

Original Research Article
**Pollution assessment of two urban soils in the
city of Ngaoundere, Cameroon.**

ABSTRACT

The aim of the present study is to assess the contamination of various chemical pollutants in two urban soils exposed to wastewater from two highly frequented human's spaces, i.e. the hospital and the prison. To achieve this objective, two soils from two contaminated sites were compared with a control site. In addition, evaluation tools such as the enrichment factor (EF) and the geo-accumulation index (IGEO) were used to better assess the level of pollution. The results show that physical-chemical parameters such as temperature, conductivity, residual moisture and organic matter content differ between sites at a statistical significance level of 1%. The same is observed for the major chemical's pollutants studied such as calcium, magnesium, carbon and phosphate. With the exception of nickel, elements such as cadmium, copper, lead and zinc have a moderate to high level of contamination. Zinc is the most enriched metal in these soils with an extreme EF. The enrichment of these two urban soils with heavy metals is a risk for the populations that consume plants grown on them.

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

UNDER PEER REVIEW

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. 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 [1–3] and organic pollutants [4–6]. Anthropogenic activities compromise the quality of urban soils by altering their physicochemical quality. 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

Figure 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.

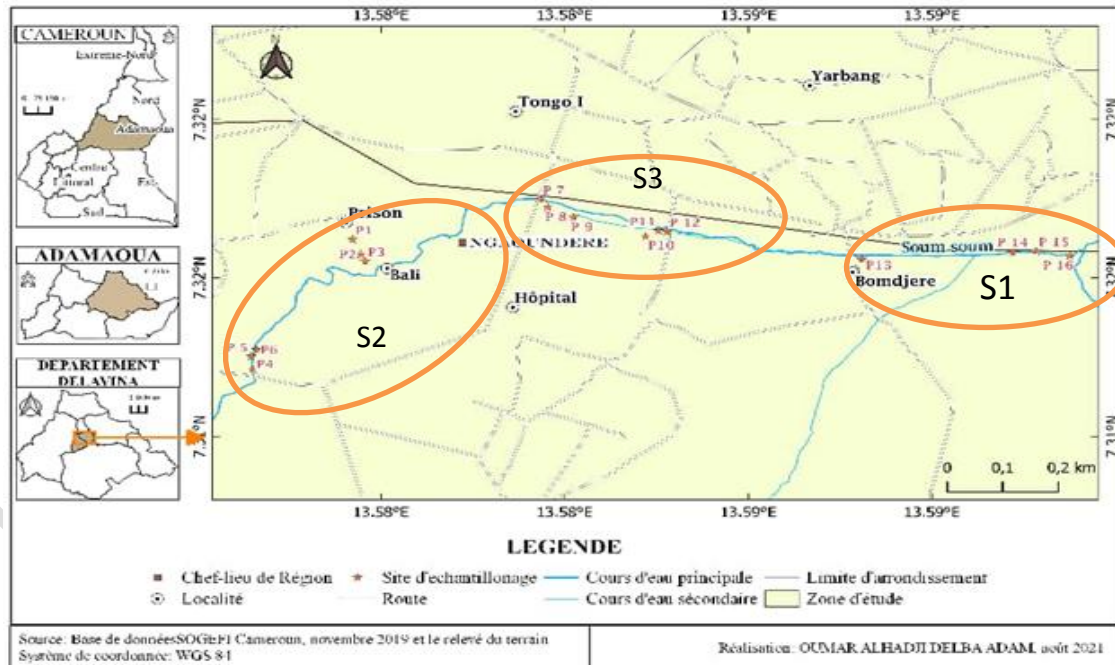


Figure 1: Geographical location of soil sampling sites.

2.2. Methods

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 [7]. 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 cm². The samples were kept at a temperature of 4°C to limit the activities of the micro-organisms and a modification of their composition.

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 [8]. 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 [9]. The final volume was passed to a flame atomic absorption spectrophotometer for reading.

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

Table 1) [13].

Table 1: Geo-accumulation Index (I_{geo}) in relation to pollution intensity ([15] [16]).

Class	Value	Soil pollution intensity
0	$I_{geo} \leq 0$	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

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:

$$EF = \frac{(C_i/C_{ie})_S}{(C_i/C_{ie})_{RS}} \quad (2)$$

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

(RM) and organic matter content (OM). Methods utilized are described by some authors [10]. Five heavy metals were selected, namely cadmium (Cd); copper (Cu); iron (Fe); nickel (Ni); lead (Pb) and finally 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).

Geo-accumulation index

One of the most widely used criteria for assessing the intensity of metal pollution is the geo-accumulation index [3, 11, 12]. This index was developed by Müller [13]. It has been successfully applied to the measurement of the intensity of heavy metal pollution in soil [14, 15]. The formula to calculate the geo-accumulation index (I_{geo}) is:

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

Where I_{geo} is the geo-accumulation index; C_i is the concentration of the metal under investigation; C_{ri} 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 7 seven grades or class (

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 [17–19]. Thus $(C_i/C_{ie})_S$ 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 2: Enrichment Factor (EF) in relation to enrichment intensity (Khan et al., 2021; Weissmannova Dolezalova and Pavlovsky, 2017).

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

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 $\alpha=0.01$.

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 [20] at Camp Prison. The mobility and bioavailability of metallic elements are largely dependent on the pH of the environment [21]. Zn, Pb, Ni, Cd and Cu are more mobile and bioavailable at acid pH (Baize et al., 2005). 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 [22]. 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 $\mu\text{s}/\text{Cm}$ to 2326.0 ± 2082.63 $\mu\text{s}/\text{Cm}$. 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 [23] 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+} , Cr^{2+} , Pb^{2+} , Ni^{2+} , Cu^{2+} , Zn^{2+}) retained in this work [24].

The proportion of residual moisture obtained in the control soil is $3.87\pm 1.25\%$, that of the prison and hospital soil is $24.08\pm 13.53\%$ and $16.34\pm 11.82\%$ 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 [25]. 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

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

Parameters	Soil Control	Prison Soil	Hospital 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 constituents			
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
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

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

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 [26]. It also plays an important role in soil structure, water retention, cation exchange and complex formation [27]. The results of the organic matter content allow us to say that our soils are rich in organic matter. The work of authors [28] 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 [29]. 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 [30].

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.

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/100g and 7.53±0.06 g/100g with the highest concentration in the hospital soil. Magnesium concentration varies from 0.86±0.04

g/100g for the control soil to 1.23 ± 0.02 g/100g 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 ± 0.13 g/100g and 5.89 ± 0.02 g/100g. The highest concentration is recorded in the prison soil. The Carbon concentration obtained in this study varies from 5.62 ± 1.57 g/100g to 8.09 ± 0.58 g/100g. The Carbon content obtained in the control soils was 5.62 ± 1.57 g/100g and 7.44 ± 1.90 g/100g in the prison soils. With a concentration of 8.09 ± 0.58 g/100g 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 (NH_4^+) and nitric (NO_3^-) 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/100g to 1.64 ± 0.25 g/100g. 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 de 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 [31] [16].

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 [31] [16].

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 [31] [16].

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) [32]. 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 [33–35]. Heavy metals are generally more mobile at pH below 7 than at pH above 7 [36]. 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 [3].

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 [37, 38]. 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 [27]. 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 ferrallitic soils are predominant and already rich in iron.

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

Heavy metals	I _{geo}	I _{geo} 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	I _{geo}	I _{geo} 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

3.5. Enrichment factor

Table 6 presents the effect of enrichment 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 6: Enrichment factor of the studied soils.

Soil	FE _{Zn}	FE _{Ni}	FE _{Cu}	FE _{Pb}	FE _{Cd}
Prison Soil	8.72	1.11	6.77	0.14	6.96
Hospital 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.

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