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Impact of Uncontrolled Landfills on Soil Metal Contamination: The Case of the Former Akouedo Landfill (Abidjan-Côte D'ivoire)

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Abstract **Original Research Article**

The uncontrolled dumping of solid waste is a risk factor for soil and groundwater contamination. Indeed, the buried waste generates a strong accumulation of metallic trace elements in the soil. The objective of this study is to investigate the impact of the Akouédo landfill on soil metallic trace elements. Soil samples (0-20 cm) were taken from the control site (soils without residues) and the three sites DAK, DAD, DJD, which correspond, respectively, to older residue soils, aged 30 years, older residue soils, aged between 20 and 30 years and young residue soils, aged 10 years. Atomic Absorption Spectrometer (AAS) analysis of trace metals showed higher concentrations of Zn, Pb, Cu, Cr and Cd in the tailings soils than in the control site.

Keywords: Uncontrolled discharge, pollution, solid waste, metallic trace elements, residues of soil, Akouédo, Ivory Coast.

1. INTRODUCTION

Poor solid waste management is one of the main causes of pollution and environmental degradation in many cities, particularly in developing countries. In these countries, the vast majority of landfills are in an uncontrolled state and are referred to as uncontrolled landfills since they do not respect the rules of environmental protection. The dumping of this solid waste without any treatment constitutes a risk factor for soil contamination, particularly in terms of trace metals. The work of Bodjona et al,(2012) on the Agoé landfill (Lomé-Togo) showed a significant contamination of soils in metallic pollutants such as lead (66.91 mgkg-1), zinc (401.13 mgkg-1) cadmium (2.51 mgkg-1). Indeed, most of the metals found in the soil of these landfills are derived from the degradation of many compounds put in landfill. These are compounds such as paints, electric accumulators, various manufactured products (boxes, metal, valves etc.), PVC objects (polyvinyl chloride), plasters, mineral fillers in plastics, materials such as television screens (Vilomet, 2000). The increase in the content of trace elements (TE) in soils could thus contribute, in the long term, to the contamination of groundwater and then of plants. In Côte d'Ivoire, the large production of domestic, industrial and hospital waste is confronted with insufficient management and economic difficulties (Soro *et al.*, 2010). In fact, the Akouedo landfill, which is overused, is overflowing and causing problems for the environment and for the local population. In addition to the nuisances generated (odors, smoke, flying plastics), pollution of the water table and soil by percolation of leachate are two major risks to be feared. Indeed, these liquid effluents from waste that are neither collected nor treated contain a significant quantity of organic and inorganic pollutants such as metallic trace elements. An accumulation of these metallic pollutants in the environment can affect the health of humans and animals (Wang, 2003). The work of (Kouadio et al, 2000), (Kian, 2005), (Koumé et al, 2006), reported metallic and organic pollution of the soils in the vicinity of the landfill and hypothesized a risk of contamination of the water table and the waters of the Bay of M'Badon by the leachate from the landfill. The objective of this work is to contribute to the study of the impact of solid waste on the soil at the uncontrolled landfill of Akouédo. For this purpose, soil samples were collected from the residue and control sites. An analysis in ETM of the samples coming from these various sites, was carried out with the atomic absorption spectrometer (AAS).

2. MATERIAL AND METHODES

2.1 Description of study area

The study area is the Akouédo landfill (Figure 1). With an area of about 153 ha, this landfill is located in the eastern part of the city of Abidjan (Côte d'Ivoire) halfway between Abidjan and Bingerville, close to the village of Ebriée whose name it bears. In operation from 1965 to 2019, it has received several tons of waste, two thirds of which is household waste and one third is industrial, hospital and some hazardous waste. This waste was dumped directly on the ground without any treatment of the garbage or collection of the leachate. The transitional equatorial climate, known as the "Atean climate," is characterized by four seasons (Tapsoba-Sy, 1995): a long dry season from December to March, a long rainy season from April to July, a short dry season from August to September and a short rainy season from October to November. The average annual temperature is 27.36° C. According to Rougerie (1960), Côte d'Ivoire is one of the hot countries where rain is the essential element in the differentiation of the seasons. The average monthly and total annual rainfall recorded over the observation period is 142.77 and 1713.28 mm respectively. The main soil types in the study area are ferralic antropol and histic antroposol soils (Kouassi, 2016).

Fig 1: Photography of Akouedo landfill, 2012

2.2 Soil sampling

Soil samples were collected during 2012 from soil pits dug at the cultivated plots. Soil pits were chosen because this method of sampling was more suitable for the site. A total of four sites were selected for this study. Three plots of land having received solid waste at different periods of exploitation: older with an age > 30 years, older with an age between 20 and 30 years and younger with an age < 10 years were the object of our investigations. Another field near the landfill, which did not receive any waste deposits during these years of operation, was included in the study as a control. On each site, three pits were dug, for a total of 12 soil pits (Figure 2). These pits are approximately 1m long, 0.8m wide and 1.20m deep. These were refreshed with plastic instruments, and then a composite sampling of about 500 g of soil was taken from the surface horizons (0-20 cm).

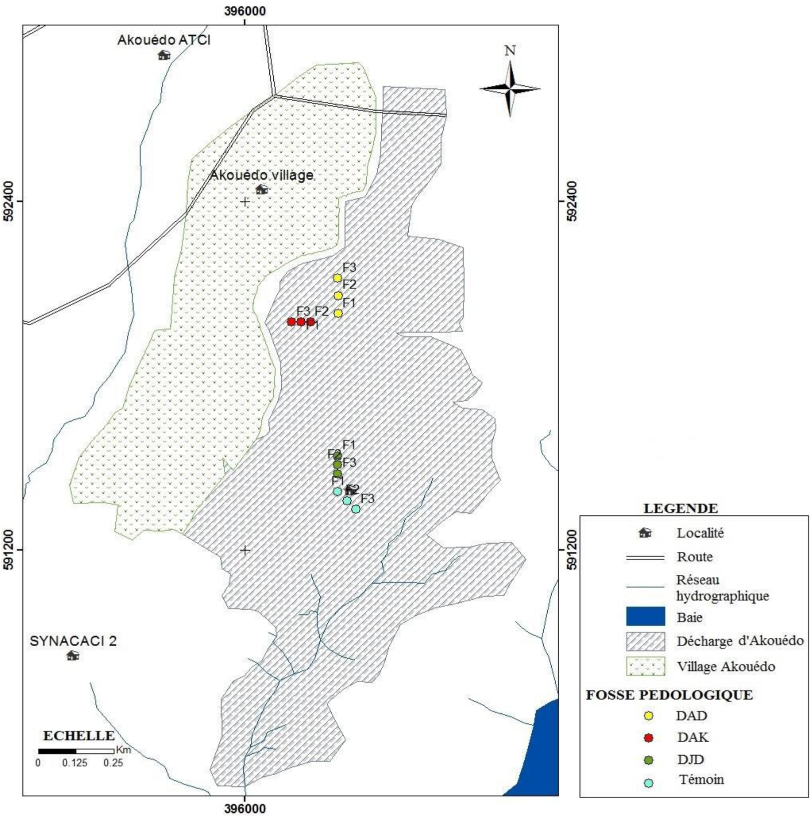

Fig 2: Location of pedological pits

2.3 Chemical analysis

2.3.1 Mineralization and microwave determination of soil samples

The obtained soil samples were air-dried for one week and sieved to 2 mm according to NFX31-101 (AFNOR NF X31-11, 1992), 20 g of soil sieve (diameter < 2 mm) were ground in a Retsch PM 400 planetary mill and homogenized on a wheel.

0.5 g of crushed soil sieve was dissolved in aqua regia (1.25 ml HNO3+3.75 ml HCl) in a Teflon canister and the whole canister was placed in the carousel of the CEM µwaves MARSX microwave for heating. The chosen reactor is XP-1500 type and the heating rate was 165°C, for 10 min, 175°C, for 3 min and 180°C, for 15 min. After 15 min of cooling, the mineralization was filtered on a Wattman type 540 filter with a diameter of 110 min and recovered in 100 mL volumetric flasks with ultra pure water. The determination of trace metals was carried out with the Atomic Absorption Spectrometer (AAS) brand Perkin Elmer PinAAcle 900T at the INRA of Bordeaux.

The quality of the results was validated by using BCR 14R and NIST Montana 2711 reference materials.

2.3.2 Measurement off soil bulk density and pH

The measurement of soil bulk density was performed by the cylinder method. A cylinder of known volume "v" is introduced completely into the soil preserving the soil structure. The soil in this cylinder is taken and dried at 105°C in the oven, and then its weight P is determined by weighing. The apparent density (Da) is obtained according to the following formula 1: Da = M/V ……….. (1)

where M is the dry mass of the sample and V the volume of the sample taken and dried. For the measurement of soil pH, we have previously obtained a soil suspension whose procedure is as follows: 10 g of fine soil were introduced into a beaker, using a spatula. 25 mL of distilled water was added with a washbowl and a bar magnet. The beaker was then placed on the magnetic stirrer for 1 hour. After a quarter of an hour of rest, the measurements are then carried out from the pH meter.

2.3.3 Calculation of the pollution index and soil TME stocks

Trace metal contamination of soils from anthropogenic activities is associated with a cocktail of contaminants rather than a single metal (Lee *et al*., 2001). Thus, the concept of a soil pollution index (PI) has been introduced in many studies to identify multi-element contamination that results in increased metal toxicity (Chon *et al*., 1998; Smouni *et al*., 2010). It is a criterion to assess the overall toxicity of a contaminated soil. According to Chon *et al*., (1998), the soil pollution index is calculated from the average of the ratios of metal concentrations in soil samples based on the limit guideline values. These limit values correspond to the tolerable levels of TME concentrations in soil according to the AFNOR U44-41 standard (Baize, 1994). The PI is determined according to the following formula 2:

$$PI = [(Cd/2 + Cu/100 + Pb/100 + Zn/300 + Cr/150)/5] \quad \text{…. (2)}$$

From the classification criteria of Chon *et al*., (1998) and Tankari Dan-Badjo *et al*., (2013):
IP > 1 corresponds to a soil that is polluted with multiple metals
IP = 1 corresponds to a soil that tends to metal pollution
IP < 1 corresponds to an unpolluted soil.

The iso-volumetric method was chosen in order to calculate the stocks of trace metals in the surface horizons of soils. The interest of this method is to determine the gains in chemical elements (Soubrand-Colin, 2004). TME stocks are calculated by multiplying the chemical content of the element considered by the bulk density and by the thickness of the horizon according to the following formula
Stocks = [X].Da. E …………. (3)

With [X] = content of element X (mg.kg-1)
Da = apparent density (Kg.dm-3)
E = thickness (m)
The stocks are expressed in gm-2.

2.4 Statistical analysis

The results of physico-chemical analysis of the soils were processed using STATISTICA 7.1 software. The comparison of the means of the data obtained was carried out by analysis of variance (ANOVA) at the 5% probability threshold. When the analysis of variance was significant, we proceeded with Tukey or Newman-Keuls tests to determine significant differences between group means. These analyses were performed after checking the normality of the data distribution and the homogeneity of the variances using the Shapiro and Barlett tests.

3. RESULTS

3.1 Physical characteristics of Akouédo soils

The histograms in Figure 3 show the pH variations of the surface horizons (0-20 cm) of the Akouédo soils. The control soils have an acidic pH, while the residue soils of the DAK, DAD and DJD sites have an alkaline pH. The values obtained on these different sites DAK, DAD, DJD and control are respectively 7.89, 7.73, 7.47 and 4.84.

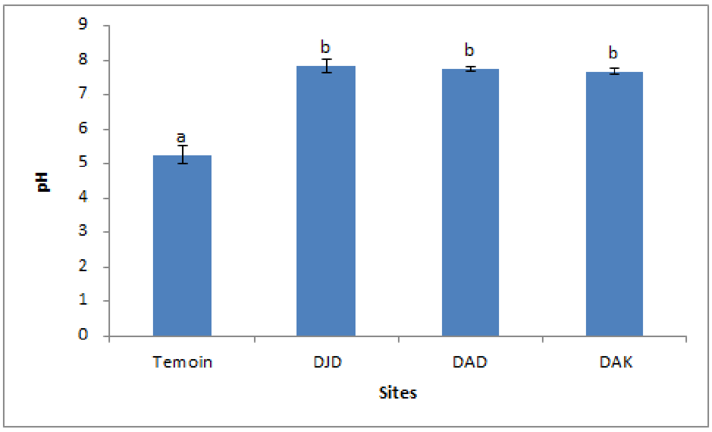

Fig 3: Variation in soil hydrogen potentials (pH) at the Akouedo landfill site

Fig 4 shows little variation in bulk density of the same horizons (0-20) of the Akouédo soils. Values are slightly higher for the control soils than for the residue soils. These values range from 1 to 1.1 gcm-3 in the control soils, 0.63 and 0.74 in the young residue soils DJD, 0.79 and 0.84 gcm-3 in the old residue soils DAD and 0.58 and 0.74 gcm-3 in the older residue soils DAK. The mean contents are 1.07 gcm-3, 0.68 gcm-3, 0.81 gcm-3 and 0.67 gcm-3 respectively.

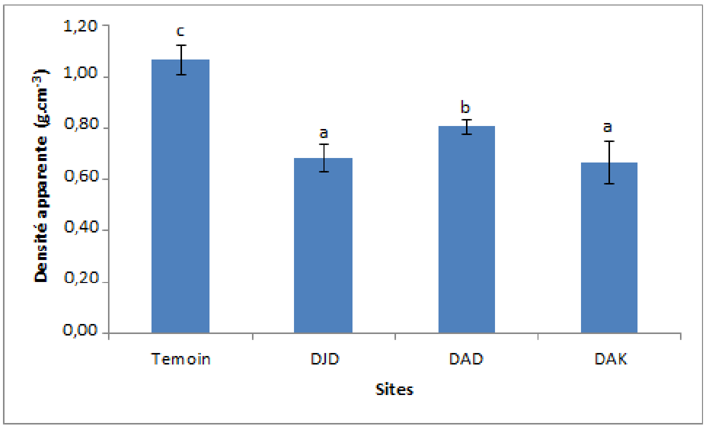

Fig 4: Variation in soil bulk density (BD) at the Akouédo landfill site

With the bulk density values obtained, the iso-volume stock balance was determined for the surface horizons of the Akouédo soils (Table I). The results indicate that the sequence of trace metal contents at each site varies in the following order: Zn > Pb > Cu > Cr > Cd. TME stocks are highest at the DAK sites, followed by DAD, DJD and the control.

Table I: Iso-volume stock assessment of trace elements in Akouédo soils

	Iso-volume stocks of trace elements (gm^2)				
Site	**Zn**	**Pb**	**Cu**	**Cr**	**Cd**
DAK	144,18	55,84	16,35	7,34	0,25
DAD	110,16	22,86	14,26	6,1	0,25
DJD	59,57	16,34	8,79	4,71	0,25
Pilot	2,57	1,35	0,64	3,73	0,25

3.2 Trace metal content in surface soil horizons

The results of chemical analyses of trace metal contents in the surface horizons of the landfill soils are provided in Table II. It is noted that the metallic trace elements contents vary according to the sampling areas and the metal element considered. On the tailings soils, the highest average concentration is Zn, followed in descending order by Pb, Cu, Cr and Cd. In natural soils, the sequence of metallic trace elements contents is Cr > Zn > Pb > Cu > Cd.

The average trace elements values in the surface horizons of the residue soils are higher than those of the natural soils (control). In addition, the respective values of Zn (1102.70 mg.kg-1 DM), Pb (464.42 mg.kg-1 DM) and Cu (122.20 mg.kg-1 DM) obtained on the older DAK residue sites, are above the regulatory thresholds. On the other hand, the metal levels recorded at the control site are below the maximum permitted values for all metals. The same observations were made for zinc and lead in the DAD and DJD residue soils.

Variability in metals levels was observed in old and young tailings soils. Indeed, they are higher in old residue soils (DAK, DAD) than in young residue soils (DJD).

Table II: TME content (mg.kg-1 DM) of the surface horizons of the Akouédo landfill

SITE	Sp	Zn	Pb	Cu	Cr	Cd
DAK (>30)	**Mean**	1102,7	462,12	122,2	54,7	1,87
	Se	344,47	195,75	16,83	8,30	0,04
DAD (<] 20-30]	**Mean**	679,83	141,09	88	37,63	1,53
	Se	369,63	54,05	55,26	10,48	1,09
DJD (<10)	**Mean**	438,04	120,14	64,64	34,65	1,28
	Se	245,58	70,99	27,81	3,11	1,22
Pilot	**Mean**	12,13	8,06	3	17,44	0,01
	Se	6,44	3,01	1,11	1,70	0,01
Maximum values (French standard)		300	100	100	150	2

Sp: Statistical parameters; Se: Standard error

3.3 Evaluation of the metallic pollution of the soils of Akouédo

Trace element contamination on the surface of Akouédo soils is associated with a cocktail of contaminants rather than a single metal. For this reason, the pollution index (PI) was determined to assess the metal toxicity of the soils. The results are given in Table III. Analysis of this table reveals PI values ranging from 0.07 to 1.50 depending on the site considered. The lowest index (0.07) is obtained at the control site, which confirms its non-polluted state. Of the three tailings sites studied, two have PI values greater than 1. The old tailings sites DAK and DAD have PI values of 1.50 and 1.11 respectively, thus revealing the pollution of their soils by TMEs. The young tailings site has a PI value (0.83), close to 1, suggesting a tendency for several metals to accumulate in their soil

Table III: Trace metal pollution index (PI) of Akouedo soils

Site	Code	IP
Residue soils age > 30 years old	DAK	1,5
Residue soils including age] 20 -30]	DAD	1,11
Age residue soils < 10 years old	DJD	0,83
Pilot	P	0,07

4. DISCUSSION

The results obtained show that TME contents vary according to the sampling areas and the metal element considered. These results are comparable to those of many authors (Smouni *et al*., 2010; Kouakou *et al*., 2019; Ekengele Nga *et al.,* 2016; Hodomihou *et al*., 2016) who have shown that the trace metal element (TME) contents of soils vary depending on the sampling site and the trace metal element. It is also noted that the average TME contents (Zn, Pb, Cu, Cr, Cd) are higher on the residue soils (DAK, DAD and DJD) than on the natural soils (control). The low levels observed at the control site could be attributed to the local soil geochemical background. TMEs are naturally present in rocks (geochemical background). The levels resulting from the inheritance of the parent material, natural processes related to soil formation and atmospheric deposition of natural origin constitute the local natural geochemical background (Baize, 1997). Since the control site is located in the impact zone of the landfill, the average concentrations obtained are the result of the cumulative effect of the geochemical background and atmospheric deposition. The sequence of TME levels obtained at this site, Cr > Zn > Pb > Cu > Cd, suggests that, originally, before the Akouédo dumping, Cr was the most abundant metal in the soil, followed by Zn, Pb, Cu and Cd. These low levels of TMEs detected at the control site contributed insignificantly to soil pollution.

On the other hand, the relatively high levels of TMEs recorded in the tailings soils would be related to the waste dumped. The variability of the levels observed in these soils could be explained by the composition and nature of the waste dumped. Indeed, the waste dumped at the Akouédo dump is of various natures. There are large quantities of used batteries or accumulators, tires, car engine drainage products, various manufactured products (boxes, metal, valves) and household appliances, notably television screens, which all contain large quantities of trace metals (Pb, Zn, Cu, Cr, Cd, etc.). Among these trace metals, lead and zinc are the most leachable metal fractions, while chromium and copper are more difficult to extract from waste (Assmuth, 1992). In addition, Zn, Pb and Cu are present in almost all landfilled wastes. For this reason, on residue soils, a change in trends has been observed as follows: Zn >Pb > Cu > Cr > Cd. The dumped waste has thus contributed to a significant enrichment of the tailings soils in Zn, Pb and Cu.

The high levels of TMEs in the tailings soils could be due to the frequent incineration of the stored waste.

Older tailings soils (DAK, DAD) had higher average TME levels than younger tailings soils (DJD). The older the residue input, the higher the TME content. The same observation was made by Gaultier *et al*., (2002) on soils subjected to the application of contaminated sludge. Indeed, the high content of old tailings soils is due to the fact that these tailings have been almost totally altered, and, consequently, have released their TME content into the soils, which is not the case for young tailings soils, which are in the presence of unaltered or partially altered waste.

Moreover, the PI calculation revealed that the old DAK and DAD tailings soils are polluted, because the respective values of 1.5 and 1.11 are greater than 1. As for the values obtained on the young DJD tailings soils, they tend to be polluted, because the PI (0.83) is close to 1. The low PI values (0.1) obtained on the control site demonstrate that the natural soils of Akouédo are not polluted, despite their location in the immediate vicinity of the dump. The values are close to those of the controls reported on the soils of Niamey (Tankari *et al*., 2013) and on the soils of Haute Moulaya (El Hachimi *et al*., 2014) whose contents, are respectively, of 0.11 and 0.19.

The results of the soil physical analyses showed that the pH is alkaline at the residue soils and acidic at the control site. These pH levels seem to favor the adsorption mechanism of the TMEs on the organic matter and clay layers. Indeed, according to Pichard *et al*., (2002), a pH higher than 5 favors the accumulation of lead. It is slowly incorporated according to Kabata-Pendias and Pendias (1992), in the organic matter and in the clay minerals. Copper, at high pH, preferentially binds to iron and Mn oxyhydroxides, clays and organic matter (Baker and Senft, 1995). Alkaline pH favors better accumulation of zinc, and this adsorption occurs under the influence of organic ligands (Pickard *et al*., 2003a). Indeed, there is a pH below which metals are abruptly released. An acidic pH favors the mobilization of metals by proton exchange. There is a contribution to the medium of protons whose fixation is strongly competitive on the exchange and sorption sites (Baize, 1997).

CONCLUSION

The results obtained in this study make it possible to affirm that the soils of the superficial horizons of the Akouédo dump are subject to multiple contamination by metallic trace elements (Zn, Pb, Cu, Cr and Cd) from the dumped waste. The pollution is effective on the soils of old residues. The pollution index (PI) obtained on older tailings soils, age > 30 years and older tailings soils, age < 20 years, are 1.5 and 1.11 respectively. As for the young tailings soils, they tend towards a pollution in these metals because IP is 0.83 close to 1. The presence of waste on the site, has led to an enrichment of the soils in Zn, Pb and Cu which has therefore modified the trend of metals. We went from Cr > Zn > Pb > Cu > Cd before the dumping of the waste to the following new sequence Zn > Pb > Cu > Cr > Cd of the TMEs after the storage of the waste.

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