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Assessment of the Physico-Chemical Parameters and Soil Pollution in Some Landfills at Ouagadougou

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Abstract: The study was conducted to evaluate the physic-chemical parameters and pollution aspect of landfill soils. The soils samples were collected in some selected landfill, at Ouagadougou. Determinations of heavy metal concentrations, physic-chemical parameters, calculation of geo-accumulation index and statistical analysis were undertaken. The atomic absorption spectrophotometer was used to determine the concentrations of heavy metals (Cr, Mn, Fe, Ni, Cu, Zn, As, Cd, Hg, and Pb) in the soils samples. This study reveals that the studied landfill contribute to increase the concentration of heavy metals (Cr, Mn, Fe, Ni, Cu, Zn, As, Hg and Pb) in soils. The pH KCl of the studied landfill soils were less than 7, which reflects the acidic nature of the landfill soils. The Landfills soils were classified between 'practically uncontaminated', 'Uncontaminated to Moderate' and 'Moderate'. The geoaccumulation of Cr, Mn, Fe, Ni, and As were less than one for the studied landfills. The classifications show that the landfill soil from KARPALA and DAGNOIN were the moderate polluted with Cu, Zn and Pb. The Cu, Zn and Pb were metal that contribute more in the pollution in the landfill soil at Ouagadougou. Statistical study reveals that increasing total organic matter tends to decrease the concentrations of manganese, zinc, copper and lead.

Keywords: Soil, Heavy Metals, Solid Waste, Landfill Sites

1. Introduction

In Burkina Faso, the rapid demographic evolution of the agglomeration continues to exacerbate the problems of housing expansion in the capital. According to INSD, the population of Ouagadougou increased from 1,475,223 in 2006 to 2,684,052 inhabitants in 2020 [1]. The increase in household and industrial waste is in line with that of the population. Approximately 600,000 tons of waste are generated annually, municipal technical services evacuate just over 50%.

The amount of household waste has increased in recent decades due to accelerated population growth. This phenomenon is more critical in developing countries which do not have the resources to properly manage waste.

Public landfills have been the source of many environmental problems in recent years [2]. Heavy metals are one of the dangerous pollutants found in the soils of these landfills. Also, heavy metal pollution of soils, leachate, plants and groundwater in the vicinity of landfills is shown in several scientific publications [3-9].

The objective of this study is to know the impact of urban landfills on the concentration of heavy metals in soils and to assess the risk of soil pollution in the city of Ouagadougou. The soil samples were analyzed by atomic absorption spectrophotometry and the analyzed heavy metals were cadmium, lead, arsenic, chromium, manganese, iron, nickel, copper, mercury and zinc.

2. Materials and Methods

2.1. Study Area

Burkina Faso is located in the West Africa. Its area is 274,000 square kilometers. It shares its borders with 6 countries, namely Mali to the north and west, Niger to the north and east, Benin to the south-east, Ghana and Togo to the south, the Côte-d'Ivoire to the west and south.

The Ouagadougou is administrative capital of Burkina Faso (1°28 to 1°36 west longitude and 12°20 to 12°26 north latitude) and is situated in the center part of the country. The table 1 shows the geographical coordinates of landfill where the soils samples have been appropriated.

Table 1. *Geographical coordinates of landfill.*

Sampling site	Geographical coordinates	
	latitude	Longitude
IDS	12.356333	-1.481067
DAGNOIN	12.366800	-1.486100
SIAO	12.352150	-1.487850
KARPALA	12.335683	-1.472683
UO1	12.377720	-1.500574
TOUDOUWEOGO	12.422533	-1.505533

2.2. Soil Sample Treatment Protocol

Mechanical preparation consisted of sieving the soil samples through a certified 200 mesh (75 micron) sieve.

The test portion used is one gram. The samples were weighed using a PA214C balance from OHAUS PIONEER, precision 10-4 gram and capacity 200g.

The mineralization consisted in mineralizing the samples weighed by aqua regia (2.5 mL of HNO3 + 7.5 mL of HCl) at controlled temperature (water bath at 90 ± 50°C) for one hour. The acids used are of the analytical type.

The solution obtained is consequently brought to 100 mL by way of demineralized water with a conductivity of less than 2 µS / cm.

Elements of interest were analyzed by atomic absorption spectrophotometry. The modes used depend on the properties of the elements. So:

1) The flame mode was used for the analysis of chromium (Cr), manganese (Mn), iron (Fe), nickel (Ni), copper (Cu) and zinc (Zn);
2) The oven mode was used for the analysis of arsenic (As), cadmium (Cd) and lead (Pb);
3) Hydride generation (FIAS) or cold vapor was used for the analysis of mercury (Hg).

The characteristics of the equipment used are:

1) Model AANALYST 200 from PERKIN ELMER for flame mode;
2) PERKIN ELMER PinnAcle900t model for oven mode and hydride generation.

The analysis results are valid on the basis of the performance of the analysis methods used (limit of detection and quantification, data of duplicates and reference materials inserted in the chemical preparation of the samples, selectivity of the method, the robustness of the method, data for control solutions, data for chemical blanks, etc.).

2.3. Quantification of the Soil Pollution

In this study, to quantify the degree of pollution in the refuse dump soils the geoaccumulation index, Igeo, was used [3, 4, 10]:

$$I_{geo} = \ln(\frac{C_n}{1,5B_n})$$

Where: C_n: measured concentration of metal in the refuse dump soil (µg/g);

B_n: background value of heavy metal (µg/g);

and 1.5: background matrix correction factor.

The degree of pollution of the refuse dumps by the metals was assessed (table 2) using the geoaccumulation index (igeo) classification (table 2) by Förstner et al. [10].

Table 2. *Geoaccumulation index classification.*

Geoaccumulation index, I_{geo}	I_{geo} class	Contamination intensity
> 5	6	very strong
> 4–5	5	strong to very strong
> 3–4	4	strong
> 2–3	3	moderate to strong
> 1–2	2	moderate
> 0–1	1	uncontaminated to moderate
< 0	0	practically uncontaminated

3. Results and Discussions

3.1. Concentration of Heavy Metals in the Soil of the Landfills Studied

Table 3 presents the average concentrations of heavy metals at the different study sites and the average concentration of the geological background (which will be taken as a reference point).

Table 3. *Average concentration (ppm) of heavy metals in some landfill soils.*

	Cr	Mn	Fe	Ni	Cu	Zn	As	Hg	Pb
IDS	44.98	505.43	32757.29	21.03	99.45	209.63	4.87	4.05	36.99
UO 1	59.79	510.29	49716.24	16.48	75.90	306.50	5.76	0.00	51.68
DAGNOIN	54.43	893.43	46365.89	20.36	183.63	842.43	5.64	2.66	141.75
SIAO	81.99	846.65	49989.28	23.83	94.46	663.75	6.35	5.61	79.53
KARPALA	52.50	1051.58	37409.35	21.13	157.09	1340.88	5.25	0.00	105.73
TOUDOUWEOGO	58.70	844.87	44168.02	22.54	97.15	538.58	4.98	0.00	57.81
Background	48.57	260.95	27539.50	15.12	33.10	317.15	3.68	4.21	24.27

Chromium: the average concentration varies from 44.98 ppm to 81.99 ppm depending on the landfills studied. The background concentration is 48.57 ppm. Only the soils of the Institute of Science landfill show an average chromium concentration lower than the background concentration. Landfills contribute to increased chromium concentration in the soil.

Manganese: the average manganese concentration was between 505.43 ppm to 1051.58 ppm. The background concentration was 260.95 ppm and very low than the manganese concentration; which reflects a strong contribution of landfills on the evolution of manganese concentration in soils.

Iron: The highest average iron concentration was 49,989.28 ppm and observed in the soils of the SIAO landfill. The background iron concentration was 27,539.50 ppm, which was lower than the lowest concentration (32,757.29 ppm), reflecting the impact of landfills on increasing iron concentration in soils.

Nickel: the lowest average concentration of nickel was 16.48 ppm and measured in the soils of the University of Ouagadougou landfill (UO1). This concentration being higher than the background concentration, this explains the contribution of landfills on the nickel concentration in soils.

Copper: the average copper concentrations measured in landfill soils varied between 75.90 ppm and 183.63 ppm but the concentration obtained in the background was 33.10 ppm; which shows a strong contribution of landfills in the evolution of copper concentration in soils.

Zinc: The mean concentrations of zinc observed in the landfills of IDS (209.63 ppm) and UO1 (306.50 ppm) were lower than the background concentration which was set at 317.15 ppm. The landfills of IDS and UO1 do not contribute to changes of zinc concentration in soils.

Arsenic: the discharges studied all contribute to the evolution of the concentration of arsenic in the soils because the measurements obtained in this study was lower than that of the concentration background (3.68 ppm).

Mercury: the concentration of mercury in the background was 4.21 ppm. Only the soil from the SIAO landfill with a mercury concentration of 5.61 ppm contributed to the change in the mercury concentration in the soil.

Lead: The smallest lead concentration obtained in this study was 36.99 ppm on the IDS landfill. This concentration was higher than that of the background which is 24.27 ppm; which reflects the contribution of landfills in the evolution of mercury concentration in soils.

In conclusion, this study reveals that the studied landfills contribute to an increase in the concentration of heavy metals (Cr, Mn, Fe, Ni, Cu, Zn, As, Hg and Pb) in soils.

3.2. Physico-chemical Parameter of Landfill Soils

Table 4 presents the pH-H_2O, pH-KCl, the electrical conductivity, apparent density, the total organic matter, the carbon-nitrogen ratio and the assimilable phosphorus of the studied landfills soils. The pH-H_2O ranges from 5.84 to 7.32 and the pH-KCl ranges from 5.14 to 6.62.

Table 4. *Physico-chemical parameter of landfill soils.*

	pH-H_2O	pH KCl	Electrical conductivity	Apparent density	Total organic matter %	Carbon Nitrogen ratio	Assimilable phosphorus ppm
IDS	7.01	6.46	1.44	1.60	1.82	12.50	4.95
UO 1	5.84	5.14	2.49	1.59	2.19	11.00	7.62
DAGNOIN	6.88	6.22	2.10	1.57	1.46	11.50	4.63
SIAO	7.32	6.46	0.89	1.60	1.46	12.00	13.46
KARPALA	6.92	5.88	0.69	1.56	0.73	12.00	7.46
TOUDOUWEOGO	7.16	6.62	0.39	1.56	2.19	13.00	3.73

The pH-KCl must be considered as the "pH" of the soil since it takes into account all the physicochemical characteristics [11]. So the soil pH of the studied landfills was less than 7, which reflects the acidic nature of the studied landfill soils. The three parameters that influence the mobility of heavy metals are organic matter, soil texture and soil pH [11, 12]. The variation in pH easily modifies the behavior of metals in the soil. The complexation mechanism seems to promote landfills of IDS, DAGNOIN, SIAO and TOUDOUWEOGO on soils because the pH is greater than 6.

Soil with an organic matter content of at least 5% and a pH greater than 5, promotes lead accumulation and allows better adsorption of zinc [11, 13, 14]. In this study, the organic matter varies between 0.73% to 2.19% on the soil of the studied landfills, therefore less than 5%, moreover the pH is higher than 5. These results of pH and organic matter could favor the accumulation of lead and allow better adsorption of zinc on soils.

When the pH is high, copper is fixed to the oxides of iron, of manganese, argil and organic matter.

In soils, the main form of chromium is chromium III and a small proportion of chromium VI. Under anaerobic conditions and low pH (pH <5), chromium III in soils and in sediments results from the transformation of chromium VI. In addition in the soil, chromium III is absorbed more easily than chromium VI. In the soils of the studied landfills, the predominant form of chromium would be chromium VI, which is more bioavailable and potentially toxic [11, 15]. This could justify the mobility of chromium in the soils of the landfills. Iron occurs regularly in reduced form (Fe^{2+}) and is quite mobile in acidic soils [11]. In this study, the pH were acidic, this will cause iron mobility in the soil of the studied landfills.

3.3. Quantification of Soil Pollution by Heavy Metal

Table 5. *Index of geo-accumulation (Igeo) of heavy metal in every site and classification.*

Ig	Cr	Mn	Fe	Ni	Cu	Zn	As	Hg	Pb
IDS	-0.482	0.256	-0.232	-0.076	0.695	-0.820	-0.126	-0.445	0.016
UO 1	-0.198	0.265	0.185	-0.319	0.424	-0.440	0.043	-	0.350
DAGNOIN	-0.292	0.825	0.115	-0.108	1.308	0.571	0.022	-0.866	1.359
SIAO	0.118	0.771	0.191	0.049	0.643	0.333	0.140	-0.118	0.781
KARPALA	-0.328	0.988	-0.099	-0.071	1.152	1.036	-0.050	-	1.066
TOUDOUWEOGO	-0.216	0.769	0.067	-0.006	0.671	0.124	-0.103	-	0.462

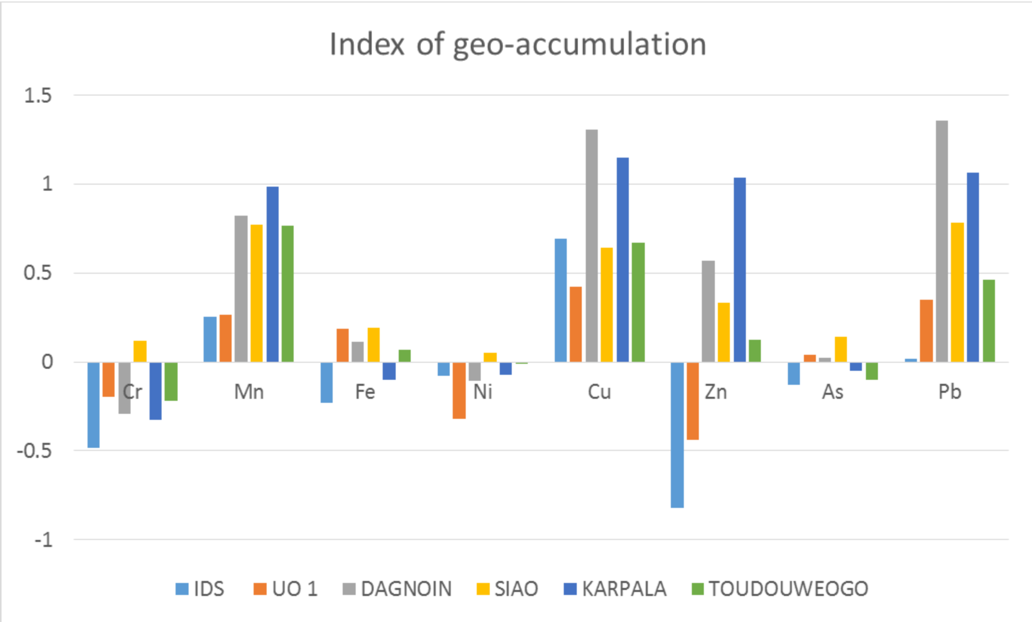

Figure 1. *Geo-accummulation indices (Igeo) of heavy metal in every site.*

The table 5 and figure 1 shown the variation and the value of geo-accumulation indices for each heavy metal.

The geo-accumulation indices various between -0,820 to 0,695 in landfill soil from Institute of sciences (IDS). The pollution levels in landfill soil from Institute of IDS for Cr, Fe, Ni, Zn and As were practically uncontaminated but uncontaminated to moderate for Mn, Cu and Pb.

The maximal value of geo-accumulation indices was 0,424 in the landfill soil from University of Ouagadougou (UO1). The metal who contribute more to the soil pollution at University of Ouagadougou (UO1) was Cu, with a level of uncontaminated to moderate.

The pollution levels in soil from DAGNOIN landfill were uncontaminated except for Cu and Pb with the geo-accumulation indices values of 1,308 and 1,359 respectively.

The pollution levels in landfill soil from SIAO and TOUDOUWEOGO were uncontaminated for all metal. In KARPALA landfill soil, the pollution levels for Cu, Zn and Pb were moderate.

In conclusion, the classifications show that the landfill soil from KARPALA and DAGNOIN were the moderate polluted with Cu, Zn and Pb. And the landfill soil from Institute of Sciences (IDS) was the least polluted with the metals. The Cu, Zn and Pb were metal that contribute more in the pollution in the landfill soil at Ouagadougou.

3.4. Statistical Analysis

The normalized principal component analysis (NPCA) applied to soil samples was performed with R software.

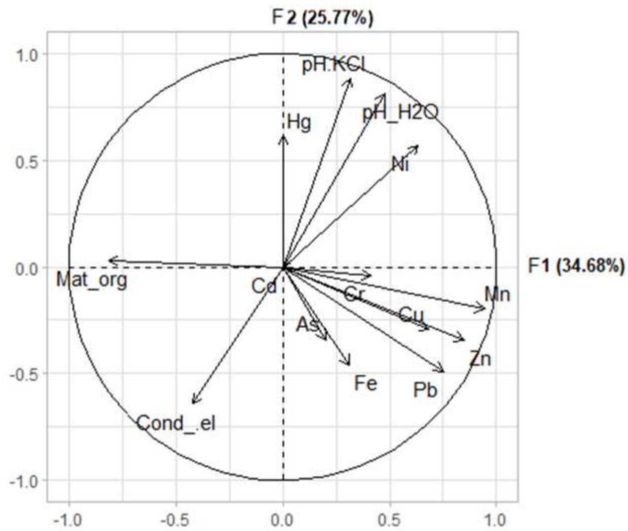

Figure 2. *Community circle of the factorial plane F1 - F2.*

The analysis of the community circle (Figure 2) allows to identify two main groups of parameters. The first group (G_1) consists of Hg, Ni, pH-H_2O and pH-KCl. The second group (G_2) is formed by the parameters Cu, Pb, Mn and Zn. The grouping of the two communities of parameters is done in the positive part of the factor F1 axis.

***Table 6.** ACPN correlation matrix.*

variables	Cr	Mn	Fe	Ni	Cu	Zn	As	Hg	Pb	pH_H_2O	pH.KCl	Cond_.el	Mat_org
Cr	1.00												
Mn	0.34	1.00											
Fe	0.78	0.33	1.00										
Ni	0.37	0.50	-0.04	1.00									
Cu	-0.08	0.68	0.10	0.41	1.00								
Zn	0.18	0.92	0.21	0.23	0.59	1.00							
As	0.72	0.15	0.72	-0.22	-0.22	0.21	1.00						
Hg	0.21	-0.29	-0.04	0.16	-0.32	-0.30	0.36	1.00					
Pb	0.14	0.78	0.41	0.12	0.78	0.77	0.32	-0.16	1.00				
pH_H2O	0.16	0.31	-0.22	0.67	-0.02	0.17	-0.03	0.59	0.04	1.00			
pH.KCl	0.04	0.13	-0.24	0.69	0.03	-0.09	-0.24	0.56	-0.07	0.92	1.00		
Cond_.el	-0.28	-0.30	-0.01	-0.56	0.06	-0.19	0.16	-0.24	0.19	-0.62	-0.59	1.00	
Mat_org	-0.11	-0.71	0.03	-0.39	-0.61	-0.82	-0.08	-0.07	-0.59	-0.31	-0.09	0.36	1.00

The analysis of the correlation matrix (Table 6), allows to note strong correlations between the parameters As and Cr (0.72), As and Fe (0.72), Cr and Fe (0.78), Mn and Zn (0.92), Mn and Cu (0.68), Mn and Pb (0.78), Zn and Pb (0.77), and Cu and Pb (0.78). These strong correlations allows to say that these parameters are governed by the same mechanism.

On the other hand, the positive and significant correlations between pH-KCl and Ni (0.69), and between pH and Ni (0.67) reflect the influence of pH in the adsorption of nickel. The negative and significant correlations between Mat_org and Mn (-0.71), Zn (-0.82), Cu (-0.61) and Pb (-0.59) indicate that the value of total organic matter tends to increase when the concentrations of manganese, zinc, copper and lead decrease.

4. Conclusion

This study showed that the studied landfills contribute to increase the concentration of heavy metals (Cr, Mn, Fe, Ni, Cu, Zn, As, Hg and Pb) in soils. The pH-KCl of the landfills studied were less than 7. The complexation mechanism is favored on the landfills soils of IDS, DAGNOIN, SIAO and TOUDOUWEOGO. The values of pH and organic matter promote the accumulation of lead, allow better adsorption of zinc on the soils and mobility of chromium and iron in the soils of the studied landfills. The landfill soil from KARPALA and DAGNOIN were the moderate polluted with Cu, Zn and Pb. The landfill soil from Institute of Sciences (IDS) was the least polluted with the heavy metals. The Cu, Zn and Pb were metal that contribute more in the pollution in the landfill soil at Ouagadougou. An increase of the total organic material causes a reduction of the concentrations of manganese, zinc, copper and lead.

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