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Evaluation of contamination by heavy metals in soils collected from four public landfills in Brazzaville, Republic of Congo

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ABSTRACT: This study evaluates the contamination by heavy metals of the grounds taken in four of the public landfills in the districts of Brazzaville. Soil samples taken at a depth of 25 cm first underwent some physical treatment (drying, sieving and grinding) before undergoing physicochemical analyzes and determination of heavy metals by ICP-OES. Physicochemical analyzes showed that Landfill soils are heavily contaminated with heavy metals: lead (Pb), chromium (Cr), cobalt (Co), nickel (Ni), mercury (Hg) and zinc (Zn). The highest levels of these heavy metals are as follows: lead (220 mg/kg) in the soils of the Tsiémé landfill; chromium (13000 mg/kg), cobalt (160 mg/kg), nickel (7500 mg/kg) and zinc (12000 mg/kg) in the soils of the Diata landfill and mercury (0.66 mg/kg) in the soils of the Moukondo landfill. Mercury is also present in these four landfills but in small quantities.

KEYWORDS: Landfills, Soilss, Heavy metals, Brazzaville.

1 INTRODUCTION

Brazzaville, capital of the Republic of Congo, like most cities in the world, continues to expand [1]. This demographic expansion is accompanied by a problem that is often poorly managed, that of solid waste management [2]. Environmental protection is an omnipresent concern in our societies [3] Landfills are currently the common option for the disposal of municipal solid waste in developing countries [4]. The management of landfills obeys standards that must be respected or risk being indirectly exposed to the pollution they generate. Public landfills continue to cause serious environmental problems [5], [6], [7]. It is therefore necessary to have control over their management [8]. Soil is contaminated when a potentially dangerous substance is naturally or artificially introduced into it. Soil contamination by heavy metals indicates an increase in the total concentrations of these elements in the soil following significant anthropogenic inputs [9]. Heavy metals are among serious soil pollutants [10], especially in areas with high anthropogenic pressure, their presence in the soil, even in traces, can cause serious problems for all organisms. The degree of metal contamination in the soil is often assessed from the total heavy metal content in the surface horizon. Several studies have been carried out on the analysis of metallic elements in soils polluted by landfills. These studies have reveled significant levels of heavy metals in these soils [11], [12], [13].

2 MATERIALS AND METHODS

2.1 DESCRIPTION OF THE STUDY AREA

The city of Brazzaville, capital of the Republic of Congo, lies between latitudes 4°6' and 4°23' South and longitudes 15°5' and 15°25' East. It is located between the Cataractes to the southwest, Mbé to the northeast and the Congo River to the east.

It has a very extensive peri-urban area both in its northern part and in its southwestern part. Brazzaville covers an area of over 309 km^2 and has nine districts (Makélékélé, Bacongo, Poto-Poto, Moungali, Ouenzé, Talangaï, Mfilou Ngamaba, Madibou and Djiri) [14].

Figure 1 shows the map of the city of Brazzaville, as well as the four landfills concerned by this study.

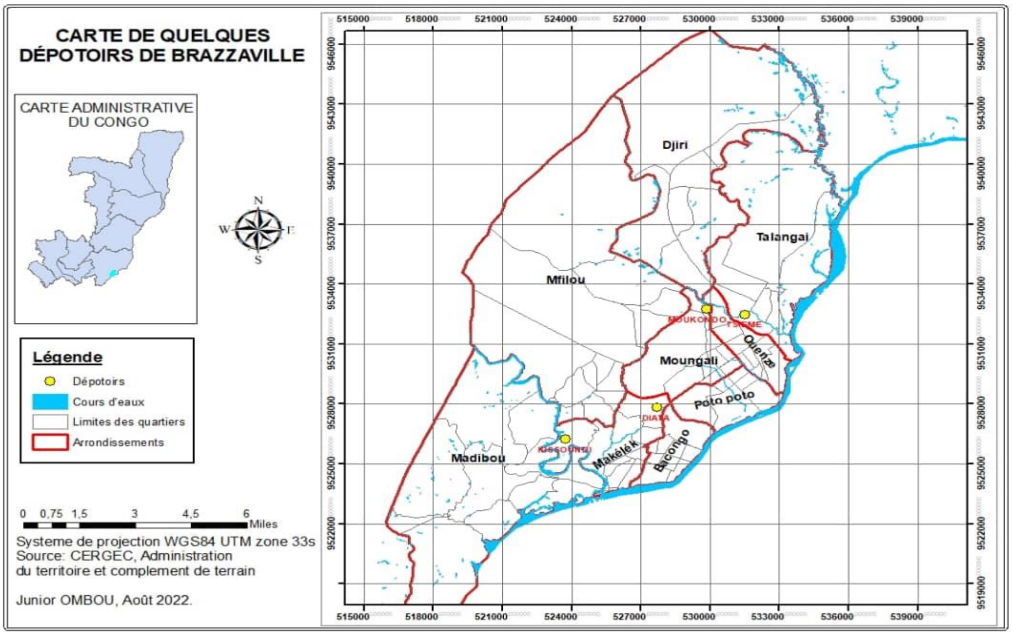

Fig. 1. Location of the four public landfills.

The city of Brazzaville has about fifty public landfills distributed in the different districts and as the garbage is exposed in the open air, this constitutes a great danger for the population and the environment because of the odors and runoff water in the raing period. Taking into account the age, the surface area of the landfills, the location and the nature of the waste present, the Tsiémé, Diata, Moukondo and Kinsoundi landfills were selected for this study (figure 2).

Fig. 2. Landfills of Tsiémé (a), Diata (b), Moukondo (c) and Kisoundi (d)

2.2 SAMPLE COLLECTION

Soil samples were taken from the four public landfills in January 2022, using an auger and to a depth of 25 cm. Five sampling points were chosen in each landfill. These samples were put in clean plastic bags and sent to the laboratory for physicochemical analyzes and the determination of heavy metals.

2.3 SAMPLE PROCESSING

In order to have a composite soil sample for each landfill, 2 kg of each individual sample were mixed together [15]. The composite samples were spread out in the open air at room temperature on the clean and dry plastic materials so as not to contaminate them during 10 days. These samples were sieved using a sieve of 2 mm porosity and crushed using an agate mortar.

2.4 DETERMINATION OF PHYSICO-CHEMICAL PARAMETERS

20 g of soil were brought into contact with 50 ml of distilled water then, after stirring for thirty minutes, the pH and conductivity of the supernatant solution were measured using a Dusto brand multi-parameter device [16], [17]. The Walkley and Black method was used to determine the organic matter content of soils. This method is based on the oxidation of organic carbon by an excess of potassium dichromate ($K_2Cr_2O_7$) in an acid medium, followed by a determination of this excess by mohr's salt [18].

2.5 DETERMINATION OF HEAVY METALS

Mineralization was carried out on 0.5 g of the composite soil sample with 6 ml of concentrated hydrochloric acid and 2 ml of concentrated nitric acid (aqua regia) at 95°C for 75 minutes on a heating block. The mineralizate was reduced to 50 ml with distilled water and the heavy metals are analyzed by ICP-OES.

3 RESULTS AND DISCUSSION

3.1 PH OF SOIL SOLUTIONS

Soil pH is a measure of the it's acidity. It controls most of the chemical and biological reactions of the soil. It entirely determines the adsorption. A high pH results in a large amount of negative charges of a polluting substance on organic matter and often induces the formation of precipitated species which can limit the solubility and bioavailability of all ionic species [19]. At a low pH, the positive charge of a polluting substance is higher [20]. The pH values of the landfill soils studied are between 6.85 and 7.14 (Figure 3). The pH values recorded in the landfill soils are neutral. This can be explained by the fact that these soils are in an area where precipitation is permanent.

3.2 CONDUCTIVITY OF SOIL SOLUTIONS

Soil conductivity is the measure of the ability of a soil solution to conduct electrical current. The electrical conductivity of a soil solution varies according to the presence of ions present, their concentration, their mobility. It is a function of the concentration of ionized species, mainly mineral matter. It is important for the soil quality control [11]. The conductivity of a soil solution gives direct information about soil mineralization. The conductivity values of the soils of the landfills studied vary from 270 to 314 µS/cm (figure 4). The landfill soils studied have an average conductivity. They are characteristic of soils of medium mineralization.

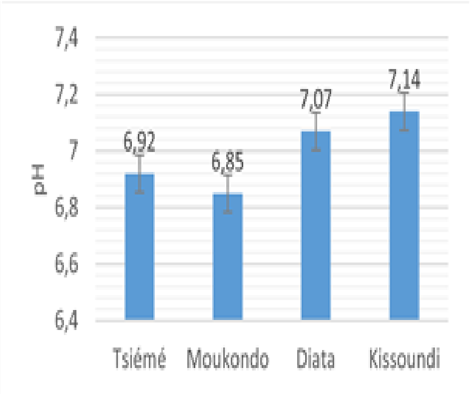

Fig. 3. pH content

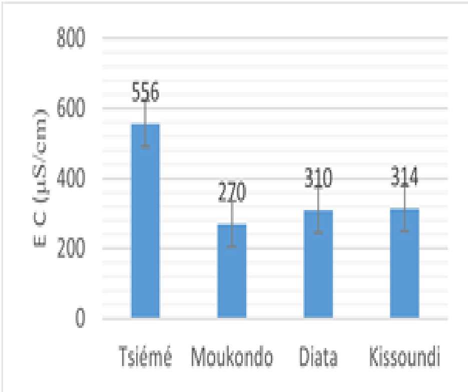

Fig. 4. Electrical conductivity content

3.3 ORGANIC MATTER CONTENT

In the soil, the presence of organic matter, especially of a humic nature, is important for the adsorption of organic pollutants. The organic matter layer plays a direct role in the ability of a soil to retain organic and inorganic compounds. Organic matter is a parameter that has a good correlation with retention power [21]. The levels of organic matter (OM) in the soils of the four landfills vary between 0.13 and 9.9% (Figure 5). The maximum content is recorded in the soils of the Kissoundi landfill. This grade is high compared to the other grades recorded in the other landfills studied. These results reveal that organic matter in landfill soils comes from several types of waste categories, which are the fermentables such as degraded compounds, papers and cardboards. Indeed, the dominant waste in the Kissoundi landfill is paper and cardboard.

3.4 LEAD CONTENT

Lead is one of the mostancientand the most widely used by man. Its toxicity has been known since antiquity. It is particularly dangerous and has no biological role [22]. It is frequently found in household waste in developing countries because of its use as a component of batteries [23]. Lead is present in landfill soils with very high levels (Figure 6). These levels in the soils of the four landfills are well above the threshold recommended by the AFNOR NF U 44-041 standard, which is 100 mg/kg. These very high values in landfill soils can be explained by the fact that lead has a great affinity with organic matter, it is not very mobile, it accumulates on the surface of the soil, it is not too entrained in depth by leaching.

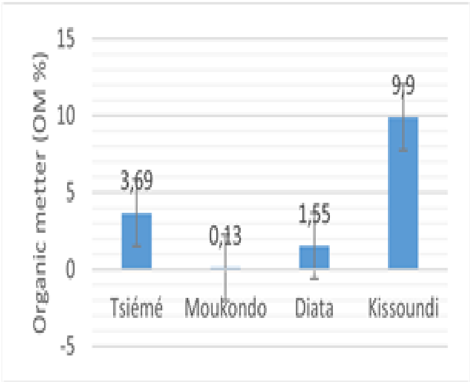

Fig. 5. Organic matter content

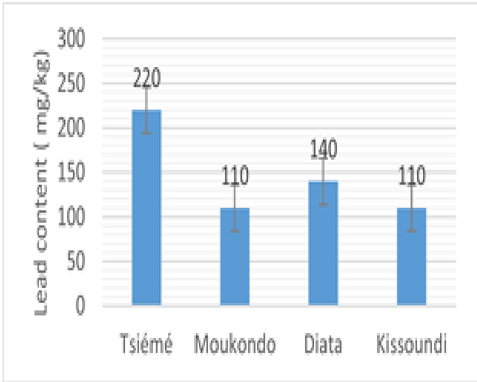

Fig. 6. Lead content

3.5 Nickel content

Nickel is considered to be an indefinitely persistent substance in soils, in the same way as its compounds. The nickel contents found in the soils of the landfills studied vary between 18 and 7500 mg/kg (figure 7). The nickel levels in the soils of the tsiémé, Moukondo and Diata landfills are much higher than that of the AFNOR standard, which is 50 mg/kg. These high levels may be due the non-recovery of certain materials containing nickel for possible recovery [24], and the fact that the residence time of nickel in soils is approximately 3500 years. Nickel can come into the environment through discharges from household waste such as: metal jewelry, staples, shoe buckles, scissors, glasses, needles, kitchen utensils, coins.

3.6 Chromium content

In the environment, chromium is mainly present in two forms: Cr (III) and Cr (VI). Chromium VI is mostly introduced into the environment by anthropogenic activities [25]. Despite the fact that chromium III and chromium VI have different chemical properties, chromium VI is the most toxic form. The speciation of chromium VI and III depends on several parameters: pH, organic matter and their content. A basic pH favors the precipitation of chromium with the carbonate, at a neutral pH, chromium VI is present in two forms CrO_4^{2-} and $HCrO_4^-$ [26]. A soil with enough richin organic matter, traps chromium by complexation with organic ligands [25]. Chromium VI has a high mobility in soils, it can migrate until it reaches aquifers. The average chromium content in soils is 50 mg/kg [27]. This value is lower than those recorded in the soils of the four landfills studied (figure 8). The high levels of chromium in landfill soils can be explained by the same hypotheses mentioned in the case of nickel. In the environment, chromium can come from dye wastes, paint coloring agents and catalysts.

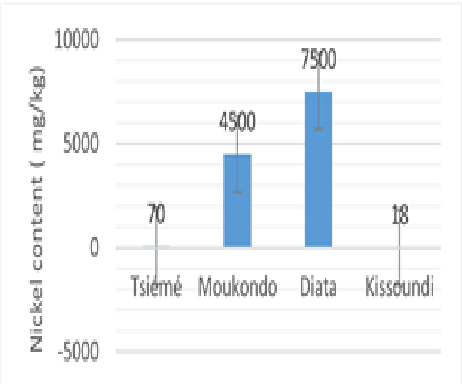

Fig. 7. Nickel content

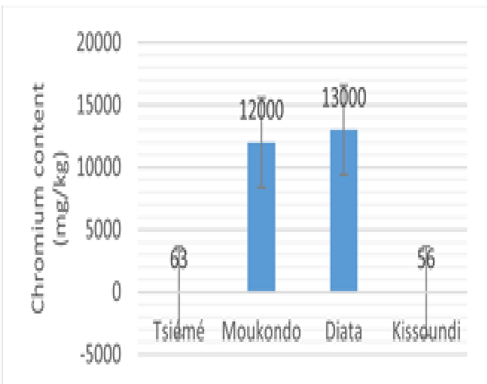

Fig. 8. Chromium content

3.7 MERCURY CONTENT

Mercury is the most toxic metal for humans and the top of the food chain while it does not present major problems for plants. In the soil samples from the landfills analyzed, the mercury levels are all below 1 mg/kg (Figure 9). These levels are all within the range of the European standard which is between 0.3 mg/kg and 10 mg/kg [21]. These low levels of mercury can be explained by the fact that the household waste received by landfill sites does not contain enough compounds containing mercury to induce significant pollution of these soils. It is possible that much of the mercury mobilized in the waste is dissolved through the complex chemical reactions that take place at the soil-waste interface and is then transported by seepage through the soil to groundwater. Landfill soils all have a pH greater than 5. It can be said that in these soils, mercury can complex with mineral ligands, since a pH greater than 5 favors the formation of the $Hg(OH)_2$ species [28].

3.8 COBALT CONTENT

The migration of cobalt depends on the characteristics of the soils. Soils rich in organic matter fix cobalt more strongly and durably. In terms of pH, the mobility of cobalt decreases with acidity. Soil structure is also an important factor in cobalt mobility [29]. During this study, cobalt is only recorded in the soils of the Moukondo landfill and in those of Diata. In the soils of two other landfills, the cobalt is in the form of traces (figure 10). And yet the soils of the Kissoundi landfill and those of the Tsiémé are richer in organic matter content. This discrepancy can be explained by the same hypotheses mentioned in the case of mercury and the non-homogeneity of waste received in landfills.

3.9 ZINC CONTENT

Zinc is considered relatively non-toxic, as its toxicity to humans is low [30]. However, in high concentrations, zinc can become toxic. The zinc contents recorded in the soils of the landfills studied are very high (Figure 11). They are much higher than the AFNOR standard which is 300 mg/kg. These values confirm the hypotheses put forward by Aulin et al. [31], who estimate that zinc levels are 5 to 127 times higher in landfills than in natural soils.

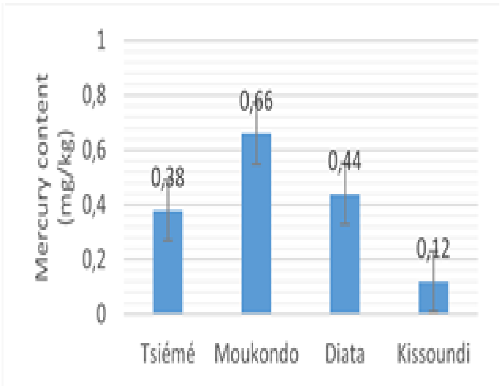

Fig. 9. Mercury content

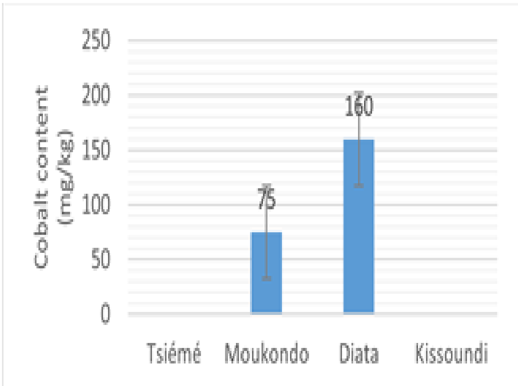

Fig. 10. Cobalt content

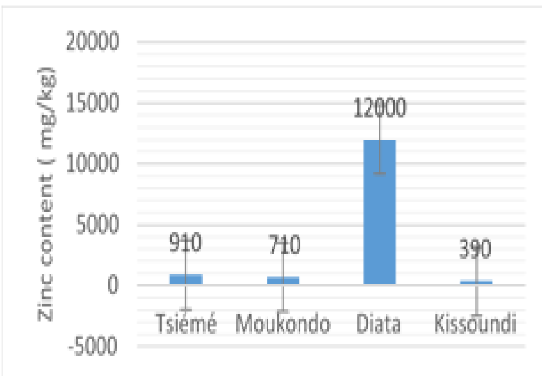

Fig. 11. Zinc content

4 CONCLUSION

The physico-chemical analyzes carried out on the soils taken from the landfills revealed that these soils all have a neutral character with pH values which vary between 6.85 and 7.13. The organic matter and electrical conductivity of these soils are relatively low, with levels varying respectively between 0.13 and 9.9% for organic matter and 405 and 471 µm/cm for electrical conductivity. Heavy metal analysis reveals that the landfills are heavily contaminated. The contents of the heavy metals studied (Pb, Cr, Ni, Co, Zn) are much higher than the AFNOR NF U 44-041 standard. Only mercury (Hg), which was recorded with levels below this standard. The levels of these heavy metals are not homogeneous in all the soils studied, this is explained by the heterogeneity of the waste received in these soils. The landfills whose soils have been researched are small in size but pose enormous environmental risks. Given the high levels of metals recorded in the soils studied, it should be noted that these landfills can be a source of metal contamination of surface water and groundwater in the city. Indeed, the Tsiémé and Moukondo landfills are located in the watershed of the Tsièmé River and those of Kissoundi is located in the watershed of the Djoué River, it should be noted that these landfills can be a source of metallic contamination of surface water and groundwater in the city. These metals can be found complexed with organic matter or trapped in several metallic forms. It will then be important to do further research on chemical speciation to better situate the state of pollution of heavy metals in these landfills.

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