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Adverse Health Effects of Level Heavy Metal Exposure in Ambient Air in Burkina Faso, West Africa

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Abstract

Background: Atmospheric heavy metal is a worldwide issue, involving factors like atmospheric emissions, anthropogenic activities, air quality, human health and climate change, but it also leads to a long-term burden on biogeochemical cycling in the ecosystem. This pilot study aimed to evaluate the adverse health effects of level heavy metal exposure in ambient air in Burkina Faso, West Africa. **Methods:** A cross-sectional study was conducted from 4 June to 9 August 2024 at two major towns in Burkina Faso (Ouagadougou and Bobo-Dioulasso). Chemical analyses of As, Pb, Cd, Ni, Cr, Hg and Cu in Particulate Matter (TSP, PM_{10} and $PM_{2.5}$) and dust samples were performed by Perkin Elmer Optima 8000 DV, Inductively Coupled Plasma-Optical Emission Spectrophotometry (ICP-OES) and quantified. **Results:** Survey data shows the proportion of the incidence of risk factors and medical history. Heavy metals result in concentrations over a weekday showed concentrations < 0.003 $\mu g \cdot m^{-3}$ in As, Cd and Cu respectively at all the sites in Ouagadougou and Bobo-Dioulasso. Concentration in city centres (Pb = 0.010, Ni = 0.010, Cr = 0.014 and Hg = 0.013 $\mu g \cdot m^{-3}$ in Ouagadougou vs. Pb = 0.010, Ni = 0.009, Cr = 0.010 and Hg = 0.008 $\mu g \cdot m^{-3}$ in Bobo-Dioulasso). Pb = 0.018 $\mu g \cdot m^{-3}$, Ni = 0.016 $\mu g \cdot m^{-3}$, Cr = 0.012 $\mu g \cdot m^{-3}$

and Hg = 0.011 μg·m^{-3} were recorded in the Ouagadougou industrial area. **Conclusion:** The atmospheric air is full of detectable concentrations of the heavy metals common to Burkina Faso's city centres, as well as in the industrial area. As, Cd, Cu, Pb, Ni and Hg are the ones most strongly affected by anthropogenic inputs such as airborne pollutants.

Keywords

Air Pollution, Health Effects, Heavy Metals, Particulate Matter, Concentrations

1. Introduction

Heavy metals are familiar environmental pollutants because of their toxicity, their longevity in the atmosphere and their persistence to accumulate in the human body through bioaccumulation. Heavy metals are found in the biosphere, including rocks, soil, and water. They originate from a variety of sources, such as mining, industrial effluents, urban runoff, sewage discharge, soil erosion, natural weathering of the Earth's crust, pesticides, disease control agents used on crops, metal pipes for water, traffic, combustion by-products from coal-burning plants and many others [1]. Heavy metals can be highly toxic when they mix with other environmental elements, such as water, soil and air. Humans and other organisms can be exposed to them along the food chain [2] as a result of the rapid expansion of agriculture and the metallurgical industry and inadequate waste disposal [3].

The term "heavy metal" refers to a metallic element that has a relatively high density (>4 g/cm^3 or 5 times greater than water) and is dangerous or poisonous even at low concentrations [4]. The atmosphere is one of the major pathways of heavy metal dispersion in the environment. The seasonal variation of the atmospheric heavy metals changes significantly [5]. However, some studies indicated that most heavy metals were enriched in fine particles [6] [7]. Heavy Metals (HMs: such as lead (Pb), chromium (Cr), cadmium (Cd), cobalt (Co), manganese (Mn), vanadium (V), nickel (Ni) and arsenic (As)) are toxic components in Particulate Matter less than 2.5 microns in diameter ($PM_{2.5}$) and are associated with many adverse health outcomes [8] [9]. However, the concentration of metals was dominated by the $PM_{2.5}$ fraction [10]. Based on their origin, major and trace inorganic elements composing particulate matter can often be distinguished in anthropogenic (e.g. V, Cr, Mn, Ni, Copper (Cu), Zinc (Zn), Cd, Pb) emissions. In the case of anthropogenic emissions, fossil fuel combustion is believed to be one of the main sources of Particulate Matter (PM) [11]. Human activities, including mining, manufacturing, urban runoff, and atmospheric deposition, have led to significantly elevated heavy metal concentrations in other areas [12] [13]. In a recent study, Yusuf and Inambao [14] found that transport activities are the major sources that emit heavy pollutants found in the environment. Heavy metals from vehicular emissions can be significant threats to humans and the environment because they have adverse effects on ecosystems, inducing contamination of air, water, and soil [15]. Numerous and consistent studies show that particulate matter and heavy metals are responsible for the occurrence of a wide range of biological and health effects and contribute to the degradation of air and human health [16]. Heavy metals can also induce toxicity in some organs of the human body, such as nephrotoxicity, neurotoxicity, hepatotoxicity, skin toxicity and cardiovascular toxicity [2], inducing toxicity to the kidneys, brain, liver, skin, and heart [1]. Strumylaite *et al.* [17] have shown the oestrogenicity of cadmium and its ability to activate Estrogen Receptor (ER) pathways. Cadmium induces proliferation of estradiol (E2) dependent breast cancer cells and increases transcription of the Pathogenesis-related Protein (PR) gene [17]. Other Heavy Metals, such as arsenic [18], mercury [19] and cadmium [20], were observed concerning high exposure and prostate cancer risk. The most tumourigenic endocrine-disrupting chemical groups were heavy metals (54%), particulate matter (47%), and pesticides (46%) [21]. Metals are considered as endocrine disruptors because of their capacity to bind to hormone receptors. Endocrine-disrupting chemicals are associated with sex-steroid receptors, namely the two estrogen receptors (ERα and ERβ) and the Androgen Receptor (AR) [22]. It has been associated with epigenetic mechanisms induced by environmental factors that lead to oxidative stress and potentially to pathogenesis and disease progression in humans. Furthermore, growing evidence reveals that environmental exposure to heavy metals involves alterations in DNA methylation by inducing oxidative stress [23]. In Burkina Faso, these concentrations are lower than the 24-hour total suspended particles recommended limit of 200 - 300 $\mu g \cdot m^{-3}$ by Burkina Faso authorities [24]. It will be noticed that there are no recommended limits, especially for $PM_{2.5}$, PM_{10} and others in Burkina Faso. The different intra-urban trends in PM concentrations between day and night can be explained by the difference between the sources of PM. Indeed, there is probably a greater influence of traffic dust suspension on paved and unpaved roads, and the exhaust emissions in the morning that adds to the effect of using biomass as a source of energy as we move forward in the day [25].

PM_{10} induced dose-dependent cytotoxicity to a greater or lesser extent by sampling district. Oxidative stress is a key source of toxic substances found in the endothelial cells of human pulmonary arteries that can trigger a proinflammatory response. PM_{10}, unlike larger particles that are filtered by the nasal and bronchial cilia, directly penetrates the upper respiratory tract and alveoli, causing inflammation and irritating the bronchi, thus affecting lung function, and exacerbating symptoms of respiratory diseases and other pathologies according to the intensity or duration of the inflammation [26]. At harmful levels in Ouagadougou, $PM_{2.5}$ caused primarily outpatient hospital visits rather than hospitalisations for respiratory diseases. The hospital frequency of respiratory diseases was 14.16% (2012) over the 1-year study period. Most respiratory cases arose during the dry season (1114/2012, 55.37%). The majority (54.57%) were males, and 1506 (74.85%) were infants. Inpatients represented 62.43% (1256 cases) of all cases. Regarding the distribution of respiratory diseases, acute bronchitis was the most frequent (46.87%), followed by pneumonia (38.57%) and rhinitis (37.08%). Forty-three deaths (3.42%) were reported, and all occurred among hospitalised patients. A high concentration of $PM_{2.5}$ was associated with increased outpatient consultations among children, a finding that could help prepare for such situations [27].

However, in Sub-Saharan Africa, an insufficient data on air quality is available regarding atmospheric heavy metals concentrations and their pollution levels. None of the previous studies have provided valuable information on possible sources of atmospheric heavy metals concentration in urban environment.

The presented work focused on evaluating the adverse health effects of level heavy metal exposure in ambient air in Burkina Faso, West Africa.

2. Methodology

2.1. Study Area

Six sites (three in Ouagadougou and three in Bobo-Dioulasso) have been included in this study. Ouagadougou and Bobo-Dioulasso are respectively the political capital and the economical capital of the country. The sites were chosen randomly and animals were exposed to different atmospheres in the open air or in closed enclosures for the rest of the experiments. Site 1 in Ouagadougou was located inside a reference animal house. Site 2 was at the Institute of Research in Health Science (IRSS), and site 3 was in the Kossodo industrial zone. For the Bobo-Dioulasso sites, site 4 was located within the precincts of a reference animal house, indoor of the International Center for Research and Development on Livestock in Subhumid Zones (CIRDES); site 5 was in the town centre, more precisely at the annex of the IRSS and site 6 was in the industrial zone (**Figure 1**). Ouagadougou and Bobo-Dioulasso are the two largest cities in Burkina Faso, with a fairly large population and different centres of activity, comprising more than a dozens of industries listed. The choice of sites 1 and 4 is due to the fact that they are reference pet shops with standard breeding conditions that comply with international standards. Sites 2 and 5 were chosen because they are located in the city centre. Sites 3 and 6 are in the industrial zone. Sites 2, 3, 5 and 6 were open-air as opposed to sites 1 and 4. For the random selection of the sites, we took into account the different activities and movements between homes and workplaces, *i.e.* town centres and industrial zones. The pet shop was chosen as the reference site because it is an enclosed area that is less polluted by heavy metals than the other sites. A Geographical Positioning System (GPS), GARMIN etrex 20 model was used for recording the geographical coordinates of the sampling sites.

2.2. Sampling and Data Collection

The GRIMM EDM (Environmental Dust Monitor) 107 by XEARPRO SRL was placed on each site for 7 days, *i.e.* 168 hours. Air sampling was done for Total Suspended Particles (TSPs) and fine particles in $\mu g \cdot m^{-3}$ ($PM_{2.5}$ and PM_{10}) from 4 June to 9 August 2024 at a stand height of 1.5 metres. Heavy metals retained by dust particles were captured by a filter (0.22 µm) inside GRIMM. Results of analytical determinations were obtained through the removal, for each chemical species,

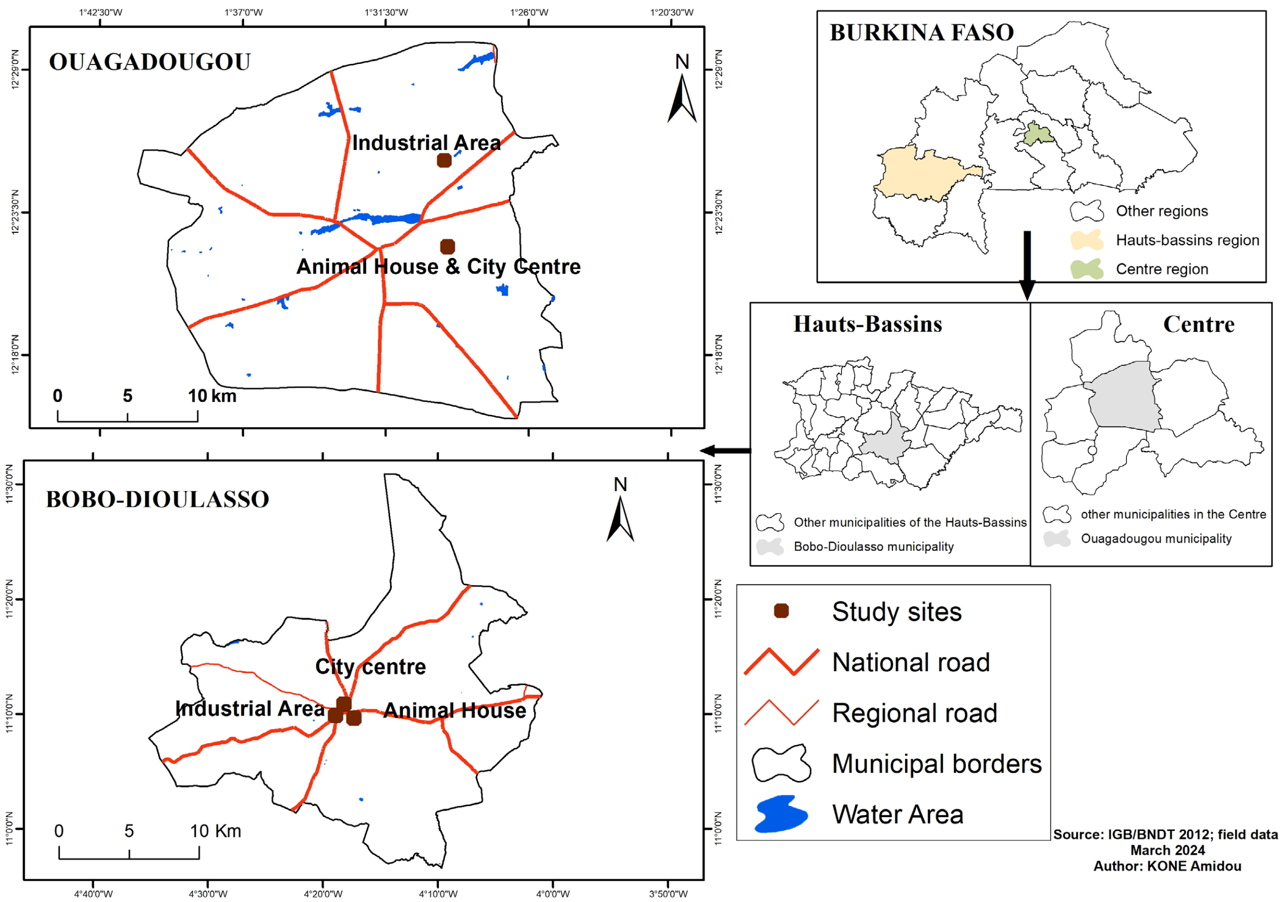

Figure 1. Geographic coordinates of the sampling sites.

of the average level present in the blank samples.

2.3. Survey

Data were collected from October to November 2024. Individual questionnaire was administrated to study participants through personal interviews. The questionnaire, which included closed and open questions, was tested, and adjusted during a pilot phase. The questionnaire included questions about the demographic information, medical history, environmental and lifestyle factors, health awareness and prevention. The interviews were conducted in French. Answers were recorded through KoboCollect, a smartphone-based questionnaire tool. Data collected was then stored on the KoboToolbox platform.

2.4. Ethical Approval

Our study was conducted in accordance with the declaration of Helsinki. Each participant agreed and gave their free verbal approval before the interview phase. Data collected from participants were kept confidential and anonymous.

2.5. Samples Analysis

After the heavy metals were retained by the passing particulate portion, digestion and quantification were carried out by the method from Zimmermann and Reisberg [28]. The filter used was a cellulose filter with a particle size of 0.22 µm, in contrast to the American standard of 0.8 µm, which allowed us to be precise in the retention of the particulate fraction used. Inorganic elements Arsenic (As), Lead (Pb), Cadmium (Cd), Nikel (Ni), Chromium (Cr), Mercury (Hg), and Copper (Cu) in PM and dust samples were quantified through the technique Perkin Elmer Optima 8000 DV, Inductively Coupled Plasma-Optical Emission Spectrophotometry (ICP-OES). The instrumental Limit of Detection (LOD) was determined following the protocol described by Perkin Elmer ICP application study number 57 [29]. Quantum Geographic Information System (QGIS) version 3.28 and ArcGIS version 10.8.0.12790 were performed for the graphics.

3. Results

3.1. Socio-Demographic Characteristics

The survey on the respiratory effects of particulate matter in the city centres of Bobo-Dioulasso and Ouagadougou showed that 86.87% of the respondents lived in the city of Bobo-Dioulasso compared to 82.70% in the city of Ouagadougou. The proportion of men surveyed in Bobo-Dioulasso (68.35%) was not significantly different from those surveyed in Ouagadougou ($p = 0.484$). Participants aged between 21 and 40 years were in the majority in both cities (**Table 1**).

Table 1. Socio-demographic characteristics.

Socio-demographic characteristics	Bobo-Dioulasso n (%)	Ouagadougou n (%)	p-value
Residence	**297**	**607**	**0.437**
City Centre	258 (86.87)	502 (82.70)	
Industrial Area	39 (13.13)	105 (17.30)	
Sex	**297 (100)**	**607 (100)**	**0.484**
Women	94 (31.65)	207 (34.10)	
Men	203 (68.35)	400 (65.90)	
Age group (years)	**297**	**607**	**0.170**
0 - 10	3 (1.01)	10 (1.65)	
11 - 20	-	74 (12.19)	
21 - 40	268 (90.23)	480 (79.08)	
41 - 60	17 (5.72)	34 (5.60)	
61 and above	9 (3.03)	9 (1.48)	
Occupation	**297**	**607**	**0.449**
Student	122 (41.08)	253 (41.68)	
Office worker	59 (19.86)	142 (23.39)	
Manual laborer	46 (15.49)	35 (5.77)	
Unemployed	26 (8.75)	60 (9.88)	
Others	44 (14.81)	117 (19.27)	

3.2. Inventory of the Various Industries in the Industrial Area at Two Major Towns

In Burkina Faso's two major cities, we have inventoried certain categories of industries in common, with a high number of mill industries, which seem to be in sufficient quantity, followed by brewing. In addition, there are more than ten industries depending on the city (Table 2).

Table 2. Inventory of the various industries in the industrial area at two major towns.

<table>
<tr><th>City</th><th>Ouagadougou</th><th>Bobo-Dioulasso</th></tr>
<tr><td>Commons Industries</td><td colspan="2">SAVOR (Oil refinery)
BRAKINA (Brewing industry)
SOBUFAB (Brewing industry)
HUNOFA (Oil refinery)
EUGENOL (Oil refinery)
Hage Matériaux (Metal industry)</td></tr>
<tr><td rowspan="12">Other industries</td><td>Pegaz and Oryx (Butane gas)</td><td>SOFITEX (Fibres and Textiles, Cotton)</td></tr>
<tr><td>Grand Moulin (Meal)</td><td>SN SITEC (Soaps)</td></tr>
<tr><td>CIMFASO (Cement)</td><td>SAP (Pneumatics)</td></tr>
<tr><td>FASO Energy (Energy Industrie)</td><td>SAPHYTO (Phytosanitary and insecticide products)</td></tr>
<tr><td>SAPEC (Painting)</td><td>Profimétaux (Building materials)</td></tr>
<tr><td>COBUFAF (Biscuit and candy)</td><td>MABUCIG (Smoking)</td></tr>
<tr><td>NANA Boureima (Metal industry)</td><td>SONACEB (Cardboard and Packaging)</td></tr>
<tr><td>WATTAM Kaizer (Motorbikes)</td><td></td></tr>
<tr><td>STEP (Wastewater treatment)</td><td></td></tr>
<tr><td>ONEA (Cleaning water)</td><td></td></tr>
<tr><td>Abattoir (Animal slaughter: the meat)</td><td></td></tr>
<tr><td>Usine de Matelas Mousse (Matthew)</td><td></td></tr>
</table>

3.3. Daily Concentrations of Heavy Metals in Ambient Air at Two Major Towns

Table 3 shows the daily concentrations of certain heavy metals that an individual who is not protected against air pollution could nevertheless inhale.

3.4. 48-Hour Concentrations of Heavy Metals in Ambient Air at Two Major Towns

Table 4 shows the atmospheric heavy metals concentrations in the city centres and industrial zones of Bobo-Dioulasso and Ouagadougou could release into the ambient air over two days of measurements.

3.5. 72-Hour Concentrations of Heavy Metals in Ambient Air at Two Major Towns

Findings in Table 5 show the concentrations and atmospheric heavy metal emissions found in the air compartment, with high concentrations of Pb and Ni in the industrial zone of Ouagadougou and in the centre of Bobo-Dioulasso, but high concentrations of Cr and Hg in the centre of Ouagadougou.

3.6. Weekly Concentrations of Heavy Metals in Ambient Air at Two Major Towns

Anthropogenic emission of heavy metals during the weekdays, revealed high

Table 3. Daily measurement concentrations of heavy metals in ambient air at two major towns.

City	Measurement sites	As µg/m³	Pb µg/m³	Cd µg/m³	Ni µg/m³	Cr µg/m³	Hg µg/m³	Cu µg/m³
Ouagadougou	Animal House	<4.29E−04	<4.29E−04	<4.29E−04	<4.29E−04	<4.29E−04	<4.29E−04	<4.29E−04
	City Centre	<4.29E−04	1.43E−03	<4.29E−04	1.00E−03	2.00E−03	1.86E−03	<4.29E−04
	Industrial Area	<4.29E−04	2.57E−03	<4.29E−04	2.29E−03	1.71E−03	1.57E−03	<4.29E−04
Bobo-Dioulasso	Animal House	<4.29E−04	<4.29E−04	<4.29E−04	<4.29E−04	<4.29E−04	<4.29E−04	<4.29E−04
	City Centre	<4.29E−04	1.43E−03	<4.29E−04	1.29E−03	1.00E−03	1.14E−03	<4.29E−04
	Industrial Area	<4.29E−04	<4.29E−04	<4.29E−04	<4.29E−04	<4.29E−04	<4.29E−04	<4.29E−04

Table 4. 48-hour measurement concentrations of heavy metals in ambient air at two major towns.

City	Measurement sites	As µg/m³	Pb µg/m³	Cd µg/m³	Ni µg/m³	Cr µg/m³	Hg µg/m³	Cu µg/m³
Ouagadougou	Animal House	<8.57E−04	<8.57E−04	<8.57E−04	<8.57E−04	<8.57E−04	<8.57E−04	<8.57E−04
	City Centre	<8.57E−04	2.86E−03	<8.57E−04	2.00E−03	4.00E−03	3.71E−03	<8.57E−04
	Industrial Area	<8.57E−04	5.14E−03	<8.57E−04	4.57E−03	3.43E−03	3.14E−03	<8.57E−04
Bobo-Dioulasso	Animal House	<8.57E−04	<8.57E−04	<8.57E−04	<8.57E−04	<8.57E−04	<8.57E−04	<8.57E−04
	City Centre	<8.57E−04	2.86E−03	<8.57E−04	2.57E−03	2.00E−03	2.29E−03	<8.57E−04
	Industrial Area	<8.57E−04	<8.57E−04	<8.57E−04	<8.57E−04	<8.57E−04	<8.57E−04	<8.57E−04

Table 5. 72-hour measurement concentrations of heavy metals in ambient air at two major towns.

City	Measurement sites	As µg/m³	Pb µg/m³	Cd µg/m³	Ni µg/m³	Cr µg/m³	Hg µg/m³	Cu µg/m³
Ouagadougou	Animal House	<1.29E−03	<1.29E−03	<1.29E−03	<1.29E−03	<1.29E−03	<1.29E−03	<1.29E−03
	City Centre	<1.29E−03	4.29E−03	<1.29E−03	3.00E−03	6.00E−03	5.57E−03	<1.29E−03
	Industrial Area	<1.29E−03	7.71E−03	<1.29E−03	6.86E−03	5.14E−03	4.71E−03	<1.29E−03
Bobo-Dioulasso	Animal House	<1.29E−03	<1.29E−03	<1.29E−03	<1.29E−03	<1.29E−03	<1.29E−03	<1.29E−03
	City Centre	<1.29E−03	4.29E−03	<1.29E−03	3.86E−03	3.00E−03	3.43E−03	<1.29E−03
	Industrial Area	<1.29E−03	<1.29E−03	<1.29E−03	<1.29E−03	<1.29E−03	<1.29E−03	<1.29E−03

concentrations of Pb and Cr in the centre of Bobo-Dioulasso. Elevated concentrations of Pb and Ni in the industrial zone of Ouagadougou. Higher concentrations of Cr and Hg in Ouagadougou city centre in (Table 6)

3.7. Risk Factors

Table 7 shows the proportion of risk factors that predispose to certain types of respiratory diseases.

Table 6. Weekly Measurement concentrations of heavy metals in ambient air at two major towns.

City	Measurement sites	As µg/m³	Pb µg/m³	Cd µg/m³	Ni µg/m³	Cr µg/m³	Hg µg/m³	Cu µg/m³
Ouagadougou	Animal House	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003
	City Centre	<0.003	0.010	<0.003	0.010	0.014	0.013	<0.003
	Industrial Area	<0.003	0.018	<0.003	0.016	0.012	0.011	<0.003
Bobo-Dioulasso	Animal House	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003
	City Centre	<0.003	0.010	<0.003	0.009	0.010	0.008	<0.003
	Industrial Area	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003

Table 7. Risk factors.

Risk factors	Bobo-Dioulasso n (%)	Ouagadougou n (%)	p-value
Duration of stay in current city	**297**	**607**	**0.983**
Less than 1 year	28 (9.43)	64 (10.54)	
1 - 5 years	71 (23.90)	230 (37.89)	
More than 5 years	198 (66.66)	313 (51.56)	
Smoke or have you been exposed to secondhand smoke regularly	**297**	**607**	**0.810**
Yes	44 (14.81)	118 (19.44)	
No	253 (85.18)	489 (80.56)	
Live or work in an environment with heavy pollution (e.g. smoke, dust, industrial emissions)	**297**	**607**	**0.840**
Yes	81 (27.27)	236 (38.88)	
No	216 (72.73)	371 (61.12)	
Frequently exposed to indoor air pollution (e.g. cooking with wood, kerosene, or charcoal)	**297**	**607**	**0.373**
Yes	64 (21.55)	140 (23.06)	
No	233 (78.45)	467 (76.93)	
Suffer from allergies that affect your respiratory system	**297**	**607**	**0.182**
Yes	35 (11.78)	73 (12.02)	
No	262 (88.21)	534 (87.97)	

Continued

Protective measures (e.g. face masks) in environments with poor air quality	**297**	**607**	**0.889**
Always	44 (14.81)	86 (14.17)	
Sometimes	139 (46.80)	278 (45.80)	
Rarely	102 (34.34)	182 (29.98)	
Never	12 (4.04)	61 (10.05)	

3.8. Medical History

Table 8 shows that 3.03% and 4.61% of respondents in Bobo-Dioulasso and Ouagadougou respectively had a history of bronchitis. In addition, 37.04% and 39.70% of the estimated respondents respectively had respiratory symptoms at least once or twice a year.

Table 8. Medical history.

Medical history	Bobo-Dioulasso n (%)	Ouagadougou n (%)	p-value
Diagnosed with any respiratory disease in the past 12 months	297	607	0.952
Yes	35 (11.78)	96 (15.81)	
No	262 (88.21)	511 (84.18)	
Previous history	297	607	
Asthma	8 (2.69)	16 (2.63)	
Asthma and bronchitis	-	5 (0.82)	
Bronchitis	9 (3.03)	28 (4.61)	
Tuberculosis	3 (1.01)	1 (0.16)	
Tuberculosis and pneumonia	1 (0.33)	-	
Pneumonia	5 (1.68)	10 (1.65)	
Other	271 (91.24)	547 (90.11)	
Experienced respiratory symptoms (cough, difficulty breathing, chest tightness) in the last 12 months	297	607	0.566
1 - 2 times	110 (37.03)	241 (39.70)	
3 - 5 times	48 (16.16)	76 (12.52)	
More than 5 times	14 (4.71)	43 (7.08)	
Never	125 (42.08)	247 (40.69)	
Receive treatment for your respiratory condition	297	607	0.43
Yes	96 (32.32)	223 (36.74)	
No	201 (67.68)	384 (63.26)	
Type of treatment did you receive	297	607	0.999
Hospitalization	2 (0.67)	7 (1.15)	

Continued

Hospitalization and medication	-	3 (0.49)
Hospitalization, medication and home remedies	-	4 (0.66)
Medication only	75 (25.25)	175 (28.83)
Medication and home remedies	11 (3.70)	22 (3.62)
Home remedies	9 (3.03)	14 (2.30)
Other	200 (67.34)	382 (62.93)

4. Discussion

Nowadays, air pollution by certain heavy metals seems to be increasing because of a certain number of allergies and symptoms of respiratory pathologies, hormone-dependent cancers, metabolic disorders, non-communicable and neurological diseases depending on the exposure period. To this day, the regulations are not sufficiently documented on standards or international limits for the atmospheric heavy metals concentrations. Airborne particulate matter, especially the fraction of particles with aerodynamic dynameters below 2.5 µm (fine particles $PM_{2.5}$) had large surface areas and adsorbed compounds such as heavy metals, Polycyclic Aromatic Hydrocarbons (PAHs), and many other organic compounds into their surface various. Their small diameters allow them to reach the alveolar compartment of lungs, where they are able to cause adverse effects on health [30] [31]. It was shown that these particles cause more toxic effects than coarse particles [32]. Respiratory diseases have been associated with the exposure of populations to some environmental pollutants such as pesticides [33]. During the rainy season, Bobo-Dioulasso recorded rainfall of 1107 mm, a temperature of 28.9˚C and average humidity of 82.54%. In Ouagadougou, rainfall was 1017 mm, with an average temperature of 30.2% and average humidity of 73.84%, according to the National Meteorological Agency. When precipitation is high, the air is washed of these fine particles [34]. The residence time of fine particles in the atmosphere varies according to their size and composition. Wind direction can also play a role in differences in concentrations from one day to the next. Wind influences pollutant concentrations through its speed and direction [25]. The limitations of our study are due to the fact that data collection was carried out during the rainy season, with the different climatic variations in the two cities of Bobo-Dioulasso and Ouagadougou. The GRIMM EDM (Environmental Dust Monitor) 107, which was used for sampling, also has its advantages and limitations, as we have a multitude of sampling devices at our disposal.

4.1. Socio-Demographic Characteristics

A total of 904 participants took part in this study, 297 in the city of Bobo-Dioulasso and 607 in the city of Ouagadougou. Of the participants in Bobo-Dioulasso, 86.87% were in the city centre, compared to 82.70% in the city of Ouagadougou. Around 13% were in the industrial area of Bobo-Dioulasso compared with 17.30%

in the industrial area of Ouagadougou. The age range of the respondents was 21-40 years. More than 60% of respondents were men in both cities. Students made up 40% of the respondents in both cities. Bobo-Dioulasso and Ouagadougou are 360 kilometres (km) apart.

4.2. Inventory of the Various Industries in the Industrial Area at Two Major Towns

The inventory of industries in the two towns enabled us to identify 6 industries in common, including oil production, breweries and metal production. We identified a dozen other industries on both sides. In fact, the oil processing category was the most preponderant, followed by the brewing category. The higher number of industries in Ouagadougou compared to Bobo-Dioulasso could be linked to the fact that Ouagadougou is the political capital of Burkina Faso, with a dynamic population (*i.e.* the population was estimated at 1,700,000 in 2010 and 2,415,226 in 2022 by the National Institute of Statistics and Demography), which requires a sufficiently high level of productivity to cover the needs of the population.

4.3. Daily Concentrations of Heavy Metals in Ambient Air at Two Major Towns

The majority of locations in Bobo-Dioulasso and Ouagadougou showed concentrations of As, Cd, and Cu < 4.29E−04 $\mu g \cdot m^{-3}$. However, we observed concentrations of Ni (1.00E−03 $\mu g \cdot m^{-3}$, 2.29E−03 $\mu g \cdot m^{-3}$), Cr (2.00E−03 $\mu g \cdot m^{-3}$, 1.71E−03 $\mu g \cdot m^{-3}$) and Hg (1.86E−03 $\mu g \cdot m^{-3}$, 1.57E−03 $\mu g \cdot m^{-3}$) respectively in the city centre and industrial zone of Ouagadougou. A concentration of Pb (1.43E−03 $\mu g \cdot m^{-3}$) in the two towns. A daily concentration of Pb = 1.00E−03 $\mu g \cdot m^{-3}$, Ni = 1.29E−03 $\mu g \cdot m^{-3}$, Cr = 1.00E−03 $\mu g \cdot m^{-3}$ and Hg = 1.14E−03 $\mu g \cdot m^{-3}$ in the Bobo-Dioulasso industrial zone. Ni, Pb are emitted mostly by oil combustion sources [10]. Ouagadougou's road network extends over a distance of 2700 kilometres with 200 km of paved roads, 400 km of laterite and 2100 km on tracks (a mixture of laterite, sand and clay), on which traffic contributes through suspension to particulate matter. Approximately 1,003,997 people travel in and out of the city centre every day. The breakdown of vehicles is as follows: 74% motorised two-wheelers, 18% private vehicles, 7% public transport vehicles and 1% heavy goods vehicles. Dusty residential sites near unpaved roads are characterised by high PM_{10} emissions [25]. Some studies on air pollution in the city of Ouagadougou have shown that this pollution is mainly due to PM and hydrocarbons [35] [36]. The relatively low concentrations of certain heavy metals in outdoor or indoor environments may be linked to the fact that we do not have massive use of materials that could be responsible for the emission of these heavy metals in low concentrations.

4.4. 48-Hour Concentrations of Heavy Metals in Ambient Air at Two Major Towns

Concentrations of Pb = 2.86E−03 $\mu g \cdot m^{-3}$ are the same in both city centres, whereas Ni = 2.00E−03 $\mu g \cdot m^{-3}$ (Ouagadougou) is higher than Ni = 2.57E−03 $\mu g \cdot m^{-3}$ (Bobo-

Dioulasso). The relative concentrations of Cr = 4.00E−03 μg·m^{-3} and Hg = 3.71E−03 μg·m^{-3} in the centre of Ouagadougou exceed that of Cr = 2.00E−03 μg·m^{-3} and Hg = 2.29E−03 μg·m^{-3} in the centre of Bobo-Dioulasso.

The industrialized area of Ouagadougou has heavy metal concentrations of Pb = 5.14E−03 μg·m^{-3}, Ni = 4.57E−03 μg·m^{-3}, Cr = 3.43E−03 μg·m^{-3}, Hg = 3.14E−03 μg·m^{-3} compared to the industrial area of Bobo with concentrations of all these heavy metals <8.57E−04. μg·m^{-3}.

Our results are lower and differ from those obtained in China by Duan and Tan [5] with heavy metal concentrations Pb = 0.19 μg·m^{-3} As = 0.015 μg·m^{-3} Ni = 0.02 μg·m^{-3} Cr = 0.04 μg·m^{-3} Cd = 0.05 μg·m^{-3} Cu = 0.06 μg·m^{-3}. Further, Cu and Pb are often associated with traffic emissions and road dust [10].

The high concentration of heavy metals in Bobo-Dioulasso city centre may be attributable on the one hand to some informal sector activities such as welding and small-scale metallurgy. Emissions from cars, dust, cockroaches and mouldy bits were the most common exposure factors in the environment at respectively 89.2%, 85.3%, 85.3% and 68.6% of our patients. A notion of smoking was found in 38 patients (4 active and 34 second-hand smoking) [37].

4.5. 72-Hour Concentrations of Heavy Metals in Ambient Air at Two Major Towns

In the city of Ouagadougou, the concentrations of heavy metals were Pb = 4.29E−03 μg·m^{-3}, Ni = 3.00E−03 μg·m^{-3}, Cr = 6.00E−03 μg·m^{-3}, Hg = 5.57E−03 μg·m^{-3} in the city centre. In the industrial zone, on the other hand, Pb = 7.71E−03 μg·m^{-3}, Ni = 6.86E−03 μg·m^{-3}, Cr = 5.14E−03 μg·m^{-3} and Hg = 4.71E−03 μg·m^{-3}.

In the city of Bobo-Dioulasso, heavy metal concentrations were Pb = 4.29E−03 μg·m^{-3}, Ni = 3.86E−03 μg·m^{-3}, Cr = 3.00E−03 μg·m^{-3} and Hg = 3.43E−03 μg·m^{-3} in the city centre. Our results differ from those obtained with Cheng [38] in China who obtained Cd = 0.016 μg·m^{-3}, Cr = 0.071 μg·m^{-3}, Ni = 0.072 μg·m^{-3}, Pb = 33.3 μg·m^{-3} in the normal season. The cumulative effect of discharges from the various industries in the Ouagadougou industrial zone could be correlated with increased concentrations of certain heavy metals such as Pb and Ni. The predominant industrial categories are oil, brewing and metallurgy.

4.6. Weekly Concentrations of Heavy Metals in Ambient Air at Two Major Towns

Heavy metal concentrations in Pb = 0.010 μg·m^{-3} are the same in Ouagadougou and Bobo-Dioulasso. Ni (0.010 μg·m^{-3} in Ouagadougou vs 0.009 μg·m^{-3} in Bobo-Dioulasso), Cr (0.014 μg·m^{-3} in Ouagadougou vs 0.010 μg·m^{-3} in Bobo-Dioulasso), Hg (0.013 μg·m^{-3} in Ouagadougou vs 0.008 μg·m^{-3} in Bobo-Dioulasso) in the city centres. Heavy metal concentrations of Pb = 0.018 μg·m^{-3}, Ni = 0.016 μg·m^{-3}, Cr = 0.012 μg·m^{-3}, Hg = 0.011 μg·m^{-3} in the Ouagadougou industrial zone. Our results differ from those obtained by Contini *et al.* [39] during weekdays measurement Cr = 5.5E−03 μg·m^{-3}, Ni = 4.2E−03 μg·m^{-3}, Cu = 0.010 μg·m^{-3}, As = 2.2E−03 μg·m^{-3}, Cd = 2.4E−03 μg·m^{-3}, Pb = 0.021 μg·m^{-3}. An urban area with mainly exhaust fumes is a strong source of PM, especially during the rainy season [40] [41]. The centres of activity are concentrated in the city centre and in a few outlying districts, hence the massive daily movement of inhabitants towards the business parks [25].

Our results also differ from those obtained by Cachon *et al.* [42] who had heavy metal concentrations in Benin after 3 weeks of measurement in Cr = 0.01 $\mu g \cdot m^{-3}$, Cu = 0.03 $\mu g \cdot m^{-3}$, Ni = 0.002 $\mu g \cdot m^{-3}$ and Pb = 0.02 $\mu g \cdot m^{-3}$. A number of industries, including metallurgy and artisanal mining, as well as other anthropogenic activities such as smoke, dust, road transport (fuel), waste incineration, charcoal, paint and plastic manufacturers, could be responsible for this increase in concentrations.

4.7. Risk Factors

Regarding risk factors, in Bobo-Dioulasso 66.67% had been in the current city for more than 5 years, 14.81% were regularly exposed to passive smoking, 27.28% live or work in an environment with high pollution (e.g. smoke, dust, industrial emissions), 21.55% are frequently exposed to indoor air pollution (e.g. cooking with wood, kerosene or charcoal), 11.79% suffer from allergies that affect their respiratory system, 61.61% take protective measures (e.g. face masks) in environments with poor air quality.

In Ouagadougou, 51.56%, more than 5 years in the current city, 19.44% were regularly exposed to passive smoking, 38.88% live or work in an environment with heavy pollution (e.g. smoke, dust, industrial emissions), 23.06% are frequently exposed to indoor air pollution (e.g. cooking with wood, kerosene or charcoal), 12.03% suffer from allergies affecting their respiratory system. 59.97% take protective measures (e.g. protective mask) in environments with poor air quality. No significant association was found ($p > 0.05$).

Sustainable development in Sub-Saharan Africa depends on productivity in the agricultural sector. Agriculture is a major contributor to Gross Domestic Product (GDP) [43]. Pesticides are used to protect crops. The use of pesticides requires protective measures to ensure the safety of users. Unfortunately, in our countries, very few producers comply with hygiene rules during and after phytosanitary treatments [44]. In environmental terms, the consequences include water, soil and air quality, as pesticide residues can be detected in all environmental compartments or in food [45]. Nevertheless, their uncontrolled and intensive use due to a lack of training can be a source of harm to animal and human health and to the environment [44]. In addition, farmers, mainly because of their low level of instruction, do not respect good agricultural practices [46]. In general, in West Africa, and particularly in Burkina Faso, small-scale vegetable growers do not follow the recommendations for the appropriate use of pesticides and equipment. The results of a study showed that after pesticide use, 70.83% of small-scale vegetable throw pesticide packaging away, 18.33% incinerate it, 3.33% dump it and 0.83% bury it in the soil [44]. Pesticides are responsible for several chronic diseases, including chronic respiratory defects [33]. These health effects are mainly rhinitis, chronic chest pains, chronic cough, breathlessness, and respiratory difficulty. The prevalence of reported chronic respiratory symptoms in the conventional group was significantly higher compared to organic ones. Pulmonary function assessment of each cotton farmer allowed to diagnose ventilatory changes among conventional and organic cotton farmers. Among organic farmers, Chronic rhinitis, Chronic chest pains and Chronic cough were significantly associated with restrictive defects [33]. Both conventional and organic cotton farmers reported similar chronic respiratory symptoms in different proportions. The main reports were rhinitis (54.45% conventional vs. 34.92% organic) [33]. The industrial zones of Burkina Faso's two major cities, which include more than a dozen industries, are not too far from either residential areas or the city centre. As a result, industrial air pollution could spread widely, they can be dispersed in the atmosphere over long distances and be deposited in regions far from where they were emitted [47].

In Burkina Faso, women and their young children are the most exposed to the effects of indoor air pollution. The prevalence of Acute Respiratory Infections (ARIs) was 3.5% in children under 5. In Burkina Faso, indoor air pollution is thought to be responsible for 8.5% of general morbidity. One study showed that 60% of households used biomass (wood or charcoal) as their main fuel, while 40% used gas. By analogy with the latter study, we can deduce the same thing for the population of Bobo-Dioulasso [48]. a statistically significant difference in respiratory symptoms prevalence amongst women who burnt biomass fuels compared to women who used clean fuels, such as Liquefied Petroleum Gas (LPG), and furthermore, if there was a difference in the health effects between wood and charcoal used as the main cooking fuel. Biomass users are acute respiratory symptoms some dry cough (26.5%), throat irritation (29.06%). Chronic respiratory symptoms such as: chronic phlegm (28.77%), Shortness of breath (20.59%), effort cough (28.28%), effort chest tightness (38.13%), effort dyspnea (48.57%), woken by shortness of breath (28.37%), woken by coughing attacks (20.859%) by LPG users [49]. A notion of smoking was found in 38 patients (4 active and 34 second-hand smoking) [37].

4.8. Medical History

In the city of Bobo-Dioulasso, 11.78% of people were diagnosed with any respiratory disease in the previous 12 months, compared with 15.81% in Bobo-Dioulasso. Bronchitis was the most common, followed by asthma and then pneumonia in both towns. Our results are similar to those of Ouédraogo *et al.* [27], who reported acute bronchitis as the most common respiratory pathology (46.87%), followed by pneumonia (38.57%) and rhinitis (37.08%) in children hospitalised for respiratory diseases. 37.04% of participants in Bobo-Dioulasso had experienced respiratory symptoms (cough, breathlessness, chest tightness) 1 - 2 times in the previous 12 months, compared with 39.70% in Ouagadougou 1 - 2 times. 32.32% of participants in Bobo-Dioulasso received treatment for their respiratory symptoms, compared with 36.74% of participants in Ouagadougou. In terms of the type of treatment used for respiratory problems, 25.25% of people in Bobo-Dioulasso used only medication, compared with 28.83% of people in Ouagadougou. One hundred and two asthmatic patients were included (76 women and 26 men) with a mean age of 38.7 ± 18.6 years. Asthma was found to be well controlled in 26.5% of cases, partially controlled in 34.3% of cases and uncontrolled in 39.2% of cases [37]. In developing countries, chronic respiratory diseases are a major concern due to their frequency, severity, and economic impact [50]. Indeed, Low- and Middle-Income Countries (LMICs) account for 80% of world deaths from noncommunicable diseases, of which about 12% are due to respiratory diseases like asthma and Chronic Obstructive Pulmonary Disease (COPD). In Sub-Saharan Africa, the prevalence of asthma ranges from 6% to 20% and COPD from 4.1% to 24.8% [51].

Respiratory diseases have been associated with the exposure of populations to some environmental pollutants such as pesticides [33]. Over eighty-eight percent (88.10%) of conventional cotton farmers vs 67.67% of organic ones reported health effects involving respiratory system after contact ($p < 0.0001$) OR = 2.263; 95% CI: 1.605 - 3.190 [52]. Self-reported chronic respiratory symptoms among cotton farmers show 66.90% and 57.67% of conventional and organic cotton farmers, respectively, declared having experienced a chronic respiratory sign at least once since they started using pesticides. Reported chronic respiratory signs such as rhinitis, chronic chest pain, chronic cough, and breathlessness were significantly associated with conventional cotton farmers compared to organic ones ($p < 0.05$) [33]. A recent literature review by Tarmure *et al.* [53] concluded that pesticide exposure strongly correlates with respiratory pathologies like asthma, COPD, and cancer. At harmful levels in Ouagadougou, $PM_{2.5}$ caused primarily outpatient hospital visits rather than hospitalisations for respiratory diseases. Hospital visits for respiratory diseases accounted for 14.16% of all visits. Children were males in the majority (54.57%) and aged between 29 days-30 months (74.85%). Rise in $PM_{2.5}$ concentrations was associated with slightly more outpatients than inpatients (ORc = 0.996 95% CI: 0.993 - 0.998; $p = 0.003$) [27]. Regarding the distribution of respiratory diseases, acute bronchitis was the most frequent (46.87%), followed by pneumonia (38.57%) and rhinitis (37.08%). Forty-three deaths (3.42%) were reported, and all occurred among hospitalised patients. A high concentration of $PM_{2.5}$ was associated with increased outpatient consultations among children, a finding that could help prepare for such situations [27]. Children are more sensitive to the adverse health effects of air pollutants due to the immaturity of their respiratory system [54]. The prevalence of Respiratory Syncytial Virus (RSV), viral infections in infants suffering from respiratory infections consulted and hospitalised in the city of Ouagadougou, and to evaluate the clinical characteristics associated with the identification of RSV infection. The age group under 6 months was the most affected, with 66.7% of cases of RSV ARI (Acute Respiratory Infection). The main histories of atopy found in the children were rhinitis (14, 58.3%) and asthma (2, 8.3%); Clinical signs observed during RSV ARI were dominated by cough, 22 (91.66%), followed by fever (temperature ≥ 38.5˚) (79.2%), rhinitis (19; 79.2%) and respiratory distress (moderate if score between 3 and 4 and severe if score ≥ 4 - 5) (16; 66.7%). The frequency of RSV ARI (16.2%) and its predilection (age < 6 months) are a real public health problem in paediatrics [55]. In Burkina Faso

(West Africa), ARIs are also a major cause of child admissions to hospital by Tall *et al.* [56] with a 17.6% mortality rate in children aged under 5 years [57] [58]. The prevalence of Functional Pulmonary Defects (FPDs) was 36.84%. Obstructive and mixed ventilatory impairments (OVI + MVI) represented 10.12% [59]. In Burkina Faso, 70.7% of males suffered from chronic irreversible airway dilatation, which corresponds to 93.3% knowledge of bronchiectasis [60].

5. Conclusions

The present work described an analysis of atmospheric heavy metals concentrations of samples collected at the six different sites in Burkina Faso during rainy season. The results showed limited differences in the concentrations measured at the six sites, indicating a relatively homogeneous spatial distribution of metals at two major towns in Burkina Faso. This was probably due to the presence of the specific meteorological circulation, which mixes air masses arriving from different directions, favouring the re-circulation and spread of pollutants in the sampling sites. Three of the sources were related to specific emissions in the various sites (traffic-industrial emissions, glass factories and fossil fuel combustion). A local anthropogenic source, rich in As, Cd, Cu, Pb, Ni, Cr and Hg, was identified on the basis of the correlation with the survey data provided us with an update on the incidence of respiratory pathologies.

The most prevalent atmospheric heavy metals' concentration in the industrial area is Pb, Ni, and Cr, whereas in the city centre, we found Cr and Hg. Heavy metals in dust were found to mainly derive from atmospheric deposition of particulate matter of both natural and anthropogenic origin.

Nowadays, most heavy metals are endocrine disruptors, causing DNA damage. It is vital to raise awareness in order to reduce anthropogenic origin of heavy metals.

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Data Availability

The datasets used and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Authors' Contributions

Conceptualization, data curation, formal analysis, methodology, writing-original draft, writing-review and editing: ZJFRT. AT, BMB, BVEJTB, OEO, and DJNK were responsible for the formal analysis, methodology, supervision, validation, visualization and writing-review and editing. LT, T-WCO, WFD and JS realize the investigation, supervision, validation and visualization.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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