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# Assessment of heavy metal contamination degree of municipal open-air dumpsite on surrounding soils: Case of dumpsite of Bonoua, Ivory Coast

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**Abstract-** In Ivory Coast, the majority of uncontrolled dumpsites are open-air. The aim of this work is to study the lateral and vertical distribution of heavy metals or metalloids in soils surrounding the open dumpsite of M'Ploussoue Park in Bonoua, which has a wet tropical climate and located at upper topographical position. The physical and chemical parameters, such as the particle size, pH, exchangeable cations, CEC and contents of heavy metals, were studied using various analytical techniques. The vertical and lateral distribution of heavy metals or metalloids in soil samples collected from the M'Ploussoue dumpsite in Bonoua were found to be in the following order: Zn > Pb > Cr > Ni > Cd > As > Cu > Se, regardless of the topographical position of the soil profile. Ours results indicate that there are high levels of heavy metals (Cr, Pb, Cd, Zn, Ni) that exceed the CCME permissible limits in agricultural and industrial soils in both the top soil layers and in soil located below the dumpsite, probably due to the migration and infiltration of dumpsite leachate. The vertical and lateral distributions of metals or metalloids at dumping sites can pose potential ecological risks if these elevated concentrations of metals migrate into soil, plants and groundwater, where they present a danger to humans. Thus, it appears to be necessary to apply proper remediation techniques.

**Keywords:** assessment, heavy metal, toposequence, solid waste, open air dumpsite, M'Ploussoue Park, Bonoua.

## INTRODUCTION

In Ivory Coast, the rapid rate of industrialization, population growth and modernization have contributed to the generation of millions of tons of solid waste in different categories, including hazardous and non-hazardous waste. Solid wastes are heterogeneous and include plastics, electronic goods, electroplating waste, painting waste, used batteries, old clothes, syringes, needles, papers and organics materials, which are the origin of the high levels of heavy metals observed in dumpsite soil [1, 2].

The continuous accumulation of municipal solid wastes from different sources causes an undesirable enrichment of heavy metals or metalloids in dumpsite areas [3]. These toxic elements can enter soil and groundwater resources and, consequently, pose a severe environmental threat [4]. Heavy metals in the environment are non-biodegradable and are subject to bioaccumulation [5]. Thus, soil and groundwater can be vertically and laterally contaminated by the migration of leachate under waste dumpsites, where they damage the environment and human health [6]. However, the stability of heavy metal(loids) in the soil is high in contrast to other components of the environment (such as the atmosphere or water), leading to long-term or even permanent pollution [3]. Soil and water contaminated with heavy metal or metalloid attract attention because of their severe threats to the food chain, human health and soil ecosystems [7].

For this reason, it is necessary to investigate soils surrounding open dumping sites, which can be possible sources of pollutants. Thus, it appears to be important to study the lateral and vertical distributions of heavy metal(loids) in soils at the open dumpsite of M’Ploussoue Park in Bonoua, which has a wet tropical climate.

Ours aims in this work are to (1) determine the nature of the toxic elements present in the dumpsite soil of the M’Ploussoue Park in Bonoua, (2) follow the lateral and vertical distributions of heavy metal(loids) in the soils along a toposequence in dumpsite areas, and (3) identify the potential ecological risks for users and residents.

## MATERIALS AND METHODS

### *Study area*

The study area is situated in the southeast region of Ivory Coast at Bonoua, 60 km from Abidjan, between latitude 5°14' to 5°31' N and longitude 3°13' to 3°51' W. The dumping site is located in the M’Ploussoue Park, Bonoua, at latitude 5°16' N and longitude 3°36' W (Fig. 1). This dumping site has been abandoned since 2006 with 10 years old and covers an area of 16 ha. One kind of waste (solid municipal waste) are dumped in this site: and the mean depth of the dumping site for garbage is 8 meters. The site which is situated at 5 km of dumping site at latitude 5°15' N and longitude 3°35' W were choose as a control site.

The study area is located in a tropical climate and has a mean annual rainfall of approximately 2000 mm, with a rainy season (May to July and September to October) and dry season (July to August and December to April). The average monthly temperature of Bonoua is above 20°C. The geology of the study area is dominated by sedimentary formations, especially detritic rocks. The soil of study area is classified as an arsenic ferralsol, and the dumping site is classified as a Fumic Anthroposol in the World Reference Base for Soil Resources [8].

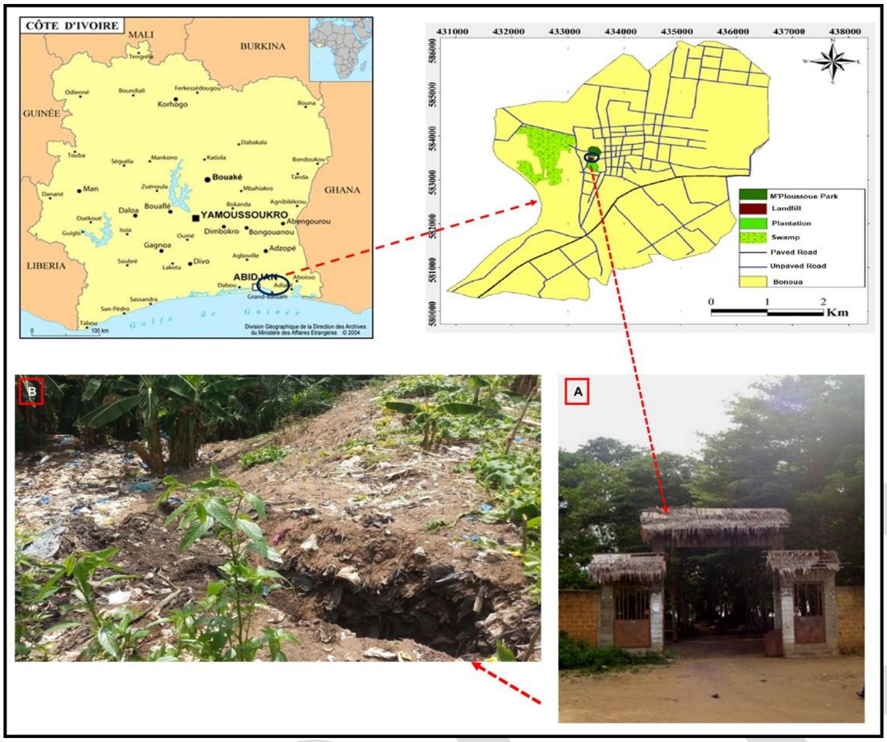


**Fig.1**: Localization of Study area. A- M'Ploussoue Park; B – Waste deposal site

*Field Procedure*

A toposequence was installed on the catchment along the line of the greatest slope according to the method described by [9]. Eight soil pits, positioned along topographic segments (upper slope, middle slope, lower slope and bottom slope) with two pits per topographic segments, were georeferenced using a GARMIN GPS 72 and were dug to 1.5 meters in depth or to bedrock and then described according to the methods of [10]. The morphological parameters considered in this study include the layer thickness, main color, organic matter, size, coarse material nature, texture, structure, porosity, consistency, drainage internal, roots (abundance and orientation), transition and boundary between horizons, and structure. Soil classification was carried out according to soil resources [8]. After the description, four representative soil pits, including the dumpsite, were chosen along the toposequence for complete characterization. The position of the four pits chosen along the studied transect are presented in Table I.

**Table I** : Characteristics of the sampling soil pits.

| Soil Pits | Topographic Position | Distance from dumpsite in (m) | Characteristics |
|---|---|---|---|
| LS 1 | Upper slope (P1) | 0 | At center of dumpsite |
| LS 2 | Middle slope (P2) | 10 | At below of dumpsite |
| LS 3 | Lower Slope (P3) | 20 | At below dumpsite |
| LS 4 | Bottom slope (P4) | 30 | At below dumpsite |

### *Soil samples*

Soil samples were collected from the horizons or layers for each soil profile selected. Soil samples were sieved to 2 mm to remove various types of waste (paper, used batteries, electronic goods, wood, plastic paper, straws, buckets, tin cans, sacks, clothes, glass bottles, cotton wool, food waste, leaves, fruit waste, medicine bottles, foams, ashes, water sachets, cardboard and human excreta) and were then air-dried and transported to the laboratory for various analyses.

Another soil sample from other sector was also taken as soil control to compare the quality of soil from dumping site.

### *Laboratory analysis*

Several analyses were performed to study parameters to evaluate the soil quality. Particle size analysis was carried out by a pipette using the Robinson-Köln method, and soil textural classes were established using the textural triangle [11] (Robert and Frederick, 1995). The Walkley and Black method and Kjeldahl method were used to determine organic carbon and total nitrogen (N-total), respectively. Soil pH was determined at a 1:2.5 (w/v) (soil/water or potassium chloride solution) ratio using an electrode pH-meter [12] (Mathieu and Pieltain, 2003). The exchangeable cations (Ca+2, Mg+2, Na+ and K+) and cation exchange capacity (CEC) were determined using the [13] Metson (1956) method. Heavy metals (Pb, Cd, Cr, As, Cu and Zn) were then analyzed by atomic absorption spectroscopy (ICP-OES) (Spectroblue). Analysis of the pH, exchangeable cations, CEC and contents of heavy metals were performed in the laboratory of the Institute of Ecology and the Sciences of Environment (IESE) in Paris, France. Analyses of the granulometry, C, and N were conducted in the Laboratory of Soils and Plants at the National Polytechnic Institute Felix Houphouet Boigny (INP-HB) in Yamoussoukro, Ivory Coast.

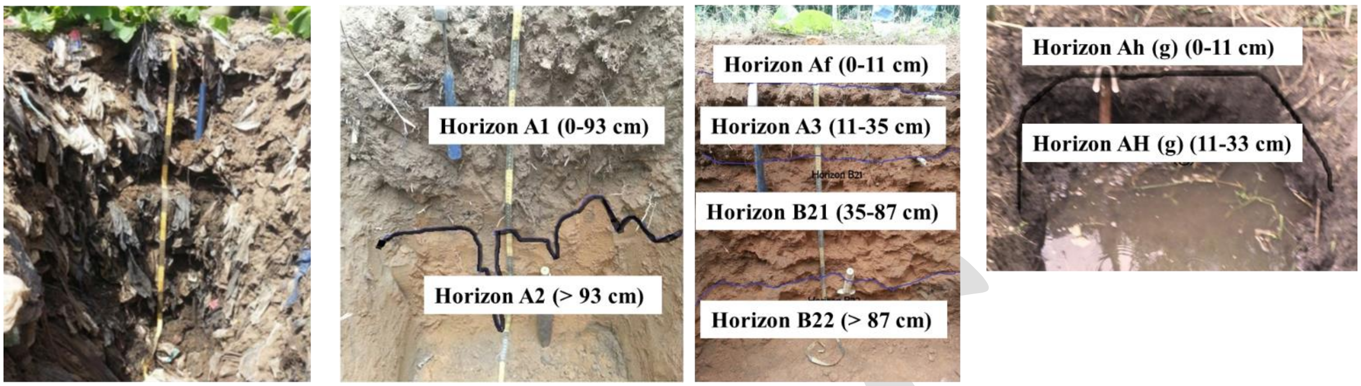
### *Statistical Analysis*

The data were subjected to statistical analysis using 7.1 Statistica software at a 5% probability level. Significant differences between different parameters (particle size, chemical parameters, and heavy metal content) of soils collected from different toposequence positions were performed using the Student–Newman–Keuls (SNK) test at $\alpha<5\%$ probability level.

## RESULTS

### *Morphological characteristics of the soil along the studied toposequence in dumpsite areas*

The results of each selected profile localized at different topographic positions in the waste deposal areas are presented in Fig. 2. The profiles show that the center of the waste deposal site (P1) is slightly deeper at the upper slope position (less than 50 cm depth) due to the accumulation of various types of municipal solid wastes found in profile 1 (P1), such as paper, used batteries, electronic goods, wood, plastic paper, straws, buckets, tin cans, sacks, clothes, glass bottles, cotton wool, food waste, leaves, fruit waste, medicine bottles, foams, ashes, water sachets, cardboard and human excreta (Fig. 2). The description of soil samples from profile 1 (P1) show that the soil is anthropogenic soil and is classified as Fumic Anthroposol soil according to the World Reference Base [8]. At 10 and 20 meters from the waste deposal site, at the middle (Profile 2) and lower (Profile 3) slope positions, respectively, the soils are deep (120 cm in depth) and are classified as Histic Arenite Ferralsol at the middle slope position and as Arenic Ferralsol at the lower slope position (Fig. 2). However, at the bottom slope, the soil depth decreases and groundwater appears from a depth of 30 cm. This soil is classified as Gleyic Histosol according to [8].



**Upper slope (LS 1)** **Middle slope (LS 2)** **Lower slope (LS 3)** **Bottom slope (LS4)**

**P1-Fimic Anthroposol** **P2-Humic Arenic Ferralsol** **P3-Arenic Ferralsol** **P4-Gleyic Histosol**

**Fig.2**: Soil morphological description along studied toposequence in dumpsite areas

*Soil Particle Size*

The soil physical properties are presented in Table II. Sand (ranging from 36% -77%) is the dominant particle size fraction of the fine earth (< 2 mm) analyzed, regardless of the slope position. Soil samples from the center of the waste deposal site and localized at the upper slope have sand as the dominant particle size fraction (77%), followed by clay (21%) and silt (2%). Along the slope position of the soil profile, the silt and clay contents significantly increase (Student's–Newman–Keuls test, 95% (Table II)), varying by 21 to 38% for clay and 2 to 26% for silt at the bottom slope. However, the sand content decreases significantly (Student's test, 95%) along the studied toposequence (Table II), where the highest contents are observed at the upper slope (77%) and the lowest contents at the bottom slope (36%).

**Table II** : Percentage particle size fraction (%) of the soil collected at different topographical positions.

| topographical Positions | Particle Size (%) | | |
|---|---|---|---|
| | Clay | Silt | Sand |
| Upper slope | $21 \pm 4^{c}$ | $2 \pm 0.1^{d}$ | $77 \pm 5^{a}$ |
| Middle slope | $24 \pm 3^{b}$ | $11 \pm 2^{c}$ | $66 \pm 4^{b}$ |
| Lower slope | $25 \pm 2^{b}$ | $17 \pm 1^{b}$ | $58 \pm 4^{c}$ |
| Bottom slope | $38 \pm 3^{a}$ | $26 \pm 5^{a}$ | $36 \pm 3^{d}$ |

a, b, c values with the same letter indicate no significant difference between particles size at different slope positions along toposequence (Student's t-test, $p < 0.05$)

*Chemical parameters of soil samples along slope position*

The chemical characterization of the soil of each selected profile indicates that the soil sample from the center of the waste deposal site is slightly acidic to neutral with the water pH = 6.9 and potassium chloride pHKCl = 6.1 (Table III). The pH variation (ΔpH = pHwater - pH KCl) of soil samples from dumpsite soil is ΔpH <1, showing high acidity potential. Thus, the soil samples from the middle, lower and bottom slope are strongly acidic, with the water pH varying 5.1 to 5.2 and potassium chloride pHKCl varying 4.1 to 4.4 (Table III). The pH variations (ΔpH = water pH - pH KCl) at the middle and lower slope are ΔpH >1, showing low potential acidity, and ΔpH<1 at the bottom slope, showing high potential acidity (Table III).

Calcium ($Ca^{2+}$) is the dominant basic cation in the exchange complex, with a range of 0.6 -10.4 $cmol.kg^{-1}$, followed by $K^+$ (range 0.3 - 8.3 $cmolkg^{-1}$), $Mg^{2+}$ (range 0.3 - 4.3 $cmolkg^{-1}$), and $Na^+$ (range 0.06 - 0.2), regardless of the slope position (Table III). The value of the cation exchange capacity (CEC) of the soil decreases along the topographic position with a lower value (7.9 - 25.9 $cmol.kg^{-1}$) at the upper, middle and lower slope and higher values at the bottom slope (43 $cmol.kg^{-1}$). The percentage of base saturation is higher at the upper position (a range of 74.6%), and our results show that the soils are weakly desaturated ($22\% < V < 75\%$) with a high exchange acidity (Table III) regardless of the slope position.

**Table III** : Mean values of pH, Cations ( $Ca^{2+}$; $Mg^{2+}$; $Na^+$; $K^+$), Cation Exchangeable Capacity (CEC) and saturation base (V % ) of soil samples collected at 0-30 cm depth at different slope positions along the toposequence.

| Topographical Positions | pH | | | Cations exchangeable (cmol $kg^{-1}$) | | | | CEC | Saturation |
|---|---|---|---|---|---|---|---|---|---|
| | $pH_{water}$ | $pH_{KCl}$ | ΔpH | $K^+$ | $Ca^{++}$ | $Mg^{++}$ | $Na^+$ | (cmol $kg^{-1}$) | V % |
| Upper slope | $6.9^a$ | $6.1^a$ | 0.8 | 0.25 | 4.39 | 1.04 | 0.21 | 7.9 | 74.6 |
| Middle slope | $5.1^b$ | $4.1^b$ | 1 | 0.25 | 2.56 | 0.27 | 0.164 | 15.2 | 21.3 |
| Lower slope | $5.2^b$ | $4.1^b$ | 1.1 | 2.34 | 3.07 | 1.13 | 0.318 | 25.9 | 26.5 |
| Bottom slope | $5.2^b$ | $4.4^b$ | 0.8 | 8,31 | 10,4 | 4.28 | 0.74 | 42.8 | 55.4 |

a, b, c values with the same letter indicate no significant difference between different slope positions along toposequence (Student's t-test, $p < 0.05$)

In addition, Table IV shows that the soils from the upper slope position (dumping site) along with those from middle and lower slope positions have low levels of nitrogen (less than 1%), carbon (1-2%), C/N ratio (< 12) and organic matter (13800 - 38872 $mg.kg^{-1}$). However, at the bottom slope, soils have a high carbon content (13%), organic matter concentration (219600 $mg.kg^{-1}$), C/N ratio (> 12) and relatively high level of nitrogen (Table IV).

**Table IV**: Mean values of carbon, azote, organic matter and C/N ratio of soil samples collected at 0-30 cm depth at different slope positions.

| Topographical Positions | Organic Matter (O.M.) | | | |
|---|---|---|---|---|
| | C ($mg.kg^{-1}$) | N ($mg.kg^{-1}$) | O. M. ($mg.kg^{-1}$) | C/N |
| Upper slope | $22600^b$ | $2400^b$ | $38872^b$ | 9.4 |
| Middle slope | $10500^c$ | $2100^b$ | $18100^c$ | 5 |
| Lower slope | 8000 d | $1300^c$ | $13800^d$ | 6.2 |
| Bottom slope | $127700^a$ | $7200^a$ | $219600^a$ | 17.7 |

a, b, c values with the same letter indicate no significant difference between C, N, or MO or C/N at different slope positions along toposequence (Student's t-test, $p < 0.05$)

*Heavy metal contents of soils collected at the waste deposal site and control site soil*

The Metal contents of both control and dumping site soils are presented in Table V. The mean values of all heavy metal (Cr, Pb, Cd, Zn, Ni, As, Cu and Se) detected in dumpsite soil are significantly higher at $p < 0.001$ than the mean concentration in control soil sample (Table V). The mean values of Pb, Cr, Cd, Zn and Ni are very high in the dumping site soil, at 118 mg kg$^{-1}$ dry soil, 130 mg kg$^{-1}$ dry soil, 81 mg kg$^{-1}$ dry soil, 344 mg kg$^{-1}$ dry soil and 119 mg kg$^{-1}$ dry soil, respectively. In control site soil, the mean values of heavy metal are 5.4 mg kg$^{-1}$ soil dry for Pb, 0.23 mg kg$^{-1}$ soil dry for Cr and 3.2 mg kg$^{-1}$ soil dry for Ni (Table V). For Cd, Zn, As, Cu and Se, their values are below the limit of detection (Table V).

**Table V:** The mean concentration (mg.kg$^{-1}$ Soil dry) of some heavy metal in both studied areas

| **Sites** | **Heavy Metal (mgkg$^{-1}$ dry soil)** | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **Cr** | **Pb** | **Cd** | **Zn** | **As** | **Se** | **Ni** | **Cu** |
| **Dump** | 130.1±16 | 118±19 | 81±11 | 344±22 | 9.1±5 | 4.3±1 | 119±13 | 9.5±2 |
| **Control** | 0.23 ±0.01 | 5.4 ±0.2 | nd | nd | nd | nd | 3.2 ±0.3 | nd |

Nd: not determined, values below the limit of detection. (a, b) values with the same letter indicate no significant difference between metal concentration detected on dumpsite and control site soils (Student's test, $P < 0.001$)

The comparison of metal contents of dumpsite soil with different maximum acceptable level of metal for Agricultural and residential soils are presented in Table VI and indicate that Cr, Pb, Cd, Zn, Se and Ni exceed different standard recommendations (Table VI). The contents of As (9 mg kg$^{-1}$ dry soil) and Cu (9.5 mg kg$^{-1}$ dry soil) are below the recommended concentrations (Table VI).

**Table VI:** Mean concentration (mg.kg$^{-1}$ Soil dry) of some heavy metal at dumping site and maximum acceptable concentration of metal in agricultural, and residential parkland soils in different countries

| **Heavy metal (mgkg$^{-1}$ dry soil)** | **Values observed in dumpsite** | **World Health Organization limit (WHO-limit)*** | **CCME soil limit** Agricultural** | **CCME soil limit** Residential Parkland** | **AFNOR soil limit***** |
|---|---|---|---|---|---|
| **Cr** | 130.1 | 70 | 64 | 64 | 70 |
| **Pb** | 118 | 100 | 70 | 140 | 100 |
| **Cd** | 81 | 0.35 | 1.4 | 10 | 1 |
| **Zn** | 344 | 300 | 200 | 200 | 300 |
| **Ni** | 119 | 50 | 50 | 50 | 50 |
| **As** | 9.1 | 40 | 12 | 12 | - |
| **Cu** | 9.5 | 100 | 63 | 63 | 100 |
| **Se** | 4.3 | - | 1 | 1 | |

*World Health Organization limit (WHO-limit) recommendation [44]. ** Canadian environmental quality Guidelines[26].
*** French Standards Association (AFNOR) limit recommendation [45].

*Lateral distribution of heavy metals in soil profiles along the toposequence*

Figure 3 depicts the lateral distribution of heavy metals in soil samples collected at a depth of 0-30 cm in each selected soil profile along the toposequence studied. The lateral distribution of heavy metals, such as Pb, Ni, Cd, Cr, Zn, Cu, As and Se, exhibits a similar trend, where an enrichment of heavy metals in the bottom profiles and depletion in the upper soil profiles were observed. Thus, the maximum significant concentration of heavy metals is observed at the bottom slope position and the minimum significant concentration of heavy metals is at the upper slope position, with the Pb, Ni, Cr Cd and Zn contents varying from 118 to 296 mg kg$^{-1}$ dry soil; 119 to 212 mg kg$^{-1}$ dry soil; 130 to 272 mg kg$^{-1}$ dry soil; 81 to 124 mg kg$^{-1}$ dry soil; and 344 to 489 mg kg$^{-1}$ dry soil, respectively. These heavy metal contents exceed the recommended concentrations from Association French Normalization (AFNOR) and Canadian Council of Ministers of the Environment (CCME) (Fig. 3). Despite the heavy metal enhancement in the bottom soil profile along the toposequence, the Cu, and As concentrations are below the recommended limits (Fig. 3 and Table VI).

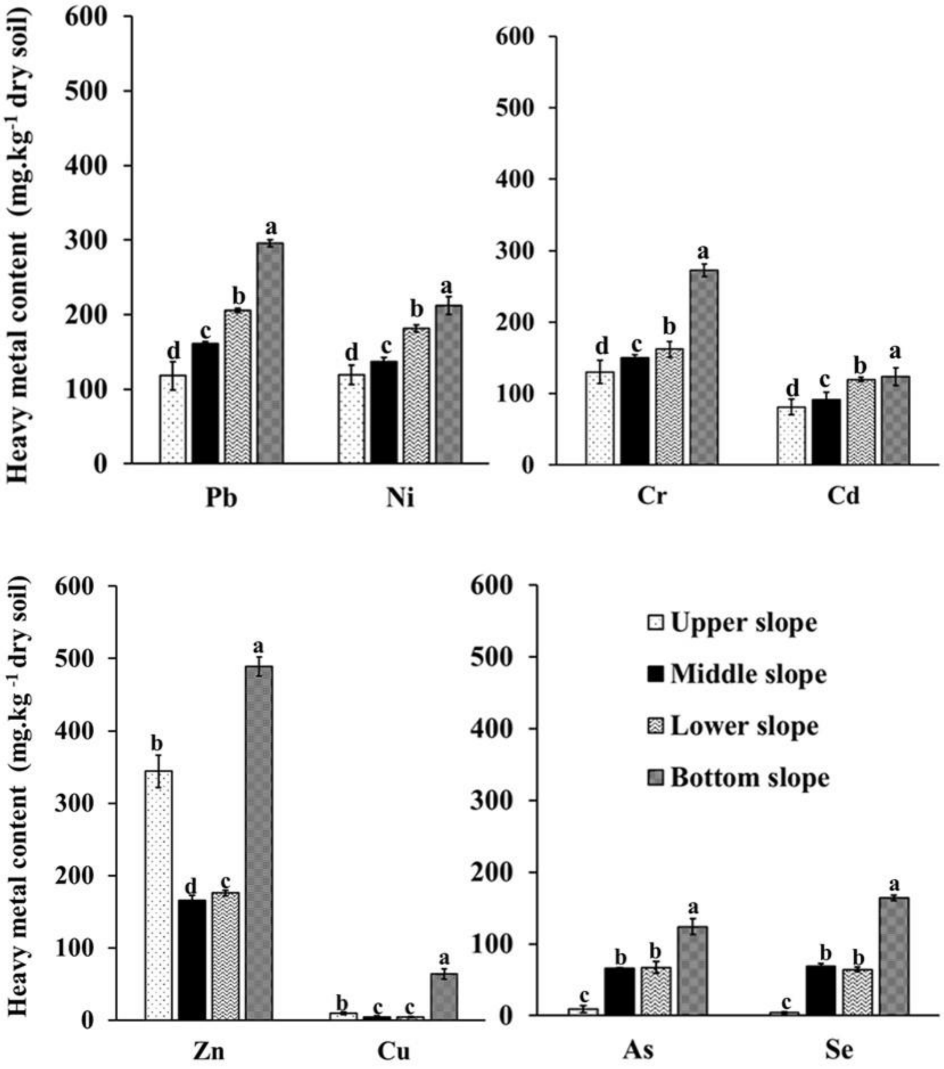


**Fig.3**: Lateral distribution of heavy metals (Chromium (Cr), Cadmium (Cd), Lead (Pb), Nickel (Ni), Zinc (Zn), Copper (Cu), Cadnium (Cd) and Selenium (Se)) of soil samples collected at 0-30cm depth along the studied toposequence. Histogram with the same letters (a, b, c, d) indicate no significant difference between heavy metal content observed at different topographical positions (upper, middle, Lower and bottom slope) according to the Newman-Keuls Student's test with $p < 0.05$.

*Vertical distribution of heavy metals in the soil profile*

The vertical distribution of heavy metals, such as Pb, Ni, Cr, Cd and Zn, display a similar trend (Fig. 4). The concentration of heavy metals (Pb, Ni, Cr, Cd and Zn) is higher in the top layers than in the deeper layers (Fig. 4) regardless of the slope position. The maximum concentrations of Pb, Ni, Cr, Cd and Zn are observed in the top layers, with the respective mean values ranging from 161-205 mg kg$^{-1}$ dry soil for Pb; 137-212 mg kg$^{-1}$ dry soil for Ni; 149-272 mg kg$^{-1}$ dry soil for Cr; 91-124 mg kg$^{-1}$ dry soil for Cd; and 165-489 mg kg$^{-1}$ dry soil for Zn, regardless of the slope position. The top layers are significantly enriched in heavy metals, where their contents exceed recommended concentrations (Fig. 4 and Table VI).

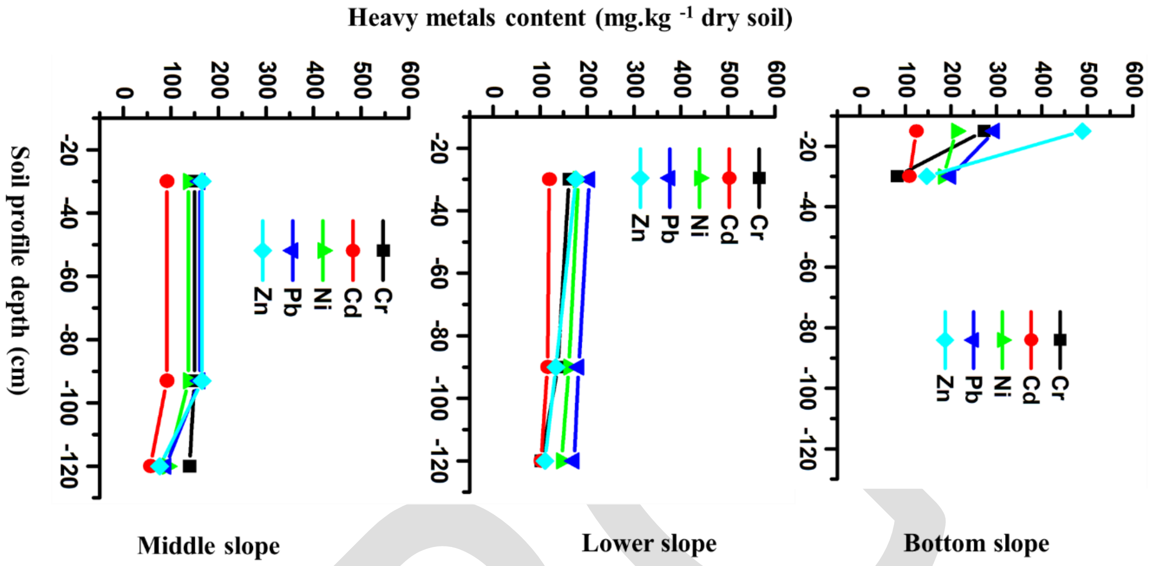


**Fig.4**: Vertical distribution of heavy metals (Chromium (Cr), Cadmium (Cd), Lead (Pb), Nickel (Ni), Zinc (Zn), Copper (Cu), and Selenium (Se)) in different layers of soil profiles located below the dumpsite (middle, lower and bottom slope positions)

## DISCUSSION

Open dumpsites are common in developing countries, such as Ivory Coast. These practices pose serious threats to groundwater resources along with the local and surrounding soil, thereby damaging soil quality.

### *Impact of the open dumping site on soil properties*

Soil is continuously contaminated by human activities, which often involves the accidental release of chemicals or the improper disposal of hazardous wastes. This is the case in the dumping site of M'Ploussoue Park in Bonoua, which is open-air and uncontrolled. In the study area, the dumping site is located at the top of the toposequence used in this study. The soil from the waste deposal site (in the upper slope position) has a shallow depth due to the accumulation of non-biodegradable materials in the waste, such as clothes, paper, plastic paper, buckets, tin cans, sacks, glass bottles, water sachets and solid waste, over the past 10 years while the dumpsite was operational.

Analysis of the soil's physical properties indicate that the soils from the dumpsite (upper slope position) have sand as their dominant particle size fraction and that their texture is dominated by sandy-clay. This texture limits the proliferation of microorganisms and the mineralization of organic matter [14, 15].

The chemical properties of the dumpsite soil show that its pH is weakly acidic. The neutral acidity of the dumpsite soil may be attributed to the age of the waste dumping site, which is 10 years old according to [2, 16]. According to these authors, after 10 years of waste deposal, the pH levels frequently increase at dumping sites. The neutral acidity (water pH = 6.9 and pH KCl = 6.1) of the open dumpsite soil can decrease the soil micronutrient availability for plants and favor the development of metal complexation [17]. Moreover, the high quantities of organic matter observed in open dumpsite soil may be attributed to the nature of various types of municipal solid wastes found in the study area, such as paper, used batteries, electronic goods, wood, plastic paper, straws, buckets, tin cans, sacks, clothes, glass bottles, cotton wool, food waste, leaves, fruit waste, medicine bottles, foams, ashes, water sachets, cardboard and human excreta. Other researchers attribute this high level of organic matter in the dumpsite soil to the presence of non-fermentable materials in the wastes, which tend to resist decomposition and therefore break down very slowly [18, 19]. The slow decomposition of soil organic matter, probably due to the nature of the waste, can explain the lowest capacity of exchangeable cations observed in the dumpsite soil as demonstrated by [2]. However, base saturation was rated high in dumpsite soils, reflecting the dominance of non-acid cations ($Ca^{2+}$; $Mg^{2+}$; $Na^{+}$; $K^{+}$) at their exchangeable sites. The high values of nitrogen, exchangeable bases and cation exchangeable capacity recorded in dumpsite soil could be attributed to the nature and content of soil organic matter (SOM), which is a major storehouse of many nutrients in soils, including nitrogen and phosphorus [21]. Therefore, the high soil organic matter content and presence of clay in dumpsite soil can also promote exchangeable bases and the cation exchangeable capacity. For [22], this high level of organic matter favored the sorption of metal because of SOM’s sorption qualities [23, 24].

Moreover, the high heavy metal content observed in open dumpsite soil than in control site soil could be attributed to the nature of various types of municipal solid wastes found in study. In fact, the continuous accumulation of different sources of municipal solid wastes, such as electronic goods, electroplating waste, painting waste, and used batteries, could be the origin of the heavy metal observed in the dumpsite soil. These results are in agreement with the findings from others researchers, which indicate that open dumpsites represents a significant source of heavy metal contamination in the environment [17, 18, 25].

The concentrations of cadmium (Cd, 81 $mgkg^{-1}$), chromium (Cr, 130 $mgkg^{-1}$), zinc (Zn, 344 $mgkg^{-1}$), lead (Pb, 118 $mgkg^{-1}$) and nicked (Ni, 119 $mgkg^{-1}$) in the dumpsite soil are greater than the limits recommended for agricultural soil [26] and also greater than those from the control soil which their concentration are below of the permissible level as demonstrated [27]. This result indicates that the main source of toxic element (metals or metalloids) found in dumpsite soil are not derived from the soil parent material as demonstrated [28]. The absence of heavy metal or metalloids in control soil seems show that their main source are anthropogenic. For [29], the contamination of dumpsite soil studied with lead (Pb), zinc (Zn), cadmium (Cd) and chromium (Cr) can come from the nature of wastes and also from the atmospheric deposition. The contamination of M’Ploussoue Park dumpsite soil with those toxic metals or metalloid may pose risks and hazards to humans and the ecosystem through the food chain. M’Ploussoue Park dumpsite soil may constitute an environmental problem if these metals migrate into the groundwater and plants.

Moreover, the soil content of Cr (130 $mgkg^{-1}$) in the dumpsite soil studied is much higher than the permissible limits and is also higher than that of Akouedo dumpsite soil (125 $mgkg^{-1}$) from Abidjan in Ivory Coast [17] as well as that of Al AIN (19.1 $mgkg^{-1}$) from the United Arab Emirates [25]. The Pb content (118 $mgkg^{-1}$) in the dumpsite soil studied was relatively higher than the Pb content from the Lome dumpsite (108 $mgkg^{-1}$) in Togo [18] and lower than the Pb content from the Akouedo dumpsite (1500 $mgkg^{-1}$) in Abidjan [17] as well as from the Yamoussoukro dumpsite (163.7 $mgkg^{-1}$) in Ivory Coast [30]. Similarly, the Zn soil content (344 $mgkg^{-1}$) in the dumpsite soil studied is above the permissible limit for agricultural soils, but lower than the Zn content from Akouedo (1164 $mgkg^{-1}$) in Abidjan [17] and the Yamoussoukro dumpsite (487 $mgkg^{-1}$) in Ivory Coast [30]. However, it is higher than the Zn content from Al-AIN (117 $mgkg^{-1}$) of the United Arab Emirates [24]. Additionally, the Cd content (81 $mgkg^{-1}$) in the dumpsite soil studied is higher than Cd content from Akouedo (11 $mgkg^{-1}$) in Abidjan [17], from the Yamoussoukro (4.65 $mgkg^{-1}$) dumpsite in Ivory Coast [30] and from Lome (37.3 $mgkg^{-1}$) in Togo [18]. The presence of heavy metals in the M’Ploussoue Park dumpsite soil could be a serious environmental hazard from the perspective of soil pollution [31]. Otherwise, the interaction between metals and soil organic matter could have various complex consequences on the solubility, mobility and bioavailability of metals if they are leached into the surrounding areas [32]. This could create soil deterioration problems for agriculture and local residents.

*Impact of the open dumpsite on surrounding soil properties along the toposequence*

Research on the open dumpsite's effects on the surrounding soil properties along the toposequence showed that soil from the dumpsite (upper slope positions) was enriched in fine particles (silt and clay) and less rich in sand. The silt and clay contents increased along the downward slope, whereas the sand content decreased in the same direction. This may be attributed to the slope angle and drainage, which facilitated erosion and transportation of fine particles from the top (dumpsite soil at the upper position) to depressed areas (middle, lower and bottom slope positions). Moreover, the high levels of soil organic matter and clay further down the slope suggests the translocation of fine particles (clay and organic matter) from the waste dumpsite soil (upper slope) to the depressed areas (middle, lower and bottom slope) along the toposequence. The transportation of eroded fine particles (clay and organic matter) may be attributed to the alluvial deposition process according to [33]. In soils from further down the slope, the high clay and organic matter contents can cause a high cation exchangeable capacity, which is able to adsorb more cations and reduce leaching. For [34, 35], the presence of the fine fraction (clay and organic matter) in the down-slope soil plays a role in the retention and bioavailability of the chemical elements essential for plants. The carbon, total nitrogen, organic matter contents and C/N ratio (> 12) are high in the soil from the bottom slope position. These results are similar of those of [36], who observed a very high amount of organic matter in the bottom slope due to the relatively weak mineralization and reductive and anoxic conditions.

Furthermore, our results indicated that the pH values of the dumpsite soil at the upper slope position (pH >6) was different from those (pH<5.5) at the down-slope position (middle, lower, and bottom) probably because of leaching process of the cations. In fact, as the study area is located in a wet tropical rainforest with an annual rainfall of > 2000 mm, the leaching processes become intensive. These climatic conditions can promote the removal and migration of acidic cations, such as hydrogen and aluminum, in soil solutions (data not shown) toward the down-slope profiles. This result is in agreement with [37], who affirms that more basic cations ($Ca^{2+}$; $Mg^{2+}$; $Na^{+}$; $K^{+}$) in soil solutions will make the soil less acidic. The presence of lower pH values (below pH <5.5) in soil from down-slope positons could favor better metal mobility and availability to plants and thus affect vegetation survival [17, 38]. This study shows that the topographic position of the dumpsite affects the texture, the organic matter content and the cation exchange capacity of the surrounding soil in the dumping areas.

The average concentration of heavy metals in the collected soil sample was found to be in the following order: Zn > Pb > Cr > Ni > Cd > As > Cu > Se, regardless of the topographical position of the soil profile. It was observed that only Zn, Pb, Cr, Ni and Cd were higher than the CCME's permissible limits [26]. In this study, the concentrations of heavy metals (Pb, Ni, Cr, Cd and Zn) in the soil profiles were higher in the top soil layers than in the deep soil layers, regardless of the topographic position of the soil profile. This difference may be linked to the infiltration of the dumpsite leachate into the soil, which only influenced the top surface soil no matter which heavy metal was studied. Ours results indicate that the accumulation of heavy metals in surface soil does not depend on parent rocks because of their lower content in deeper soil layers. This enrichment of heavy metal in the study area soil could be attributed to human activities, urbanization and atmospheric deposition [3]. These results suggested higher ecological risks for Cr, Pb, Ni, Zn and Cd than for others metals such as and Se.

However, the lateral distribution of Pb, Ni, Cr and Cd in soil showed a higher enrichment of these heavy metals in soil profiles located below the dumpsite. This enhancement of the Pb, Ni, Cr and Cd levels in soil along the toposequence could be linked to the dumpsite leachate, which is produced in association with rain when water passes though the waste in a dumpsite and may contain a wide range of pathogens and chemical pollutants [39].

In fact, as the study area is located in a wet tropical rainforest with an annual rainfall > 2000 mm in this tropical climate; a large quantity of dumpsite leachate could be formed in the presence of precipitation and then migrate from waste into the down-slope soil profiles, contaminating the surrounding soil. [40] clearly demonstrates that the leachate flow increases linearly with increasing rainfall. In addition, it had been reported in others studies that in open dumping sites, soil and groundwater could be contaminated by leachate migration [39, 41, 42]. It appears that in the M'Ploussoue Park dumpsite in Bonoua, the dumpsite leachate poses a real danger to soil solutions through infiltration [43] and influences the vertical and lateral distribution of heavy metals (Pb, Ni, Cr, Cd and Zn), modifying the soil's physical and chemical properties. Ours results suggest that the dumpsite leachate has a significant impact on local soil as well as the surrounding area's soil quality in a wet tropical climate. Thus, the M'Ploussoue Park dumpsite at Bonoua appears to harbor potential ecological risks for all residents living within 30 m of the dumping site. Preventing soil contamination by dumpsite leachates is highly recommended.

## CONCLUSION AND RECOMMENDATION

Analyses of the vertical and lateral distributions of heavy metals in soil samples collected from the solid waste disposal site of M'Ploussoue Park in Bonoua indicate that there are high levels of heavy metals (Cr, Pb, Cd, Zn, N) in the top soil layers as well as in the soil at the bottom of the slope, with contents that exceed permissible limits, suggesting a high pollution potential. Examination of the metal distribution in the soil profiles indicates the accumulation of metals in the surface soil layers is a result of human activities, urbanization or atmospheric deposition. The heavy metals in surface soil layers can migrate to plants, groundwater and surface water resources. Furthermore, our study also show that the heavy metal enrichment of soil located under the dumpsite is probably due to the migration and the infiltration of the dumpsite leachate. The vertical and lateral distributions of metals in M'ploussoue Park in Bonoua can pose potential ecological risks if these elevated concentrations of metals migrate into soil, plants and groundwater, which would lead to adverse effects on plants, animals and humans. It appears that in a wet tropical climate, the open dumpsite has a significant impact on soil and on the soil quality in surrounding areas, likely due to the dumpsite leachate produced. It is thus recommended to prevent soil contamination via dumpsite leachates. Finally, it is necessary to study this dumping site and determine the exact boundaries of the contamination area and the risk people living there. To limit heavy metal migration in plants, groundwater and surface water resources, it appears necessary to develop proper remediation techniques.

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