Journal of Geography, Environment and Earth Science International

Volume 27, Issue 9, Page 83-92, 2023; Article no.JGEESI.103347
ISSN: 2454-7352

Pollution Assessment of Two Urban Soils in the City of Ngaoundere, Cameroon

Ngoudzeu Lontsi Hareinda [a], Hassana Boukar [b*], Adjia Robert [c], Talba Dalatou [a] and Ibrahima Adamou [b]

[a] *Department of Chemical Engineering, University Institute of Technology (U.I.T.), P.O. Box 455, Ngaoundere, Cameroon.*
[b] *Department of Biological Sciences, Faculty of Science, Ngaoundere (F.S.), P.O. Box 454, Ngaoundere, Cameroon.*
[c] *Department of Applied Chemistry, National School of Agro-Industrial Sciences (ENSAI), P.O. Box 454, Ngaoundere, Cameroon.*

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/JGEESI/2023/v27i9707

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/103347

Original Research Article

Received: 24/05/2023
Accepted: 26/07/2023
Published: 07/08/2023

ABSTRACT

Urban soils contain high concentrations of both inorganic and organic pollutants due to anthropogenic activities that compromise their physicochemical quality. The aim of the present study is to assess the contamination level of the soils around the central prison and the regional hospital of Ngaoundere (Cameroon) exploited for crop production. To achieve this objective, soil samples were collected from the surface at a depth of 0-20 cm and 20-30 cm and were analysed to determine heavy metals level on one hand and the enrichment factor (EF) and the geo-accumulation index (I_{GEO}) on the other hand to better assess the level of contamination. Results

---

**Corresponding author: E-mail: hassanaboukar65@gmail.com;*

showed that the concentrations of heavy metals in soils varied according to sites and ranged from 0.51±0.01 to 4.93±0.07 mg/kg for Cd, 10.57±0.01 to 99.47±0.80 mg/kg for Cu, 595.57±0.60 to 872.85±1.58 for Fe, 24.35±0.56 to 43.62±0.65 mg/kg for Ni, 35,25±0.26 to 307.21±0.32 mg/kg for Pb and 31.73±0.11 to 384.32±5.84 mg/kg for Zn. The sequence of heavy metal concentrations in the hospital and prison soils was as follows: Fe>Zn>Pb>Cu>Ni>Cd. Base on the IGEO and the EF the results showed, apart from iron, an accumulation of various metals in both prison and hospital soils. These soils are not suitable for crop production because there is a risk of contamination of the human food chain.

Keywords: Pollution; urban soils; enrichment factor; geo-accumulation index; Ngaoundere, Cameroon.

1. INTRODUCTION

Schools, hospitals and prisons are the places in a city with the highest concentration of people. As a result, they generate a lot of solid, gaseous and liquid waste [1,2]. This puts a lot of pressure on the city and one of the consequences is the pollution of the urban soil. Studies have shown that urban soils contain high concentrations of both inorganic [3–5] and organic pollutants [6–8]. Anthropogenic activities compromise the quality of urban soils by altering their physicochemical quality [9,10]. The extent to which the quality of urban soils is modified can vary depending on the extent of anthropogenic activities on the one hand and the type of urban soil on the other. Ngaoundere, the capital of the Adamawa region, is a medium-sized city with over 200,000 inhabitants. The solid and liquid waste generated by health care activities or in the prison environment increased pollutant load on the urban soil of this city. The present study aims to assess the pollution of two soils, i.e. the soil around the central prison and the soil around the regional hospital. After a physicochemical characterization of the three soils and measurements of the average concentrations of some chemical constituents, calculations of the geo-accumulation index and the enrichment factor will make it possible to assess the extent of the pollution.

2. MATERIALS AND METHODS

2.1 Materials

Fig. 1 shows the geographical location of the study area and the three main sites where the soil samples were collected. These are (S1) soil from the control area (P13 to P17), (S2) soil from the prison (P1 to P6) and (S3) soil from the hospital (P7 to 12)). The control site is located upstream of the two above-mentioned sites and does not suffer from any pollution. Three replicates were performed and averages were obtained.

2.2 Methods

2.2.1 Soil sampling

The sampling area was identified and limited, and then divided into 5 samples for the selected points. Soil sampling was carried out on each selected points, to form a composite sample per site. Each sampling unit is 200 to 300 g of soil. The units were determined diagonally [11]. To this end, using a chisel (cylindrical and solid) and a shovel, the samples were taken from the surface at a depth of 0-20 cm and 20-30 cm from the soil surface at a depth of approximately 100 cm. The samples were kept at a temperature of 4°C to limit the activities of the micro-organisms and a modification of their composition.

2.2.2 Sample processing of soils

The soil, previously dried in the open air and at room temperature in the laboratory, was homogenised and dried in an oven at 105°C for 24 hours [12]. After introducing 0.5 g of soil into the beaker, 9 mL of HNO3 (69%) and 3 mL of HCl (37%) were added. The mixture was kept hermetically sealed for 2 h and then heated to 150°C for 2 h. After cooling, the mineralization was then brought to a final volume of 50 mL with distilled water and filtered at 0.45 µm using a "Whatman" filter paper filter paper [13]. The final volume was passed to a flame atomic absorption spectrophotometer for reading.

2.2.3 Selected parameters and methods for pollution level assessment

From the several physicochemical parameters, four were chosen because of their importance for the bioavailability of heavy metals, namely Hydrogen potential (pH); electrical conductivity (EC); residual moisture (RM) and organic matter content (OM). Methods used are described by some authors [14]. Six heavy metals were selected, namely cadmium (Cd); copper (Cu); iron (Fe); nickel (Ni); lead (Pb) and finally

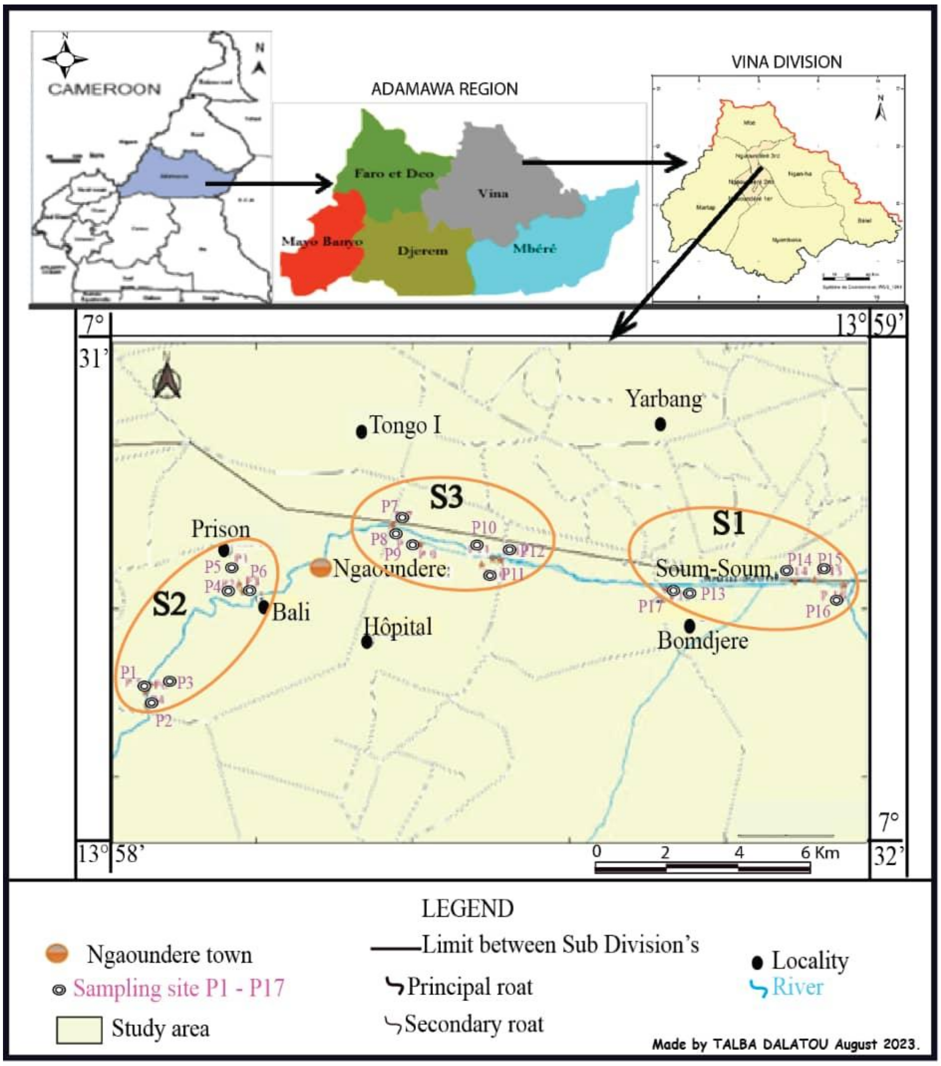

Fig. 1. Geographical location of soil sampling sites

zinc (Zn). The concentrations were analysed using an atomic absorption spectrophotometer (AAS), model of VARIAN Spectra AA.20. The evaluation of the pollution itself was carried out using two indices, the geo- accumulation index (IGEO) and the enrichment factor (EF).

2.2.4 Geo-accumulation index

One of the most widely used criteria for assessing the intensity of metal pollution is the geo-accumulation index [5,15-18]. This index was developed by Müller [19]. It has been successfully applied to the measurement of the intensity of heavy metal pollution in soil [20,21]. The formula to calculate the geo-accumulation index (I_{geo}) is:

$$I_{geo} = log_2\left[\frac{C_i}{1.5*C_{ri}}\right] \qquad (1)$$

Where Igeo is the geo-accumulation index; Ci is the concentration of the metal under investigation; Cri is the concentration of the geological background or control site; 1.5 is the exaggeration factor of the geological background or control site. It consists of seven (7) seven grades or class (Table 1) [19].

2.2.5 Enrichment factor

The enrichment factor indicates the number of times an element is enriched relative to the abundance of that element in the reference material. The formula to calculate EF is:

$$EF = \frac{\left({}^{C_i}/_{C_{ie}}\right)_S}{\left({}^{C_i}/_{C_{ie}}\right)_{RS}} \qquad (2)$$

Where EF is the enrichment factor; C_i the concentration of the element under investigation in the sample, C_{ie} the concentration of an immobile element in the sample. In our case, we choose Iron (Fe) who was considered as the immobile element and on the fact that iron is naturally present in the soils of the study area. In addition, it is part of the reference materials widely used in the literature [23–25]. Thus $(Ci/C_{ie})s$ is the ratio of the concentration of the metal under investigation to the concentration of the selected immobile metal and mobile element in the sample or reference sample $(C_i/C_{ie})RS$ the same ratio but in the reference sample (RS).

The following table (Table 2) present the different class of enrichment Factor in relation to enrichment intensity.

Table 1. Geo-accumulation index (I_{geo}) in relation to pollution intensity [21,22]

Class	Value	Soil pollution intensity
0	$I_{geo}≤0$	Practically uncontaminated
1	$0<I_{geo}<1$	Uncontaminated to moderately contaminated
2	$1<I_{geo}<2$	moderately contaminated
3	$2<I_{geo}<3$	Moderately to heavy contaminated
4	$3<I_{geo}<4$	heavy contaminated
5	$4<I_{geo}<5$	Heavy to extremely contaminated
6	$5<I_{geo}$	extremely contaminated

Table 2. Enrichment Factor (EF) in relation to enrichment intensity [16, 22]

Class	Value	Enrichment intensity
0	EF<2	Deficiency to minimal enrichment
1	2<EF<5	Moderate enrichment
2	5<EF<20	Significant enrichment
3	20<EF<40	Very high enrichment
4	EF<40	Extremely high enrichment

2.2.6 Statistical analysis of the data

Statistical analyses were carried out with Statgraphics Centurion software, version XVI. The comparison of the soil means of the three sites was performed by analysis of variance (ANOVA) to see if the differences were significant. The Scheffe test was chosen to determine the difference between the soil means of the three sites. The ANOVA was performed at the significance level α=0.01.

3. RESULTS AND DISCUSSION

3.1 Soil Physical-Chemical

Table 3 summarizes the values of physicochemical parameters of the three soils studied. The soil pH concentration obtained from the study sites varies from 5.83±0.92 to 8.05±0.50. The highest value was obtained in the control soil followed by the hospital soil and finally the prison soil. These results corroborate those obtained by some authors [26] at Camp Prison. The mobility and bioavailability of metallic elements are largely dependent on the pH of the environment [27]. Zn, Pb, Ni, Cd and Cu are more mobile and bioavailable at acid pH [28,29]. Thus, these elements would be more bioavailable in the soil of the Prison and the Hospital. These pH values could be linked to soil moisture. In fact, the hydrolysis of alterable minerals (a phenomenon that is more important when the soil is wet) consumes the H protons+ and contributes to an increase in pH [30]. Indeed, the input of organic matter and other mineral elements through effluents is one of the causes of the variation of soil pH.

The conductivity in the studied soils varies from 1255.33±302.728 µs/Cm to 2326.0±2082.63 µs/Cm. The highest value is obtained at the Prison. The conductivity values of the prison and hospital soils differ from the conductivity value of the control soil. The high conductivity values obtained in this study would indicate a high mineral load in the different soils studied. This shows that the soils studied are soils with excessive mineralization. These results are comparable to those found by some authors [31] who found that the soils of Adamawa Region are highly mineralized. This would be due either to the organic matter or the geochemical composition of the latter. Indeed, the contribution of organic matter by effluents contributes to the mineralization of organic matter which releases various mineral elements into the soil. In addition, these results could be explained by the positive charges of the heavy metals (Cd^{2+}, Fe^{3+} , Pb^{2+} , Ni^{2+} , Cu^{2+} , Zn^{2+}) retained in this work [32].

The proportion of residual moisture obtained in the control soil is 3.87±1.25%, that of the prison and hospital soil is 24.08±13.53% and 16.34±11.82% respectively. The results presented show that the prison soil samples are the wettest and the control soil samples the driest. Residual moisture promotes solubility, mobility, and bioavailability of heavy metals in soil through the formation of complexes with organic ligands [33]. As a result, Zn and Cd would be more soluble and mobile in the prison and hospital soil due to the high moisture content of these soils.

The organic matter content varies from 9.71±2.70 to 13.96±1.01%. The highest proportion of residual moisture is obtained in the hospital soil (13.96±1.01%) followed by the prison soil (12.83±3.27%). Organic matter is an important source of plant nutrients and knowledge of its total content in the soil provides information on its fertilizing potential [34]. It also plays an important role in soil structure, water retention, cation exchange and complex formation [35]. The results of the organic matter content allow us to say that our soils are rich in organic matter. The work of authors [36] have shown that the soils of Adamawa Region are ferralitic soils. In the soil classification, ferralitic soils have an organic matter content of 2-4%. From this, we can conclude that the high organic matter content of our soils is of exogenous origin. The high content observed would be favored by the flow of effluent water rich in organic waste which decomposes and enriches the environment in organic matter. The increase in these contents is accompanied by an improvement in structure, ease of water infiltration and an increase in water retention capacity [37]. In addition, with its colloidal properties, its character as an element-fixing substance and its chelating power, it plays an important chemical role in soils: release of nutrients after mineralization and increase in the cation exchange capacity [38].

The analysis of variance shows a significant difference for all physicochemical parameters studied at a 99% probability level and the Scheffe test distinguishes two distinct groups. In the first group belong the prison and hospital soils and in the second group the control soil.

Table 3. Parameter's values of the soils of the different sites

Parameters	Control Soil	Prison's Soil	Hospital's Soil
Physical parameter			
pH	8.05±0.50^{b}	5.83±0.92^{a}	6.43±0.90^{a}
Conductivity (µs/cm)	1255±302^{a}	2326±208^{b}	2113±907^{b}
Soil moisture (%)	3.87±1.25^{a}	24.08±13.53^{b}	16.34±11.82^{b}
Organic matter (%)	9.71± 2.70^{a}	12.83±3.27^{b}	13.96±1.01^{b}
Major chemical constituants			
Calcium (g/Kg)	40.24±1.5^{a}	15.22±1.03^{b}	17.53±1.06^{c}
Magnesium (g/Kg))	10.86±1.4^{a}	10.08±1.03^{b}	11.23±1.02^{c}
Nitrogen (g/Kg)	13.98±1.3^{a}	15.89±1.02^{c}	15.58±1.02^{b}
Carbon (g/Kg)	15.62±1.57^{a}	17.44±1.90^{a}	18.09±1.58^{a}
Orthophosphate (g/Kg)	10.92±1.06^{a}	11.64±1.25^{b}	10.63±1.24^{a}
Heavy metals			
Cadmium (mg/kg)	0.51±0.01^{a}	4.93±0.07^{c}	3.5±0.06^{b}
Copper (mg/kg)	10.57±0.01^{a}	99.47±0.80^{c}	51.78±2.06^{b}
Iron (mg/kg)	595.57±0.60^{a}	827.36±0.62^{b}	872.85±1.58^{c}
Nickel (mg/kg)	24.35±0.56^{a}	37.68±0.32^{b}	43.62±0.65^{c}
Lead (mg/kg)	35.25±0.26^{a}	307.21±0.32^{c}	95.02±7.02^{b}
Zinc (mg/kg)	31.73±0.11^{a}	384.32±5.84^{c}	201.03±1.81^{b}

Values with the same letter are not statistically different at the 1% probability level

3.2 Major Chemical Constituents Assessment

The average concentrations of major elements in the three soils studied are also presented in Table 3.

The Calcium content in the sampled soils varies between 4.24±0.05 g/100 g and 7.53±0.06 g/100 g with the highest concentration in the hospital soil. Magnesium concentration varies from 0.86±0.04 g/100 g for the control soil to 1.23±0.02 g/100 g for the hospital soil. A high cation content could have an impact on the conductivity of the soils and consequently on the capacity to fertilize the soil. The high concentrations obtained in this study may be due to contamination from calcium and magnesium rich in the wastewaters of the prison and the hospital.

The concentration of nitrogen in the sampled soils varies between 3.98±0.13g/100g and 5.89±0.02 g/100 g. The highest concentration is recorded in the prison soil. The Carbon concentration obtained in this study varies from 5.62±1.57 g/100 g to 8.09±0.58 g/100 g. The Carbon content obtained in the control soils was 5.62±1.57 g/100 g and 7.44±1.90 g/100 g in the prison soils. With a concentration of 8.09±0.58 g/100 g the hospital soils have the highest carbon concentration. Organic carbon and nitrogen contents are high in our sampled soils. The nitrogen concentration in our soils could be the result of the transformation of ammoniacal nitrogen into nitrate by nitrifying bacteria. In sum, we can deduce that prison and hospital effluents are at the origin of these high concentrations. Indeed, nitrogen (inorganic ammoniacal ($NH4+$) and nitric ($NO3-$) forms that can be used for crops could also come from the transformation of organic matter deposited under the action of micro-organisms.

Finally, the concentration of orthophosphate varies from 0.92±0.06 g/100 g to 1.64±0.25 g/100 g. The high orthophosphate content is probably the result of the phosphate input from the effluent. The high ortho-phosphate content at the prison site could explain the presence of these pollutants in the wastewater. The wastewater penetrates more easily, increasing the water reserve of the soil and decreasing the susceptibility to erosion. It is the main indicator of soil quality for both the physical and chemical properties and the biological properties of the organic matter that contains it.

The analysis of variance shows a significant difference between the different soils studied for all the parameters mentioned above except for the carbon concentration ($F=2.29$; $P=0.1823>0.05$). The same is true for the Scheffe test, which distinguishes two distinct groups. The prison and hospital soils belong to one group, while the control soil belongs to another.

3.3 Heavy Metals Assessment

Table 3 summarizes the concentration values of the heavy metals in the study. Of all the heavy metals studied, the concentration of cadmium is the lowest, less than 5 mg per kilogram of soil. The concentration of cadmium in the sampled soils varies from 0.51±0.01 mg/kg to 4.93±0.07 mg/kg. The lowest concentration is obtained in the control soils and the highest in the prison soils. The concentration in the hospital soil is close to that in the prison soil. The concentration of copper in the control soil is 10.57±0.01 mg/kg and that in the prison and hospital soil is 99.47±0.80 mg/kg and 51.78±2.06 mg/kg respectively. Our results for cadmium and copper concentrations in the three sites are above the average concentrations obtained from soils worldwide, which are 0.06 mg/kg and 20 mg/kg respectively [39,22].

Of all the heavy metals studied, the concentration of iron is highest, 500 mg per kilogram of soil. The concentration of iron in the sampled soils varies between 595.57±0.60 mg/kg and 872.85±1.58 mg/kg. The highest concentration is recorded in the hospital soil.

The concentration of nickel in the sampled soils varies between 24.35±0.56 mg/kg and 43.62±0.65 mg/kg. The concentration of nickel in the control soils is 24.35±0.56 mg/kg, the concentration of Ni in the Prison soils is 37.68±0.32 mg/kg, the concentration in the hospital soils is 43.62±0.65 mg/kg. The highest concentration of Nickel is found in the hospital soil. The average concentration of Nickel in the eastern control area of the Prison is below the world average while that of the Hospital is slightly above the average of 40 mg/kg [39,22].

The concentration of lead recorded in the control soils is 35.25±0.26 mg/kg, the concentration obtained in the prison soils is 307.21±0.32 mg/kg and that obtained in the hospital soils is 95.02±7.02 mg/kg. As for lead, the lead concentrations in all study sites are in the range of 10-150 mg/kg world-wide average [39,22].

The concentration of zinc varies from 31.73±0.11 mg/kg to 384.32±5.84 mg/kg with the highest concentration in the hospital soil. The concentration of Zinc in the three sites is also in the range of the world standard which is 10-300 mg/kg except for the Prison site. Thus, higher levels of Zn (101.2 to 6448.3 mg/kg), Ni (11.5 to 986.2 mg/kg), Cu (17.4 to 115.8 mg/kg) and Pb (31.3 to 3544.6 mg/kg) were obtained in the Abidjan market garden soils amended with poultry droppings, but lower levels of Cd (0.22 to 1.72 mg/kg) [40]. The high levels of heavy metals, especially Zn, observed in the prison and hospital soils could be attributed not only to the parent material of which they are composed, but also to anthropogenic activities in the immediate vicinity of the study area.

The amount of metals mobilized in the soil environment is a function of pH, metal properties, redox conditions, soil properties, organic matter contents, clay contents, cation exchange capacity [41–43]. Heavy metals are generally more mobile at pH below 7 than at pH above 7 [44]. The pH of the prison and hospital soils varies from 5.83±0.92 to 6.43±0.90. This is an indicator of risk for the use of these soils for agricultural purposes as the crops can absorb and accumulate heavy metals from the contaminated soils [5].

The sequence of heavy metal concentrations in the hospital and prison soils is as follows: Fe>Zn>Pb>Cu>Ni>Cd. This sequence is similar to that obtained by several authors [45,46]. Their sequence was as follows: Fe>Zn>Cr>Cu>Ni>Pb>Cd.

The analysis of variance shows a significant difference for all heavy metals studied. The Scheffe test distinguishes three groups representing soils from three study sites, regardless of the heavy metal chosen.

3.4 Geo-Accumulation Index

Table 4 and Table 5 present the indices, classes and contamination levels of the prison and hospital soil respectively. The geo-accumulation index was calculated using the heavy metal concentrations of the control site soil as a reference. A high to moderately high contamination of zinc is observed, which is the most polluting heavy metal in both soils. This can be explained by the low mobility of this metal when the soil pH is acidic [35]. It is followed by nickel, which is more present in the hospital soil. Cadmium, lead and copper show a moderate geo-accumulation index whatever the soil. Finally, the soils do not accumulate iron during pollution. This can be explained by the type of soil present in this area where ferralitic soils are predominant and already rich in iron.

3.5 Enrichment Factor

Table 6 presents the effect of enrichment factor (EF) of the various heavy metals in the soil of the prison and that of the hospital. This shows zinc in the prison soil (8.72) has the high enrichment factor, followed by cadmium still in the prison soil (6.96). This can be explained by the proximity of the prison to a landfill and the use of compost from this landfill in the surrounding fields. With an enrichment factor greater than 1.5 for all heavy metals in both soils except nickel and lead in the prison soil, widespread enrichment with heavy metals can be accepted in both soils.

Table 4. Geo-accumulation index, class and level of contamination (Prison's soil)

Heavy metals	Igeo	Igeo Class	Level of contamination
Cd	2.72	2	Moderately contaminated
Cu	2.65	2	Moderately contaminated
Fe	-0.11	0	Not contaminated
Ni	0.07	1	Not contaminated to moderately contaminated
Pb	2.54	2	Moderately contaminated
Zn	3.01	4	Heavily contaminated

Table 5. Geo-accumulation index, class and level of contamination (Hospital's soil)

Heavy metals	Igeo	Igeo Class	Level of contamination
Cd	2.22	2	Moderately contaminated
Cu	1.71	2	Moderately contaminated
Fe	-0.03	0	Not contaminated
Ni	0.28	3	Moderately to heavily contaminated
Pb	0.85	1	Not contaminated to moderately contaminated
Zn	2.08	3	Moderately to heavily contaminated

Table 6. Enrichment factor of the studied soils

Soil	EF_{Zn}	EF_{Ni}	EF_{Cu}	EF_{Pb}	EF_{Cd}
Prison’s Soil	8.72	1.11	6.77	0.14	6.96
Hospital’s Soil	4.32	1.22	3.33	1.84	1.65

4. CONCLUSION

The aim of this study was to carry out a physico-chemical characterization and to assess the degree of pollution of two urban soils by comparing them with a control soil. The results showed that for all physico-chemical parameters, there is a difference between the two soils subjected to pollution and the control soil. The same observation applies to heavy metal concentrations. Indices such as the geo-accumulation index and the enrichment factor were used to determine the extent of pollution. It shows that, apart from iron, all other heavy metals have been accumulated in polluted soils. The soils are mainly polluted with zinc and cadmium. Enrichment factor values are also high for these two heavy metals. The high degree of pollution is a risk if these soils are used for crops because there is a risk of contamination of the human food chain.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Sellami S, Zeghouan O, Dhahri F, et al. Assessment of heavy metal pollution in urban and peri-urban soil of Setif city (High Plains, eastern Algeria). Environ Monit Assess. 2022;194:126. Available:https://doi.org/10.1007/s10661-022-09781-4
2. Boukar H, Hareinda NL, Dalatou T, et al. Physico-chemical characterization and assessment of the risk of pollution: A Case of Wastewater Generated by the Regional Hospital and the Central Prison of the City of Ngaoundere, Cameroon. Int J Environ Clim Chang. 2023;13:921–932. Available:https://doi.org/10.9734/ijecc/2023/v13i92314
3. Duong TTT, Lee BK. Determining contamination level of heavy metals in road dust from busy traffic areas with different characteristics. J Environ Manage. 2011;92:554–562. Available:https://doi.org/10.1016/j.jenvman.2010.09.010
4. Rate AW. Inorganic Contaminants in Urban Soils. In: Rate AW (ed) Urban Soils: Principles and Practice. Springer International Publishing, Cham. 2022;153–199.
5. Wei B, Yang L. A review of heavy metal contaminations in urban soils, urban road dusts and agricultural soils from China. Microchem J. 2010;94:99–107. Available:https://doi.org/https://doi.org/10.1016/j.microc.2009.09.014
6. Fitzgerald L, Wikoff DS. Persistent Organic Pollutants. In: Wexler P (ed) Encyclopedia of Toxicology (Third Edition), Third Edit. Academic Press, Oxford. 2014;820–825.
7. Rate AW. Organic Contaminants in Urban Soils. In: Rate AW (ed) Urban Soils: Principles and Practice. Springer International Publishing, Cham. 2022;201–242.
8. Thakur M, Pathania D. Environmental fate of organic pollutants and effect on human health. Elsevier Inc; 2019.
9. Sarkar A, Deb S, Ghosh S, et al. Impact of anthropogenic pollution on soil properties

in and around a town in Eastern India. Geoderma Reg. 2022;28:e00462.
Available:https://doi.org/https://doi.org/10.1016/j.geodrs.2021.e00462

10. Novák TJ, Balla D, Kamp J. Changes in anthropogenic influence on soils across Europe 1990–2018. Appl Geogr. 2020;124:102294.
Available:https://doi.org/https://doi.org/10.1016/j.apgeog.2020.102294
11. AFNOR (2000) AFNOR NFX 31-130. Soils quality -Chemical methods - Determination of cationic exchange capacity (CEC) and extracible cations. 15
12. Fekhaoui M, Bennasser L, Bouchrine M. Utilisation d'un nouvel indice d'évaluation de la contamination métallique des sediments: Cas du bas Sebou (Maroc). Bull Inst Sci. 1996;20:143–150
13. Marcellin YK, Bernard SM, Trokourey A, Yobou B. Assessment of sediments contamination by heavy metals in a tropical lagoon urban area (Ebrié Lagoon, Côte d'Ivoire). Eur J Sci Res. 2009;34:280–289.
14. Rodier J, Legube B, Merle N. L'analyse de l'eau. ISBN 13: 9782100072460, Dunod. Dunod-technique, Paris ; 2009.
15. Sun Y, Zhou Q, Xie X, Liu R. Spatial , sources and risk assessment of heavy metal contamination of urban soils in typical regions of Shenyang , China. 2010;174:455–462.
Available:https://doi.org/10.1016/j.jhazmat.2009.09.074
16. Weissmannova Dolezalova H, Pavlovsky J. Indices of soil contamination by heavy metals – methodology of calculation for pollution assessment (minireview). Env Monit Assess. 2017;189:616:
17. Prasad Ahirvar B, Das P, Srivastava V, Kumar M. Perspectives of heavy metal pollution indices for soil, sediment, and water pollution evaluation: An insight. Total Environ Res Themes. 2023;6:100039.
Available:https://doi.org/https://doi.org/10.1016/j.totert.2023.100039
18. Fadlillah LN, Utami S, Rachmawati AA, et al. Ecological risk and source identifications of heavy metals contamination in the water and surface sediments from anthropogenic impacts of urban river, Indonesia. Heliyon. 2023;9: e15485.
Available:https://doi.org/https://doi.org/10.1016/j.heliyon.2023.e15485
19. Müller G. Index of geoaccumulation in sediments of the Rhine River. Geo Journal. 1969;2:968–980
20. Loska K, Cebula J, Pelczar J, et al. Use of enrichment, and contamination factors together with geoaccumulation indexes to evaluate the content of Cd, Cu, and Ni in the Rybnik water Reservoir in Poland. Water. Air. Soil Pollut. 1997;93:347–365.
21. JI Y, FENG Y, WU J, et al. Using geoaccumulation index to study source profiles of soil dust in China. J Environ Sci. 2008;20:571–578.
Available:https://doi.org/10.1016/S1001-0742(08)62096-3
22. Khan S, Naushad M, Lima EC, et al. Global soil pollution by toxic elements: Current status and future perspectives on the risk assessment and remediation strategies – A review. J Hazard Mater. 2021;417:0–2.
Available:https://doi.org/10.1016/j.jhazmat.2021.126039
23. Liu W, Zhao J, Ouyang Z, So L. Impacts of sewage irrigation on heavy metal distribution and contamination in Beijing, China. 2005;31:805–812.
Available:https://doi.org/10.1016/j.envint.2005.05.042
24. Fang T-H, Hwang J-S, Hsiao S-H, Chen H-Y. Trace metals in seawater and copepods in the ocean outfall area off the northern Taiwan coast. Mar Environ Res. 2006;61: 224–243.
Available:https://doi.org/10.1016/j.marenvres.2005.10.002
25. Inengite AK, Abasi C. Flood Impacted Soil Application of Pollution Indices for the Assessment of Heavy Metal Pollution in Flood Impacted Soil; 2015.
Available:https://doi.org/10.9734/IRJPAC/2015/17859
26. Adjia R, Fezeu WML, Tchatchueng JB, et al. Long term effect of municipal solid waste amendment on soil heavy metal content of sites used for periurban agriculture in Ngaoundere, Cameroon. African J Environ Sci Technol. 2008;2: 412–421.
27. Dousset S, Morel JL, Wiart J. Influence du chaulage sur la biodisponibilité des éléments métalliques en trace incorporés au sol lors de l'épandage de boues. Etude Gest Des Sols. 1999;6:105–114

28. De Matos AT, Fontes MPF, da Costa LM, Martinez MA. Mobility of heavy metals as related to soil chemical and mineralogical characteristics of Brazilian soils. Environ Pollut. 2001;111:429–435. Available:https://doi.org/https://doi.org/10.1016/S0269-7491(00)00088-9
29. Deng W, Wang F, Liu W. Identification of factors controlling heavy metals/metalloid distribution in agricultural soils using multi-source data. Ecotoxicol Environ Saf. 2023;253:114689. Available:https://doi.org/https://doi.org/10.1016/j.ecoenv.2023.114689
30. Bourrelier PH, Berthelin J. Contamination des sols par les éléments traces : les risques et leur gestion. Rapport n°42; 1998.
31. Fezeu Wombuwou ML. Statut minéral des sols, des plantes des eaux d'abreuvage et de bovins du pâturage de Wakwa au Cameroun; 2006.
32. Moszkowicz P, Tiruta-Barna L, Barna R. Modéliser pour prévoir les flux de polluants émis par un dispositif contenant les déchets. Révue des Sci l'eau. 2002; 15/n°(Spéc):41–55.
33. Martinelli I. Infiltration des eaux de ruissellement pluvial et transfert de polluants associés dans le sol, urbain. Vers une approche globale et pluridisciplinaire. Thése de Doctorat. Institut National Des Sciences Appliquées de Lyon; 1999.
34. Mathieu C, Pieltain. Analyse chimique des sols. Méthodes choisies. Lavoisier, France; 2003.
35. Alloway BJ, Ayres DC. Chemical Principles of Environmental Pollution, Second edition, Blackie Ac. London; 1997.
36. Tchotsoua M, Yetgan JB, Tchouass W. Indicateurs, processus et causes de l'érosion accélérée des parcours pastoraux sur le plateau de Ngaoundéré au Cameroun. Le Flamb. 1999;50:39–43.
37. Leprun JC. Matière orgnique et conservation des sols, exemples brésilien. Cah ORSTOM Pédologie. 1988;24(4):333–338.
38. Ben Hassine H, Gallali T, El Amri S, Ben Hassen R. Evaluation quantitative et rôles de la matière organique dans les sols cultivés en zone subhumides et semi-humides méditerranéennes de la Tunisie. Agro Solut. 2008;19.
39. Vodyanitskii YN. ScienceDirect Standards for the contents of heavy metals in soils of some states. Ann Agrar Sci. 2016;14:257–263. Available:https://doi.org/10.1016/j.aasci.2016.08.011
40. Kouassi JK, Ahoua ES, Baize D, et al. Diagnostique d'une contamination par les éléments traces métalliques de l'épinard (Spinacia Oléracea) cultivé sur des sols maraîchers de la ville d'Abidjan (Côte d'Ivoire) amendés avec de la fiente de volaille. Eur J Sci Res. 200 ;21:471–487.
41. Arun B, Mukherjee A. Nickel: A review of occurence, uses, emissions and concentration in the environment in Finland. Environ Rev. 1988;6:1–15.
42. Kimberley MFH, William H. Trace metals in Montreal urban soil and the leaves of Teraxacum officinale. Can J Soil Sci. 1999;79:385–387.
43. Sauve S, Henderson W, Allen H. Solid-solution portioning of metals in contaminated soils: Dependence of pH, total metal burden and organic mater. Env Sci Techn. 2000;1125–1131.
44. Baize D, Sterckman T, Piquet A, et al. Dérogations relatives à la réglementation sur l'épandage des boues de stations d'épuration. Comment formuler une demande pour les sols à teneurs naturelles élevées en éléments traces métalliques. Guide Technique; 2005.
45. Ekengele LN, Blaise A, Jung MC. Accumulation of heavy metals in surface sediments of Lere Lake, Chad. Geosci J. 2017;21:305–315. Available:https://doi.org/10.1007/s12303-016-0047-4
46. Okunola OJ, Uzairu A, Ndukwe G. Levels of trace metals in soil and vegetation along major and minor roads in metropolitan city of Kaduna, Nigeria. African J Biotechnol. 2007;6:1703–1709.

© 2023 Hareinda et al.; This is an Open Access article distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/4.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/103347