/kg) have the highest concentrations, followed by Kintambo Magasin (0.39 ± 0.01 mg/kg) and Mongata (0.01 ± 0.00 mg/kg).

3. **Lead:** Lead concentrations differ significantly across sampling sites (F = 41.9, p = 0.0000). The LSD value (0.0314) indicates that samples from the Kingasani site (0.22 ± 0.02 mg/kg) have higher concentrations than those from other sites, including Victoire (0.04 ± 0.01 mg/kg).

4. **Aluminium:** The Matadi Kibala site exhibits the highest average aluminium concentration (0.13 ± 0.04 mg/kg), with significant differences noted (F = 8.36, p = 0.0013, LSD = 0.0465). This is followed by the Mongata (0.10 ± 0.01 mg/kg), Mbankana (0.07 ± 0.00 mg/kg), Kingasani (0.05 ± 0.00 mg/kg), Victoire, and Kintambo Magasin sites (0.02 ± 0.01 mg/kg).

These findings align with those of Mondo et al. (2020), who reported trace element contamination (aluminium, cadmium, and lead) in rainwater samples collected from major streets and intersections in Kinshasa. Their study revealed higher contamination levels at Rond-Point Victoire and Kingasani, with lead (79.40 ± 5.47 ppb and 78.93 ± 2.60 ppb), cadmium (69.2 ± 2.69 ppb and 54.61 ± 0.3 ppb), and aluminium (35.7 ± 3.32 ppb and 44.48 ± 2.5 ppb). Conversely, samples from the Bombo-Lumene hunting reserve on Kinshasa's outskirts exhibited lower average concentrations of lead (0.51 ± 0.01 ppb), cadmium (0.42 ± 0.01 ppb), and aluminium (0.35 ± 0.02 ppb). These observations corroborate the present study's findings, which indicate higher trace metal contamination levels in downtown Kinshasa compared to the outskirts.

Figure 9:
Variation in mercury concentration (mg/kg) in water samples collected from different study sites



Legend: MTK (N-M 22) = Matadi Kibala (November – March 2022); MB (N-M 22) = Mbankana (November – March 2022), Mong (N-M 22) = Mongata (November – March 2022); Vict (N-M 22) = Victoire (November – March 2022); Kit (N-M 22) = Kintambo Magasin (November – March 2022) and King (N-M 22) = Kingasani. (Novembre – Mars 2022)

The hierarchical clustering analysis of dust samples during the rainy and dry seasons of 2022 from various sites in Kinshasa indicates significant seasonal variations and inter-site similarities based on measured trace element concentrations.

During the Rainy Season (2022)

A hierarchical ascending classification dendrogram was developed to categorize the sampling sites based on the average concentrations of various elements measured in the dust samples. Two main ecological entities were identified, with high correlation (R2 = 0.9732), each containing subgroups:

- **First entity**: Includes the Victoire, Kintambo Magasin, and Kingasani sites. The Victoire and Kintambo Magasin sites were closely related, forming the first subgroup, while Kingasani formed a distinct second subgroup.

- **Second entity**: Comprised of Mongata, Mbankana, and Matadi Kibala, with a stronger affinity between Mbankana and Matadi Kibala, distinguishing them from Mongata.

During the Dry Season (2022)

Similarly, during the dry season, the clustering revealed two main groups, subdivided into three distinct subgroups (R2 = 0.9014):

- **First entity**: The Kingasani site stood alone as a separate entity.
- **Second entity**: The remaining sites (Kintambo Magasin, Mbankana, Victoire, Mongata, and Matadi Kibala) formed a second entity, further divided into three subgroups:
    - **First subgroup**: Kintambo Magasin and Mbankana exhibited a strong affinity.
    - **Second subgroup**: Victoire and Mongata.
    - **Third subgroup**: Matadi Kibala was isolated in its own subgroup.

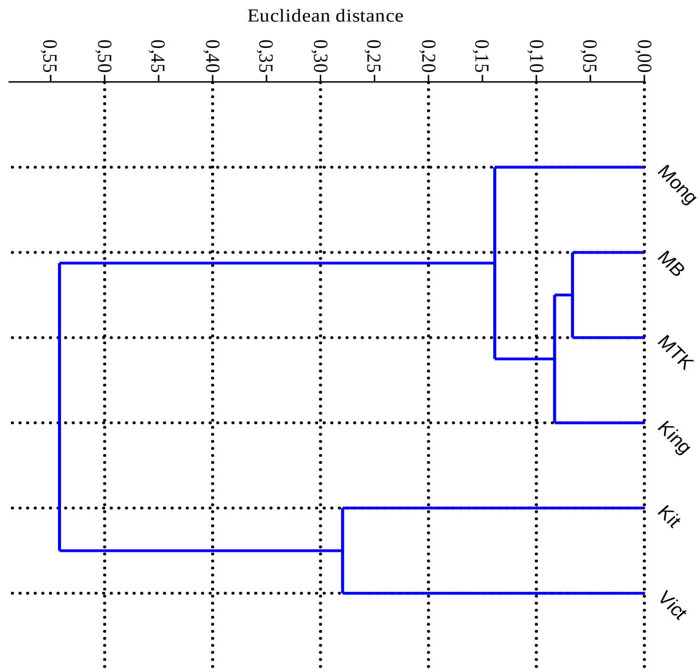
Trace Metal Concentrations in Rainwater (2022)

The analysis of trace metal concentrations in rainwater samples from various sites revealed significant fluctuations and differences in concentration levels, highlighting potential contamination sources:

- **Mercury**: The highest concentrations were observed at Victoire (0.43 mg/kg), followed by Kintambo Magasin (0.31 mg/kg). Kingasani had the lowest concentration (0.03 mg/kg), with statistically significant differences between the sites (F = 11.2; p = 0.0003).
- **Cadmium**: The Victoire site exhibited the highest concentration (0.57 mg/kg), with Kintambo Magasin (0.39 mg/kg) and Mongata (0.01 mg/kg) following. A highly significant difference was found between the sites (F = 242; p = 0.0000).
- **Lead**: Kingasani had the highest concentration (0.22 mg/kg), significantly higher than the other sites, including Victoire (0.04 mg/kg) (F = 41.9; p = 0.0000).
- **Aluminum**: Matadi Kibala showed the highest concentration (0.13 mg/kg), with significant differences across sites (F = 8.36; p = 0.0013). Victoire and Kintambo Magasin had the lowest levels.

The results corroborate those from Mondo et al. (2020), who observed similar trends in contamination by heavy metals such as lead, cadmium, and aluminum in rainwater samples from Kinshasa. Their findings suggest higher contamination in central Kinshasa compared to more peripheral areas, aligning with the present study's conclusion that sites located in the downtown areas of Kinshasa show higher levels of trace metal contamination.

Figure 10:
Dendrogram of similarity of sampling sites based on water quality (MTK = Matadi Kibala; Mong = Mongata; MB = Mbankana; King = Kingasani; Vict = Victoire; and Kit = Kintambo Magasin)



Diaspore Content in Roof Dust from Kinshasa

The list of the different plant species that germinated from the diaspores during the experimentation of the dust samples collected during the rainy season and the dry season of the year 2022 is presented in **Table 1**.

Table 1:
Plant species that germinated in petri dishes from the diaspores present in dust samples (+ = presence ; - = absence ; Kin_Mag = Kintambo Magasin and Mat_Kib = Matadi Kibala)

Botanical families	Germinated plant species	Sampling sites					
		Mongata	Mbankana	Kingasani	Victoire	Kin_Mag	Mat_Kib
Asteraceae	*Chromolaena odorata* (L.) King & Robinson	+	+	+	+	+	+
	Emilia coccinea (Sims) G. Don	+	+	-	+	-	-
	Ajeratum sp	-	+	+	+	-	+
	Conyza sumatrensis (Retz) E. Walker	+	-	+	+	-	+
Capparaceae	*Cleome rutidosperma* DC	+	+	+	-	+	-
Commelinaceae	*Commelina diffusa* Burn	-	-	+	-	-	-
Cyperaceae	*Cyperus distans* L.f	+	+	-	-	+	+
Euphorbiaceae	*Croton hirtus* l'Hérit.	+	+	+	+	-	+
	Chaetocarpus africanus Pax	+	-	+	-	-	+
	Euphorbia heterophylla Pax	+	+	+	-	-	-
Fabaceae	*Acacia auriculiformis*A. Cum. Ex Benth.	-	+	-	-	-	+
Malvaceae	*Urena lobata* L.	+	+	+	-	-	+
Piperaceae	*Peperomia pellucida* (L.) Kunth	+	+	+	-	-	-
Phyllanthaceae	*Phyllantus amarus*	+	+	+	-	-	-
	Phyllantus niruri L.	+	+	+	-	+	+
Polytrichaceae	*Polytrichum commune* Hedw	+	+	+	-	-	-
Poaceae	*Megatyrsus maximus* (Jacq.) B.K Simon & S.W.L Jacobs	+	+	+	+	+	+
	Hyparrhenia diplandra (Hack.) Stapf	+	+	-	-	+	+
	Eleusine indica (L.) Gaertn	+	+	+	+	-	-
	Digitaria polybotrya Stapf	+	+	+	-	-	+
	Anthephora cristata (Doll.) Hack. Ex De Wild & Durand	+	-	+	-	+	-
Polypodiaceae	*Platycerium elephantotis* Schweinf	+	+	-	-	-	+
	Drynaria laurentii (Christ.) Hieron	-	+	+	-	+	+
Portulacaceae	*Portulaca oleraceae*	-	+	+	+	_	-
Rubiaceae	*Oldenlandia corymbosa* L.	+	+	-	+	+	-
Talinaceae	*Talinum triangulare* (Jacq.) Wild	-	+	+	+	-	+
Uriticaceae	*Laportea aestuans* (L) Chew	+	+	+	+	+	-
16	**27**	**21+**	**23+**	**21+**	**11+**	**11+**	**18+**

The dust collected from the roofs of houses across various sampling sites in Kinshasa contains diaspores from twenty-seven (27) plant species belonging to sixteen (16) botanical families **(Figure 11)**. This finding is consistent with the work of Mondo et al. (2020), who identified twenty plant species from fourteen botanical families in roof dust collected at various intersections in Kinshasa, including Victoire Roundabout, Kingasani, and Kintambo.

Diaspore dispersal, which refers to the movement or transport of plant seeds away from the parent plant, is vital for plant ecology. It enables seeds to find areas conducive to germination, fostering population stability through genetic diversity and promoting the dynamics of plant communities (Willson et al., 2000). This process is key to the survival and expansion of plant species, especially in urban environments like Kinshasa, where plant life is subject to high levels of human activity.

Figure 11:
Illustration of some species of plants germinated from the dust collected across the sampling sites (**Source** : Mondo & Lusasi, 2022)

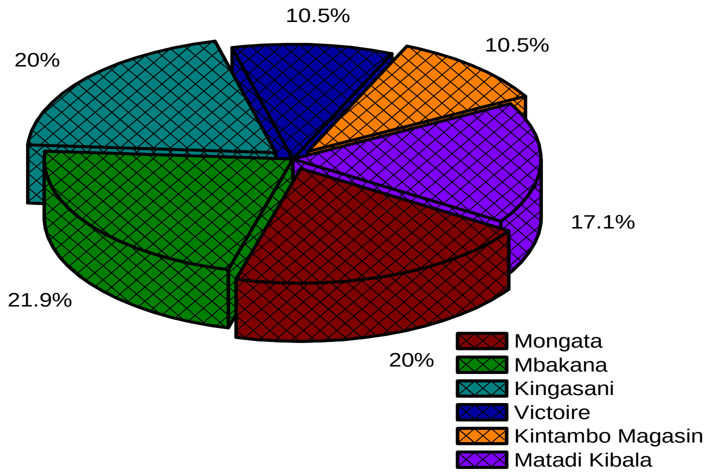
Grasses are the most common plant species found in dust circulating in Kinshasa, as noted by Musibono et al. (2009) and observed in this study. The prevalence of grass species is largely due to the anemochory mechanism, or wind dispersal, which is common among herbaceous plants. The small size and lightweight nature of the seeds enable their transport over long distances.

Additionally, birds play a significant role in the dispersal of plant seeds through zoochory (Barnea et al., 1992). For example, passerine birds feed on the seeds of *Panicum maximum* and help disperse them across various locations. The presence of diaspores in the dust samples collected from the surveyed sites in Kinshasa indicates biological contamination of the city's atmospheric air, which could pose potential health risks, including respiratory conditions.

Plant Species Distribution in Dust Samples

Among the surveyed sites, Mbankana's dust is the most heavily loaded with diaspores, containing 23 plant species, which accounts for 21.9% of the total. The Mongata and Kingasani sites follow closely, each with 21 species (20%), while the Matadi Kibala site contains 18 species (17.1%). The Victoire and Kintambo Magasin sites have the least, each with 11 species (10.5%) (**Figure 12**).

Figure 12:
Relative abundance of plant species based on collection sites



The higher abundance of diaspores in the dust from Kingasani and Matadi Kibala can be attributed to intense human activity in these areas, particularly the presence of warehouses and processing units for agricultural products. These locations are major commercial crossroads in Kinshasa, and the handling of agricultural products leads to the movement of plant diaspores, which are ultimately discarded after sorting. Conversely, the abundance of diaspores in the dust from Mongata and Mbankana is linked to the presence of wild vegetation surrounding these sites. Here, both anemochory and zoochory contribute to the dispersion of seeds, which are transported by wind and animals.

The inhalation of these plant diaspores, which circulate in the air, presents a public health risk in Kinshasa, especially during the dry season when respiratory illnesses like lung diseases and influenza tend to increase.

Seasonal Variation in Diaspore Contamination

The frequency with which plant species diaspores germinated in dust samples, collected across the various sampling sites during different seasons (rainy and dry), is summarized in **Table 2**. The data reflect seasonal variations in dust contamination and highlight the impact of seasonal conditions on the dispersal of plant diaspores in the urban environment.

Table 2:
Frequency of Observation of Germinated Plant Species in Dust by Season

Germinated plant species	Sampling sites											
	Mongata		Mbankana		Kintambo		Victoire		Kintambo		Matadi_Ki	
	SS	SP	SS	SP	SS	SP	SS	SP	SS	SP	SS	SP
Chromolaena odorata (L.) King & Robinson	+	+	+	+	+	+	+	+	+	+	+	+
Emilia coccinea (Sims) G. Don	+	+	+	+	-	-	-	+	-	-	-	-
Ajeratum sp	-	-	+	-	+	-	+	-	-	-	+	-
Conyza sumatrensis (Retz) E. Walker	-	+	-	-	+	+	+	-	-	-	-	+
Cleome rutidosperma DC	+	-	+	+	+	+	-	-	-	+	-	-
Commelina diffusa Burn	-	-	-	+	+	+	-	-	-	-	-	-
Cyperus distans L.f	+	+	+	+	-	-	-	-	+	-	+	-
Croton hirtus l'Hérit.	+	+	+	-	+	+	-	+	-	-	+	+
Chaetocarpus africanus Pax	+	+	-	-	-	+	-	-	-	-	+	-
Euphorbia heterophylla Pax	+	-	+	+	+	+	-	-	-	-	-	-
*Acacia auriculiformis*A. Cum. Ex Benth.	-	-	+	+	-	-	-	-	-	-	+	+
Urena lobata L.	+	+	+	-	-	+	-	-	-	-	+	+
Peperomia pellucida (L.) Kunth	+	+	+	-	+	-	-	-	-	-	-	-
Phyllantus amarus	+	+	-	+	+	+	-	-	-	-	-	-
Phyllantus niruri L.	+	-	+	+	+	+	-	-	+	-	+	-
Polytrichum commune Hedw	-	+	+	-	+	-	-	-	-	-	-	-
Megatyrsus maximus (Jacq.) B.K Simon & S.W.L Jacobs	-	+	+	+	-	+	+	-	+	-	+	-
Hyparrhenia diplandra (Hack.) Stapf	+	+	+	-	-	-	-	-	+	-	+	+
Eleusine indica (L.) Gaertn	+	-	+	-	+	+	+	-	-	-	-	-
Digitaria polybotrya Stapf	+	+	+	+	+	+	-	-	-	-	+	-
Anthephora cristata (Doll.) Hack. Ex De Wild & Durand	+	-	-	-	+	+	-	-	+	-	-	-
Platycerium elephantotis Schweinf	+	-	-	+	-	-	-	-	-	-	+	+
Drynaria laurentii (Christ.) Hieron	-	-	+	-	+	-	-	-	+	+	+	-
Portulaca oleraceae	-	-	+	-	+	+	+	+	-	-	-	-
Oldenlandia corymbosa L.	+	+	+	-	-	-	+	-	-	+	-	-
Talinum triangulare (Jacq.) Wild	-	-	+	-	+	+	+	+	-	-	+	+
Laportea aestuans (L) Chew	+	+	+	-	+	+	+	+	+	+	-	-
27	**18+**	**15+**	**21+**	**+12**	**19+**	**17+**	**9+**	**+6**	**8+**	**+5**	**14+**	**+8**
Percentage (%)	**54.54**	**45.45**	**63.63**	**36.36**	**52.77**	**47.22**	**60**	**40**	**61.53**	**38.46**	**63.63**	**36.36**

The data in Table 2 illustrate that the biological contamination of dust by plant species diaspores at the sampling sites varies with the season, with a significantly higher proportion of contamination observed during the dry season compared to the rainy season. This increase during the dry season can be attributed to the favorable climatic conditions that promote the dispersal and survival of certain plant species. In contrast, the higher frequency of identified plant species during the rainy season is linked to the optimal climatic factors—particularly rainfall, relative humidity, and temperature—that foster the growth and maintenance of plants during this period.

CONCLUSION AND PERSPECTIVES

This study aimed to evaluate the atmospheric air quality in Kinshasa, Democratic Republic of the Congo, by analyzing both chemical and biological pollution in dust collected from several major intersections throughout the city. The samples were gathered over the course of 2022 at various sites, including Kintambo Magasin, Victoire Roundabout, Kingasani, Matadi Kibala, Mbankana, and Mongata.

The findings revealed that the dust and rainwater collected from rooftops in these areas were contaminated with trace metal elements and plant diaspores, indicating both chemical and biological pollution. It was observed that air quality in high-traffic, densely populated downtown areas was poorer than in Mongata and Mbankana, which are situated outside the city center. The inhalation of dust particles and consumption of rainwater, particularly during the dry season, poses significant health risks, exposing residents to a variety of diseases.

Given the findings, it is crucial for the political and administrative authorities in the country to implement systems for monitoring air quality, such as fixed stations or mobile units, to provide forecasts and warnings to the public. Further research is needed to quantify additional pollutants in the atmospheric air that were not covered in this study.

Contributions of the Authors

- **MONDO, M. T.**: Conceptualized the study, conducted data sampling, and wrote the manuscript.
- **LUSASI, S. W.**: Contributed to data sampling, statistical analysis, and manuscript writing.
- **NSIMANDA, I. C.**: Provided guidance and revised the manuscript.
- **MULAJI, K. C.**: Provided guidance and revised the manuscript.
- **PWEMA, K. V.**: Designed the research, provided guidelines, and assisted in manuscript writing.
- **MUSIBONO, E. A. D.**: Contributed to the conception and orientation of the research.

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Ethical Approval: The data collection for this study was authorized by the University and the political and administrative authorities of the various surveyed entities.

Conflicts of Interest: None declared.

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