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Research Article

Determination of lead (Pb) Pollution Levels in Soils from Different Mechanical Garages and Bus Stations in Dakar Using X-ray Fluorescence (XRF) Spectrometry

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Abstract

Heavy metals are among the most toxic pollutants found in soils. Lead, in particular, is one of these metals that exerts harmful effects on living organisms even at very low concentrations. Therefore, the objective of this study is to assess the level of lead contamination in soils from garage areas. In this work, we collected soil samples from eight different garages, including five bus stations and three mechanical workshops. On each site, we collected a composite sample that we analyzed in order to quantify the lead content using X-ray fluorescence spectrometry (XRF). The XRF device provided the elemental analysis results of each sample in parts per million (ppm). These results highlighted the presence of trace metal elements such as lead (Pb), copper (Cu), chromium (Cr), zinc (Zn), and arsenic (As), as well as other less toxic metals like iron (Fe), molybdenum (Mo), zirconium (Zr), sulfur (S), and tin (Sn). The comparative study of the concentrations found shows a heterogeneous distribution of lead in the soils of the garages, with values ranging from 36.62 to 53.26 ppm. Concentrations are higher in the soils of mechanical workshops than in those of bus stations, with a few exceptions. The most concerning site (S4) shows the maximum lead content of 53.26 ppm, which does not exceed the alert level of 400 ppm set by the US EPA for soils. Thus, the soils do not currently present major health risks for adults, but long-term exposure could negatively affect children living near these areas.

Keywords

Pollution, Soil, Lead, Garage, X-ray Fluorescence

1. Introduction

Heavy metal pollution is one of the most serious environmental threats to soil quality [1]. This phenomenon is receiving increasing global attention and is generally observed in regions with advanced industrialization, but it is also closely linked to the automobile and transport sectors.

Today, all major cities worldwide are affected by this pollution, whether in the air, water, or soil [2]. In 2013, Dakar was ranked as the second most polluted city in Africa and 28th in the world. Approximately 350,000 new vehicles are registered in Senegal each year [3]. In 2009, 60% of the automobile fleet was more than 10 years old, and over 10 million daily trips shape the daily life of Dakar and its inhabitants [4].

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Consequently, the Senegalese capital hosts numerous vehicle repair and dismantling workshops as well as bus stations that provide interurban transport.

However, activities carried out in these garages, along with the frequent handling of chemical substances, are potentially dangerous for soils and groundwater. For example, the handling of lead batteries, motor vehicle emissions, leaks of used oil, brake fluids, tire wear, varnishes, solvents, heating, and corrosion of metal roofs all represent diffuse sources of pollutants that are highly harmful to human health, such as heavy metals. These processes can increase the concentration of naturally occurring heavy metals in soils, resulting in accumulations of potentially toxic elements for the environment.

These trace elements are among the most toxic pollutants due to their persistence in the environment [5]. Their sources of emission are multiple, including bedrock weathering, the automobile industry, road traffic, agricultural practices, and urban waste. According to the World Health Organization (WHO) and the United States Environmental Protection Agency (US EPA), the main heavy metals involved in soil pollution are copper (Cu), mercury (Hg), arsenic (As), cadmium (Cd), nickel (Ni), chromium (Cr), zinc (Zn), and lead (Pb) [6, 7]. Even at low concentrations, these heavy metals are highly harmful to both humans and animals [8].

The main objective of our study is to identify and quantify lead in the soils of mechanical garages and bus stations in Dakar in order to evaluate the variation and distribution of this metal in these sites.

Environmental analysis requires sensitive, reliable, rapid, reproducible, and preferably cost-effective analytical methods that can cover a wide range of concentrations. Suitable analytical techniques include X-ray fluorescence (XRF) [9], atomic absorption spectrometry (AAS) [10], inductively coupled plasma optical emission spectrometry (ICP-OES) [11], and electrochemical analysis methods [12].

X-ray fluorescence (XRF) spectrometry has the advantage of being simple, rapid, and allowing the direct and simultaneous analysis of several trace elements in soils [9].

Lead was chosen due to its highly toxic properties, which are commonly associated with current levels of soil contamination in automotive garages. As this metal is indestructible and can persist in the environment for decades, severe poisoning cases may occur in humans, including anemia, kidney complications, reproductive health issues, neurological and digestive disorders, and even death [13]. For example, in 2008, 18 children under the age of six living in the Ngagne DIAW neighborhood in Thiaroye sur Mer (Dakar) died from lead poisoning caused by battery and accumulator recycling activities [14].

To prevent such tragedies among mechanics and to raise awareness, this study aims to determine the level of lead pollution in soils from different mechanical garages and bus stations in Dakar.

2. Materials and Methods

2.1. Sampling Sites

2.1.1. Presentation of Study Area

The Dakar region is one of the 14 administrative regions of Senegal. It represents the country's capital in every respect economic, political, and cultural. Covering an area of 550 km², it is the smallest region in the country (0.34% of the national territory) but hosts the largest share of the Senegalese population, with a population density of 6,786 inhabitants/km² [15]. Across the national territory, Dakar also concentrates the largest share of the automotive sector and is therefore undoubtedly the most polluted city.

2.1.2. Site Selection

A preliminary study was conducted through interviews with professionals in the field in order to select the study sites. The objective was to target automobile garages (mechanical and bus stations) whose soils are more exposed to pollution resulting from garage activities (Figure 1).

2.1.3. Location of Sampling Sites

Soil sampling was carried out in March 2022 in automobile garages (mechanical and bus stations) located in the southeastern area (mechanical garage in Mermoz, Dem Dikk terminus in Liberté 5) and the central area of the westernmost part of the region (Lat-Dior and Petersen bus stations, Dem Dikk terminus at Palais 2), as well as at the entrance of the city of Pikine (Baux Maraîchers bus station and Dalifor mechanical garage) (Figure 2).

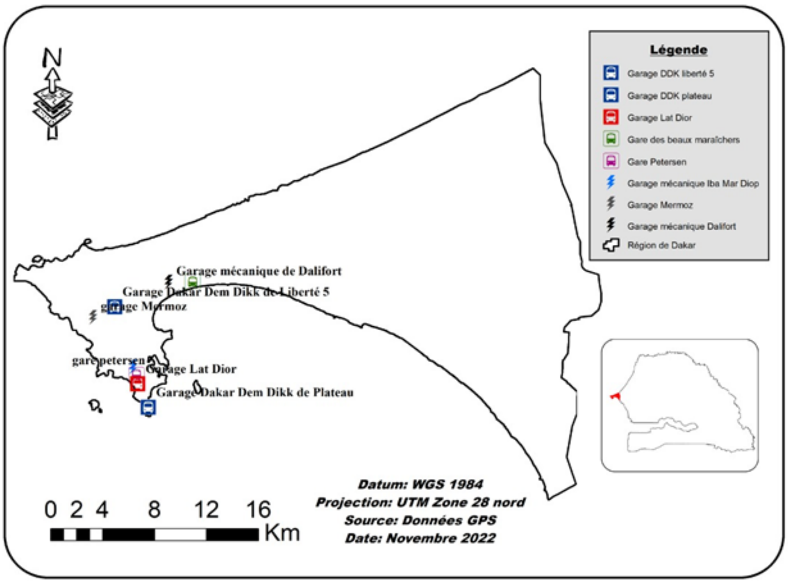

Figure 1. *Location of sampling sites.*

Figure 2. *Soil sampling sites (A: Dem Dikk terminus Libert é 5; B: Dalifor mechanical garage; C: Iba Mar DIOP mechanical garage; D: Petersen bus station; E: Dem Dikk terminus Palais 2; F: Baux Mara ĉhers bus station; G: Lat Dior bus station; H: Mermoz mechanical garage).*

2.2. Sampling Method

Soil samples were collected from three different spots at each automobile site: two (2) samples inside the site and one (1) sample outside the site. A composite sample was thus obtained in order to better determine the average lead content in the soil covering the sampling zone.

A control soil sample was collected from a rural, non-polluted area located far from traffic, in the Saint-Louis region. This region is about 270 km from Dakar.

2.3. Preparation of Soil Pellets

Pelletizing consists of forming a circular tablet made of a mixture of soil sample and binder. This process is carried out using two tungsten carbide cylinders, between which the sample is placed inside a compression die. A test portion of 1.2 g of soil was mixed with a binder mass equivalent to 10% of the soil sample mass. The mixture was homogenized and then placed in the compression die, where it was subjected to a pressure of 25 tons. After a resting period of 2 minutes, the pellet was removed from the die and analyzed using the Niton

XLT900s device. The soil masses collected were optimized and subsequently analyzed at the X-ray fluorescence laboratory of ITNA.

3. Results and Discussion

The XRF results (Table 1) for the composite soil samples analyzed highlighted the presence of trace metallic elements: heavy metals (Pb, Cu, Zn, and Cr), a metalloid (As), and other non-toxic metals (Fe, Mo, Zr, S, Sn). The concentrations of these metals, obtained from a single XRF measurement of 180 seconds for each composite sample, are presented in Table 1.

In the control samples 6, 7, and 8 (from sites CS, S6, S7, and S8, respectively), lead (Pb) was not detected; therefore, its concentration was below the detection limit of the XRF instrument in soil, DL(Pb) = 2 ppm. Conversely, all Pb concentrations found in sites S1, S2, S3, S4, and S5 remained below the alert level of 400 ppm, established by the United States Environmental Protection Agency (US EPA) [6, 7].

Table 1. *Trace metallic element concentrations (ppm) in composite soil samples collected from automobile garages in the Dakar region.*

Sites	Pb	As	Fe	Cu	Zn	Cr	Mo	S	Zr	Sn
CS	<DL	0,26	<DL	<DL	<DL	601,79	<DL	263,69	15,3	<DL
S8	<DL	1,13	<DL	47,05	<DL	718,04	318,52	370,03	111,13	<DL
S7	<DL	0,68	<DL	101,46	<DL	502,56	398,5	98,87	100,94	<DL
S6	<DL	1,58	<DL	67,73	21,3	928,66	<DL	131,02	137,02	<DL
S5	42,28	0,8	$53,98.10^3$	220,97	<DL	684,25	<DL	87,34	131,21	<DL
S4	53,26	1,57	$44,00.\ 10^3$	201,46	<DL	786,45	539,03	147,41	191,77	<DL
S3	<DL	3,46	<DL	89,09	92,61	1568,1	<DL	295,39	183,66	<DL
S2	49,43	0,7	$63,77.\ 10^3$	330,13	<DL	224,61	537,77	83,13	112,92	51,16
S1	36,62	0,99	$97,70.\ 10^3$	311,6	<DL	598,51	491,11	91,46	187,44	<DL

DL: detection limit

CS: rural zone of Saint-Louis (control site), *S1:* mechanical garage, Iba Mar DIOP Stadium; *S2:* Petersen bus station; *S3:* Dem Dikk terminus, Palais 2, *S4:* Lat Dior bus station; *S5:* mechanical garage, Mermoz; *S6:* Baux Maraîchers bus station; *S7:* mechanical garage, Dalifor; *S8:* Dem Dikk terminus, Liberté 5

These analytical results enabled a comparative study of Pb levels across the soils of each automobile garage visited.

3.1. Variation of Lead Content in Different Automobile Garages

The maximum Pb concentrations in soils from the different garages are shown in Figure 3.

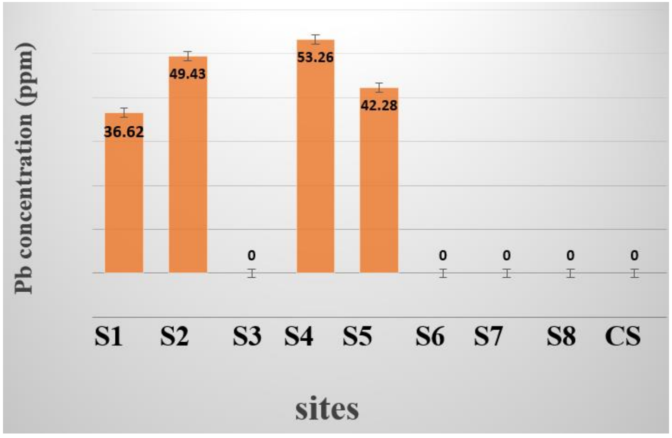

Figure 3. *Lead content in soils from the different garages visited.*

Pb concentrations in garage soils ranged from 0 to 53.26 ppm. In general, Pb concentrations were higher in soils from mechanical workshops compared to bus stations, due to the large amounts of chemical substances discharged (oil, brake fluids, leaded gasoline, lead-acid batteries, etc.) from vehicle repair activities. However, the highest Pb concentration was measured at the Lat Dior bus station, while no detectable Pb concentration was found at the Dalifor mechanical garage. This can be explained by the fact that at Lat Dior, mechanical activities take place both inside and outside the station, whereas at Dalifor, sampling was conducted in an area dedicated only to bodywork, which does not involve lead-containing substances.

The natural pedogeochemical background in the soils of these sites contains Pb only as traces or not at all (Pb < DL = 2 ppm). Overall, the Pb values found remain within the US EPA [6, 7] threshold of 400 mg/kg.

The soil pH analysis was conducted to determine, in case of Pb presence, its chemical speciation and mobility in garage soils.

3.2. Soil pH Analysis

Soil pH at each site was determined using a pH-meter (Model 2700) with a soil-to-water ratio of 1:25, i.e., 1.2 g of soil in 30 mL of distilled water. This ratio ensures a saturated solution and an optimal pH value for the soil.

Table 2. *pH values of soils collected from the different sites.*

Sampling Sites	S1	S2	S3	S4	S5	S6	S7	S8	CS
pH	7,83	7,88	8,17	8,08	7,8	7,6	8,76	8,2	7,65

The soils collected from the different garages in Dakar, including the control site, were alkaline, with pH values ranging from 7.60 to 8.76. Thus, Pb is likely retained at the soil surface in insoluble forms such as lead oxide (PbO), red lead (Pb_3O_4), etc. [16]

3.3. Distribution of Lead in Automobile Garages

The minimum, maximum, mean, and standard deviation of Pb concentrations are shown in Table 3, calculated using XL STAT software.

Table 3. *Lead concentrations across all garages visited.*

Variable	Minimum	Maximum	Mean	Standard deviation
Pb (ppm)	36,62	53,260	20,177	24,353

The standard deviation was high and slightly greater than the mean Pb concentration, indicating that Pb levels in garage soils were not homogeneous.

Soil Pb contamination in garages may potentially arise from chemical substances used in vehicle repair activities as well as from dust deposits from exhaust emissions. To better understand the Pb sources, a correlation study was carried out between Pb and the other metals detected.

3.4. Correlation Matrix of Lead with Other Metals Detected

The correlation matrix (Table 4) identifies possible chemical associations (alloys or ores) between Pb and other metals detected, shedding light on specific Pb sources among the materials used in automobile garages.

Table 4. Correlation matrix between Pb and other metals.

Metals	Pb	As	Fe	Cu	Zn	Cr	Mo	S	Zr	Sn
Correlation with Pb	1	-0,21	0,85	0,88	-0,38	-0,41	0,56	-0,61	0,422	0,45

The correlation analysis shows:

1) a strong correlation between Pb and Fe, Cu;
2) a moderate correlation between Pb and Mo, Zr, Sn;
3) no correlation between Pb and As, Zn, Cr, S.

However, in automotive garages, lead is more commonly found in ferrous materials (cast iron, steel, sheet metal, etc.) and copper-based components (engines, tires, car cables, casings). Furthermore, the average correlation between lead and tin indicates the presence of the Pb–Ca–Sn–Al alloy, which is generally found in one of the electrodes of lead-acid batteries used in motor vehicles [17]. In addition, the average correlation between Pb and molybdenum (Mo) or zirconium (Zr) suggests that Mo and Zr—known for being refractory, robust, and resistant to corrosion—may be associated with lead in varnishes applied to ceramics, paints, glassware, lubricants, hydrocarbons (with Mo acting as a catalyst), etc. [18, 19].

The set of heavy metals detected in soils allows for a comparative study of automotive garages with respect to their levels of trace metal pollution.

3.5. Comparative Study of Automobile Garages

The minimum, maximum, mean, and standard deviation values of all detected metals are presented in Table 5. The total metal concentration in garage soils ranged from 0 to 97,700 ppm.

Table 5. Metal concentrations detected in garage soils (ppm).

concentration/ppm				
Variable Sites	**Minimum**	**Maximum**	**Moyenne**	**Standard deviation**
CS	0,000	601,790	88,104	198,409
S8	0,000	718,040	156,590	241,136
S7	0,000	502,560	120,301	181,630
S6	0,000	928,660	128,731	286,294
S5	0,000	53980,000	5514,685	17030,256
S4	0,000	44000,000	4592,095	13848,937
S3	0,000	1568,100	223,231	482,831
S2	0,000	63770,000	6515,985	20117,725
S1	0,000	97700,000	9941,773	30835,843

The maximum concentrations of metals in mechanical garages were higher than those found in bus stations. This difference is due to vehicle repair activities being generally carried out in mechanical garages, not in bus stations. The highest total metal content was found in soils from the mechanical garage near Iba Mar DIOP stadium (S1), while the maximum concentration at the Dem Dikk Liberté 5 bus terminus (S8) was even lower than in the control soil (CS). Thus, bus station soils, where no vehicle repair activities take place, showed no significant trace metal pollution and therefore no health risks.

To assess the similarity of garages based on their activities, a correlation study was carried out (Table 6).

Table 6. *Correlation matrix between the different garages visited.*

Sites	CS	S8	S7	S6	S5	S4	S3	S2	S1
ST	1								
S8	0,914	1							
S7	0,691	0,893	1						
S6	0,943	0,856	0,738	1					
S5	-0,145	-0,219	-0,224	-0,146	1				
S4	-0,143	-0,212	-0,215	-0,144	1,000	1			
S3	0,960	0,869	0,730	0,997	-0,151	-0,148	1		
S2	-0,155	-0,225	-0,227	-0,157	1,000	1,000	-0,162	1	
S1	-0,152	-0,223	-0,226	-0,153	1,000	1,000	-0,158	1,000	1

The matrix shows that:

1) all mechanical garages where vehicle repair activities are performed are in perfect correlation (correlation = 1) with each other: S1, S2, S4, S5;
2) all bus stations (S3, S6, S7, S8) show strong correlation among themselves and with the control site (CS), with correlation values ranging from 0.691 to 0.997.

Thus, mechanical garages share similar characteristics, and Pb levels found can be attributed solely to mechanical activities.

4. Conclusion

The XRF fluorescence technique was used to evaluate the level of lead (Pb) pollution in soils from different mechanical garages and bus stations in Dakar**.** Experimental analysis results show that toxic metals, particularly lead, are more abundant in mechanical garages than in bus stations. Overall, across the surveyed automotive garages, lead concentrations ranged from 36.62 to 53.26 ppm. The maximum lead values, generally found in mechanical garages, reflect the level of soil pollution in these sites. The detection limit for lead in soil was 2 ppm.

These lead concentrations remain below the soil alert level of 400 ppm established by the United States Environmental Protection Agency (US EPA), above which soil contamination with lead would be confirmed. Based on these experimental results, it can be concluded that long-term exposure could negatively affect mechanics and garage workers, as well as children living nearby.

Finally, it should be noted that arsenic, copper, zinc, and chromium detected in garage soils may warrant particular attention regarding their environmental fate. It is therefore necessary, and even urgent, to carry out regular analyses of heavy metals in order to monitor and control their pollution levels in automotive garage soils.

Abbreviations

AAS	Atomic Absorption spectrometry
ICP-OES	Inductively Coupled Plasma Optical Emission Spectrometry
ITNA	Institute of Applied Nuclear Technology
LCPOAE	Laboratory of Organic Physical Chemistry and Environmental Analysis
TME	Trace Metal Element
WHO	World Health Organization
LD	Limit of Detection (LOD)
US EPA	United States Environmental Protection Agency
XRF	X-ray Fluorescence Spectroscopy

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Author Contributions

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Ababacar Diouf: Conceptualization, Methodology, Validation, Writing – original draft

Alassane Traore: Writing – original draft

Arona Ngom: Writing – original draft

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Conflicts of Interest

The authors declare no conflicts of interest.

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