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Diagnostic Of Metal Pollution In The Soil, Vegetation And Water At The Andralanitra Landfill Level

Harilanto Miarantsoa Rabenirina *[1], Tianjanahary Nathalie Razafiarisoa[2], Hanitrinisoa Harimisa Andriamafana [1], Christine Ravonizafy[1], Yves Jean Michel Mong[1], Rado Rasolomampianina[1]

[1]National Center of Environmental Research, Antananarivo Madagascar
[2] Mention of Processes and Industrial Ecology, Faculty of Sciences, University of Antananarivo, Antananarivo, Madagascar
*Corresponding author: miari_lanto@yahoo.fr

Abstract— The Andralanitra landfill is the waste disposal site for the city of Antananarivo. The accumulation of waste can lead to serious environmental problems, such as heavy metal contamination of the soil, surrounding vegetation and nearby water resources. The aim of this study is therefore to assess the level of metal contamination in the water, soil and edible vegetation located 50 to 500 m from the Andralanitra landfill. 53 samples were collected at each sampling point. The concentrations of heavy metals (Pb, Cd, Cu, Zn, Cr, Ni, Fe, Mn) in the various samples were determined by atomic absorption spectroscopy. For the soil samples, the results showed high levels of contamination exceeding acceptable standards, such as lead (24.80 mg/kg to 1034.02 mg/kg), manganese (112.7 to 1276.7 mk/kg) and cadmium (1.33 to 6.31 mg/kg). Analysis of the vegetation showed a high accumulation of iron (142.6-1265.8 mg/kg), chromium (0.89-16.28 mg/kg), copper (3.82-19.31 mg/kg), nickel (3.11-9.48 mg/kg) and zinc (46.83-261.34 mg/kg), which may pose potential risks to the health of the plant and above all to the food chain. The water samples are less contaminated compared to soil sample and plant sample because heavy metal migration is limited to the soil. The results were then statistically analyzed by the Principal Component Analysis (PCA) method, followed by a correlation study between the heavy metals measured.

Keywords— Water; Soil; Edible Plants; Heavy Metals; Principal Component Analysis

I. INTRODUCTION

The development of human activities followed by incredible demographic growth generates tonnes of waste. The world has always faced the problem of waste management, especially in developing countries such as Madagascar [1]. Over the last ten years, the issue of municipal solid waste has seen little improvement. Public landfill is the most common method of waste disposal. However, it has been identified as one of the main threats to groundwater contamination [2]. In Antananarivo city home to 4 million inhabitants [3], the waste collection is taken care of by the Municipal Sanitation Company and is reduced to landfill. The Andralanitra landfill site has been the capital's main refuse dump since 1966. The waste stored there may be of domestic or industrial origin, such as electronic waste, out-of-date medicines, batteries and cosmetics. It may contain heavy metals [4]. The absence of prior treatment of this waste can therefore cause metallic contamination of the soil, water resources and surrounding vegetation through the infiltration of leachates released by the waste [5,6]. This contamination can lead to potential risks for the environment and above all for human health through contamination of the food chain by plant products [7].

The aim of this study is to assess the level of heavy metal contamination in the receiving environments (water, soil, surrounding vegetation) in the vicinity of the Andralanitra landfill site. The aim is to estimate the extent of metal pollution in these environments and the potential sources of contamination. Trace metal levels in each sample were measured, followed by a principal component analysis of the data obtained in order to understand the spatial distribution of heavy metals and identify the most polluted areas. The environmental indices in the soil samples (pollution load index, contamination factor and geo-accumulation index) were calculated to determine the degree of toxicity of the metals in each sample in the different areas.

II. MATERIALS AND METHODS

2.1. Study Area

The Andralanitra landfill is on the perphery of the city and located about 9 km East of the capital, about 6 km South of Ambohimangakely, Fokontany of Ikanja, in the Antananarivo-Avaradrano. Geographically, the study zone is between 47°34 and 47°36 East longitude, and 18°53 and 18°55 South latitude, between 1290 m of altitude in the hills and around 1245 m of altitude in rice fields and marshes. Andralanitra is part of the Malagasy Central Hyghlands [8].

2.2. Sample collection

The study was covried out on three areas around the landfill: an area East of the river and an area South of the ring road were the subject of this work. Each area contains water, soil and edible plants samples. Fyfty-three samples were collected including 20 samples soil (S1 to S20), 15 edible samples plants (P1 to P15) and 18 samples waters taken from spring water, well water, suface water and river. The location of sample point is shown in figure 1.

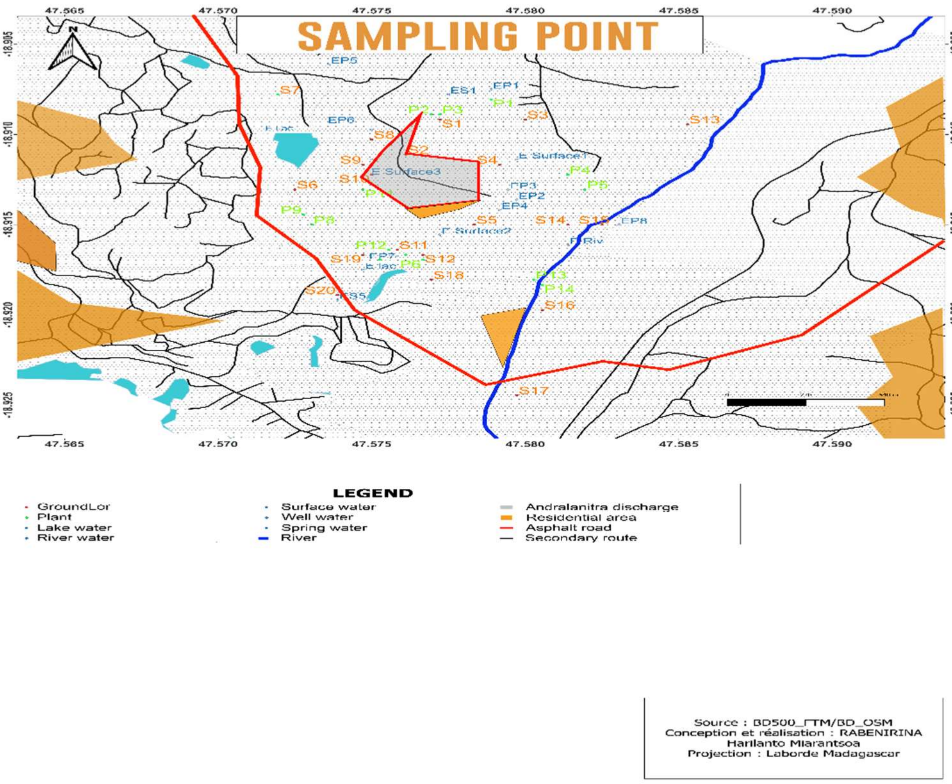

Figure 1. *Location of sampling point*

2.3. Analysis of heavy metal in the samples

2.3.1. Determination of dry weight 2g of the sample was used. The determination of the dry weight for samples soil and samples plant was carried out by weighing the empty capsule then the sample and the capsule, everything was dried in an oven at 105ºC for 1 hour and weighing the capsule and the dry sample at the exit from the oven. The dry weight of the sample was calculated as follows (1) [9]:

$$W = (\mathrm{VSd} - \mathrm{V}) \qquad (1)$$

W: dry weight of sample (g)

VSd: weight of the capsule and the sample after oven (g)

V: weight of empty capsule (g)

2.3.2. Mineralization of samples soil and samples plant

The method used for soil mineralization is the Rodier method [9]. To do this, 2g of soil are weighed into a capsule, 4ml of sodium nitrate (100g/l) are added, everything is mixed then dried in the oven at 110°C. The capsule is then placed in the oven gradually heated to reach 450°C and this temperature is maintained for 2 hours. To the residue, 5ml of HNO3 are added and the mixture is brought to a gentle boil for around ten minutes then evaporated to dryness. Then, the residue was taken up with 20ml of HCl (2N) and heated until boiling. It was then filtered and the filtrate was collected in a 50ml flask and finally it was adjusted with distilled water. For the mineralization of plants [10], 0.5 g of each sample is weighed then introduced into a well-rinsed Teflon bomb. Then, 10ml of nitric acid (HNO3) 65% was added, the mixture was left predigested overnight at room temperature. Everything was placed in a water bath at 90°C for 3 hours. After cooling, the solution was filtered into a 25 ml flask, using Whatman filter paper.

2.3.3. Dosage of heavy metals

The analysis of heavy metals in the water samples and in the minerals obtained was carried out by atomic absorption spectroscopy. The metallic elements to be analyzed were Fe, Cu, Ni, Mn, Pb, Cd, Cr, Zn. For the determination of each element, standards with known concentrations were measured first to allow calibration of the device. The concentration of soils and plants was calculated according to the f

$$C = \frac{\mathrm{Cd\,.\,V\,.\,F}}{\mathrm{W}} \qquad (2)$$

C: concentration of the element in the starting sample mg/kg.

Cd: concentration of the element in the soil sample solution (µg/ml)

V: volume of sample solution (ml)

W: dry weight of sample (mg)

F: dilution factor (if necessary)

2.4. Calcul of environmental indices

2.4.1. Pollution load index

The pollution is definied as the average of the ratios of metal concentrations in soils samples in relation to limit values [11]. These limit values correspond to the supposedly tolerables level in the soil. Therefore, to know the degree of site contamination, it is necessary to calculate its pollution index, which can be calculated from the following equation

(IP=[(Cd/2+Cr/150+Cu/100+Ni/50+Pb/100+Zn/300+Mn/89)/7]   (3)

2.4.2. Contamination factor

The contamination factor of metallic element in the soil consists of expressisng the ratio of the content of a given substance in relation to that of the normalizing factor [12]. This contamination factor is expressed by the following formula (4):

$$\mathrm{FCx} = \frac{\mathrm{Cx}}{\mathrm{Bgx}} \qquad (4)$$

Cx: concentration measured for an element x

Bgx; Background for an element x

2.5. Statistical analysis

The statistical study was based on principal component analysis (PCA). The heavy metal content data from laboratory analyzes were subject to a principal component analysis whose variables are the parameters to be analyzed (Pb, Fe, Cu, Cr, Cd, Zn, Ni, Mg) and the individuals are the collection points for each sample. All analyzes and graphics were carried out in the R 3.5.1 software environment.

III. RESULTS AND DISCUSSION

3.1. Evaluation of the heavy metal concentration in the waters, soils and plants samples

3.1.1. Waters

The results of heavy metals concentration in the water samples figure 2a to figure 2h are illustrated by the following graph:

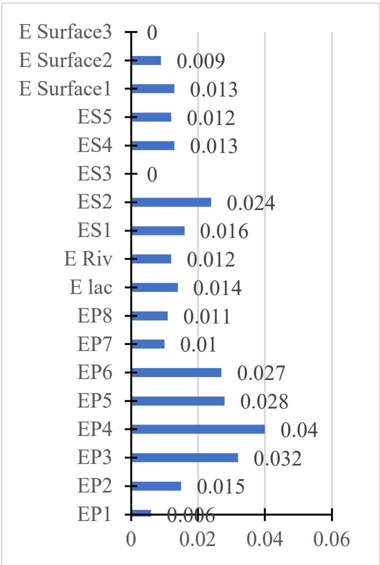

Figure 2a : Cadmium concentration mg/l

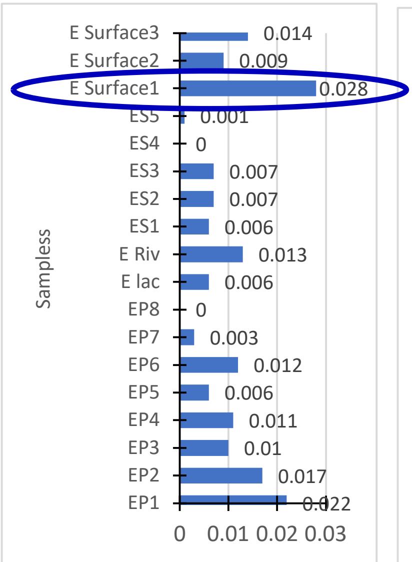

Figure 2b : Copper concentration mg/l

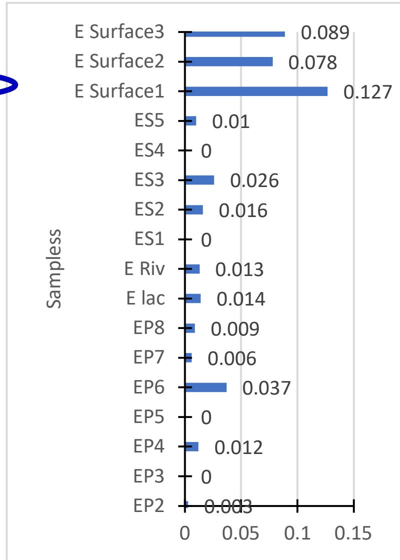

Figure 2c : Nickel concentration mg/l

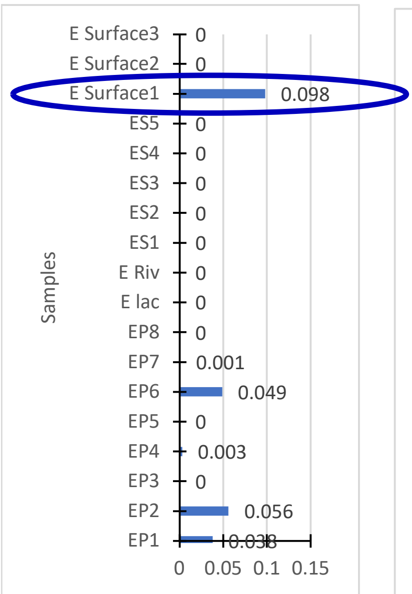

Figure 2d : Lead concentration mg/l

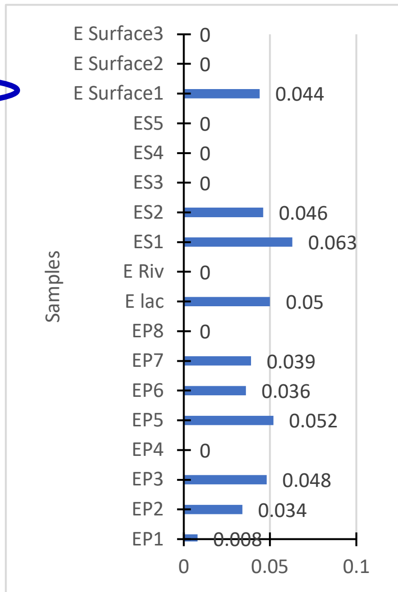

Figure 2e: Chrome concentration mg/l

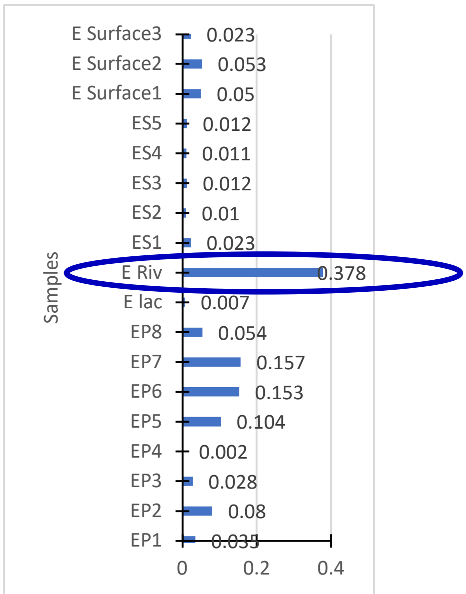

Figure 2f : Zinc concentration mg/l

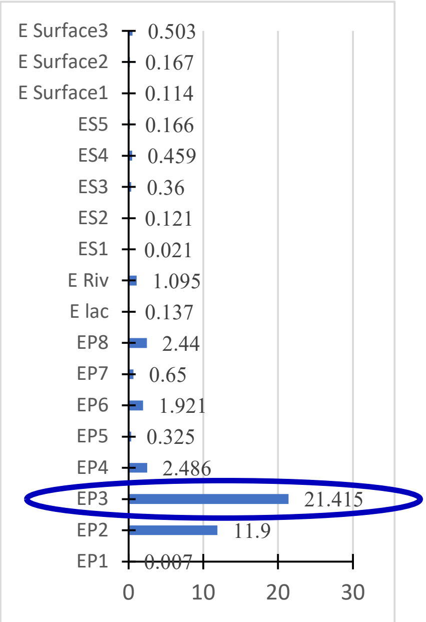

Figure 2g : Manganese concentration mg/l

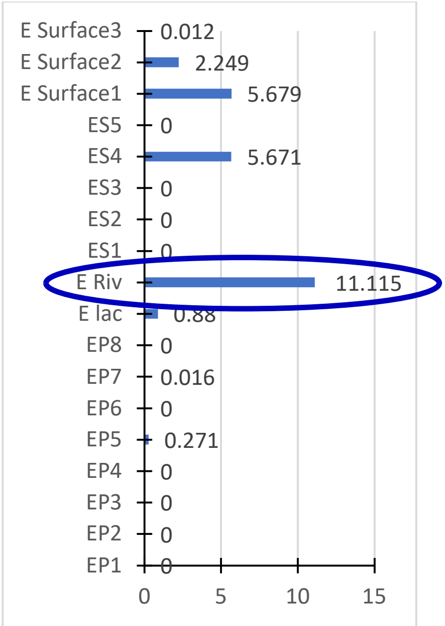

Figure 2h. Iron concentration mg/l

According to the results, the iron and manganese concentrations with values of 11.11 mg/l and 21.41 mg/l, are the hightest in relation to limit values by the drinking water standard for 18 samples, this high concentration is observed above all in surface water, which is located at a distance of approximately 100 m from the landfill. These results are similar to those of [13] where the values of the parameters measured from wells located in the direction of the leachate flow and closer to the dumpsite most often present higher concentrations of elements analyzed relative to other wells located further from the landfill.

3.1.2. Soils

The results of heavy metals concentration in the soils samples figure 3a to figure 3h are illustrated by the following graph:

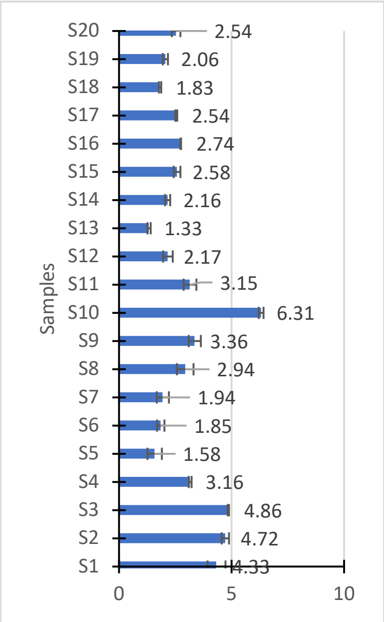

Figure 3a : Cadmium concentration (mg/kg)

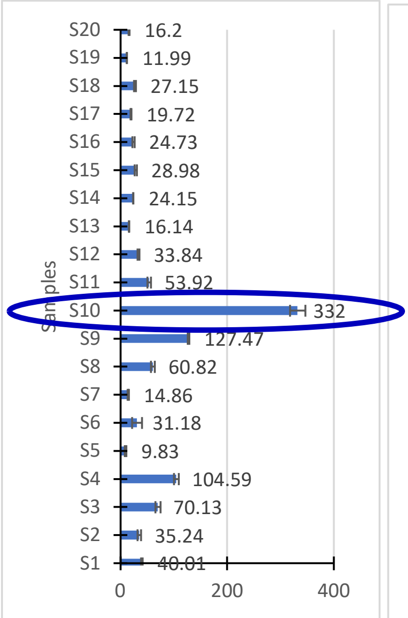

Figure 3b : Cooper concentration (mg/kg)

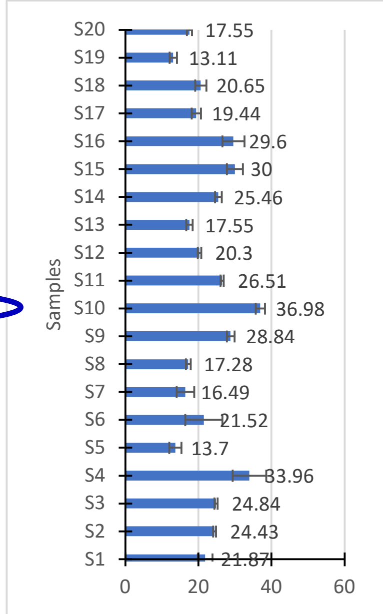

Figure 3c : Nickel concentration (mg/kg)

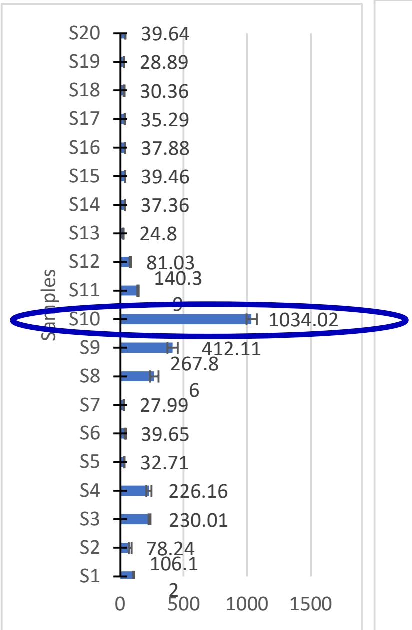

Figure 3d : Lead concentration (mg/kg)

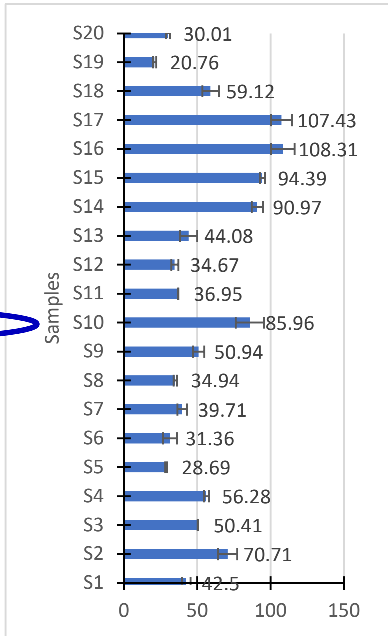

Figure 3e : Chrome concentration (mg/kg)

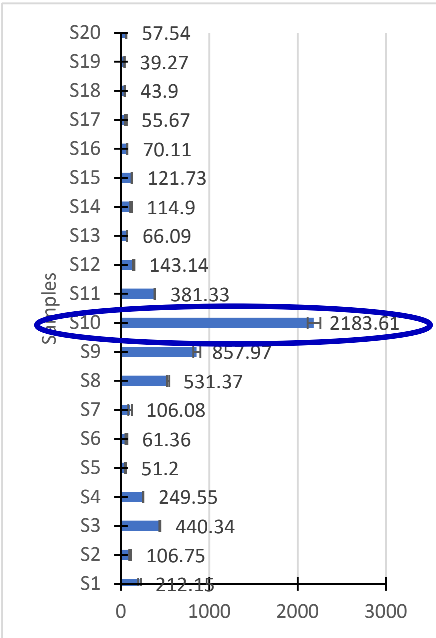

Figure 3f : Zinc concentration (mg/kg)

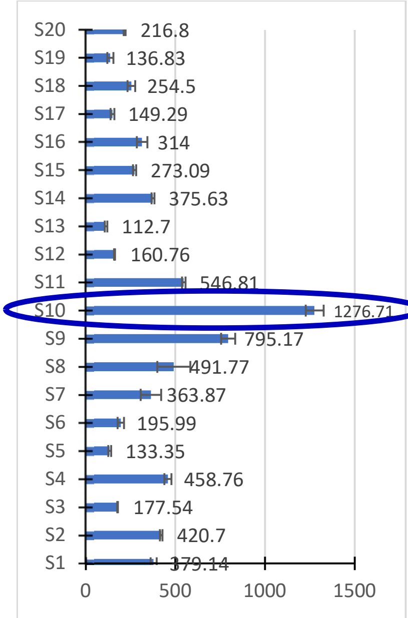

Figure 3g : Manganese concentration (mg/kg)

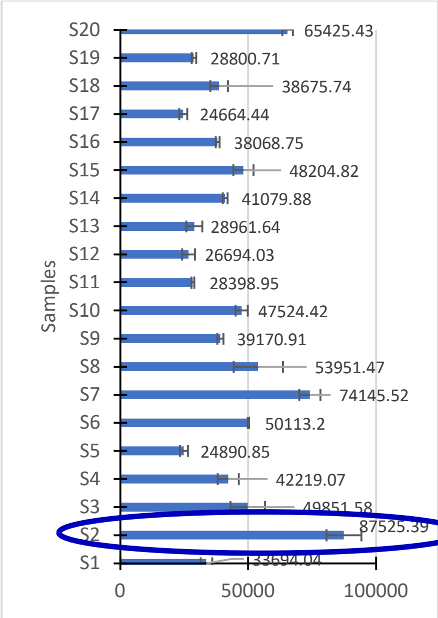

Figure 3h : Iron concentration (mg/kg)

The results of the analysis of heavy metals showed that the values of metallic elements in several soil samples exceeded the values recommended by the AFNOR N F U 44-041 standard. The concentrations of iron, manganese, cadmium and lead are the highest compared to other heavy metals, hence the trend Fe>Mn>Cd>Pb>Zn>Cu>Cr>Ni. The determination of heavy metals showed that sample S10 among the 20 samples is the most contaminated with a Lead content of 1034.02 mg/kg and a cadmium content of 6.36 mg/kg. The concentrations of iron and manganese are the highest, these results are similar to those of [14] where the levels of iron and manganese measured in the soil near the landfill were higher compared to other parameters, this strong contamination can be caused not only by pollution but also by the lithological contribution. [15] also confirmed this hypothesis where the presence of high levels of Mn and Fe in the soil concretions is mainly due to the hydroxides and oxides of soils during their pedogenetic treatment. High levels of heavy metals in soil are mostly due to anthropogenic activities such as industry, agriculture and uncontrolled waste disposal. This high content is mainly found in the surface layer of soils and varies according to the source. Our results concur with those of [16], where the surface layer is the part of soil where heavy metal is most accumulated.

3.1.3. Plants

The results of heavy metals concentration in the plants samples figure 4a to figure 4h are illustrated by the following graph:

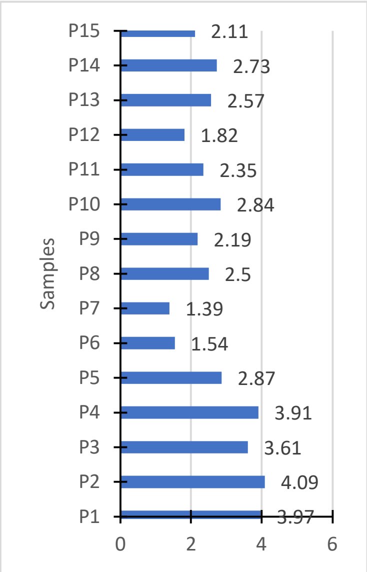

Figure 4a : Cadmium concentration (mg/kg)

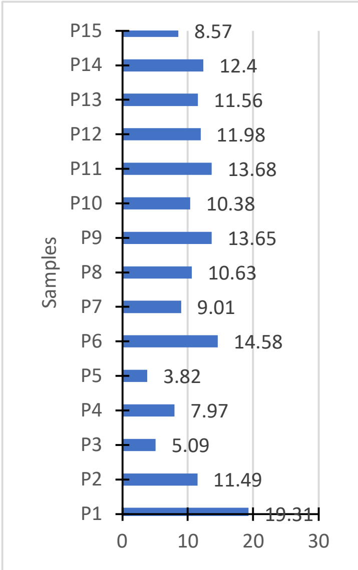

Figure 4b : Copper concentration (mg/kg)

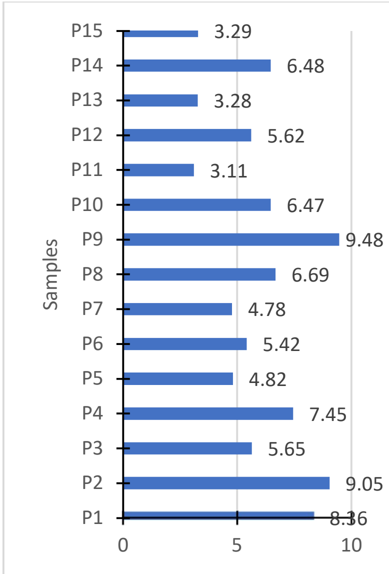

Figure 4c: Nickel concentration (mg/kg)

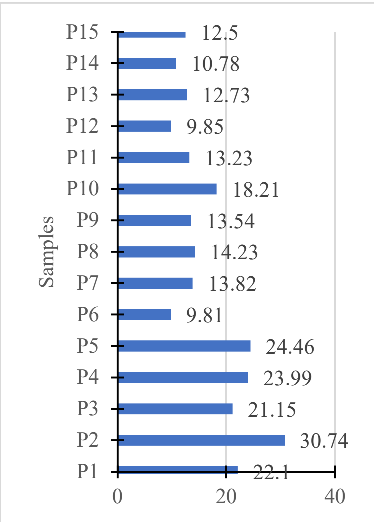

Figure 4d: Lead concentration (mg/kg)

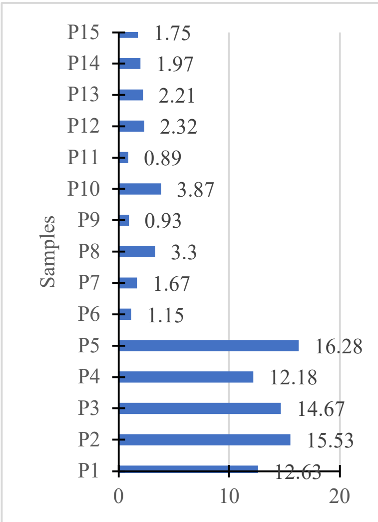

Figure 4e: Chrome concentration (mg/kg)

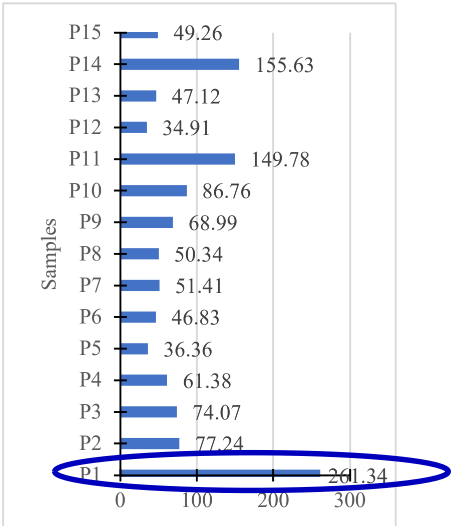

Figure 4f: Zinc concentration (mg/kg)

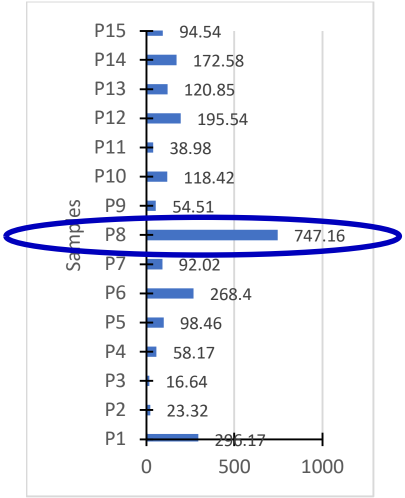

Figure 4g. Manganese concentration (mg/kg)

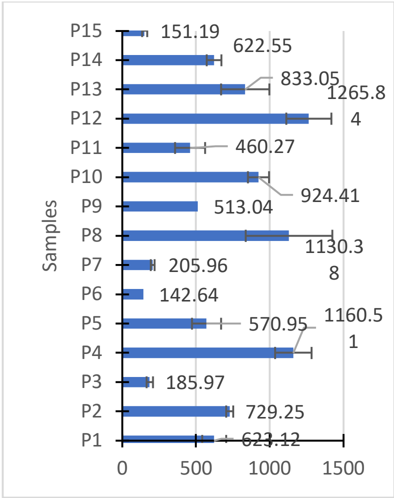

Figure 4h : Iron concentration (mg/kg)

According to these results, the analysis of heavy metals in edible plants showed high contamination in nickel, lead, cadmium, chromium, iron and zinc for the 15 samples where Ni>Pb>Cd>Cr >Fe>Zn>Cu>Mn. For iron, the concentrations varied from 151.19 to 1265.84 mg/kg, the nickel concentrations varied from 3.11 to 9.48 mg/kg, the lead concentrations varied from 9.81 mg/kg at 30.74 mg/kg, cadmium concentrations varied from 1.59 to 4.09 mg/kg, chromium contents varied from 0.89 to 15.53 mg/kg. These 5 metallic elements presented values well above the values recommended by the standard. The most contaminated samples are taros and squash. This concentration can be linked to soil pollution, water used for irrigation and atmospheric pollution. This confirms the results published by [17] et [18] on foliar absorption of metals. The metal transfer factor is an essential index for assessing the soil-plant transfer potential of given a metal. It is essential for estimating the health risk associated with contaminated soils [19].

3.2. Study of environmental index of heavy metal in soils samples

The pollution load index (PLI) method was applied to the soil samples. The results are shown in the table 1 below:

Table 1. Pollution load indices and contamination factor

	FC-Cu	FC-Mn	FC-Ni	FC-Pb	FC-Cd	FC-Cr	FC-Zn	PLI
S1	0.40*	4.26**	0.43*	1.06**	2.16**	0.28 *	0.70*	1.33
S2	0.35*	4.72***	0.48*	0.78*	2.36**	0.47*	0.35*	1.36
S3	0.70*	1.99**	0.49*	2.30**	2.43**	0.33*	1.46**	1.39
S4	1.04**	5.15***	0.67*	2.26**	1.58**	0.37*	0.83*	1.70
S5	0.09*	1.49	0.27*	0.32*	0.79*	0.19*	0.17*	0.47
S6	0.31*	2.20**	0.43*	0.39*	0.92*	0.20*	0.20*	0.66
S7	0.14*	4.08***	0.32*	0.27*	0.97*	0.26*	0.03*	0.91
S8	0.60*	5.52***	0.34*	2.67**	1.47**	0.23*	1.77**	1.80
S9	1.27**	8,93****	0.57*	4.12***	1.68**	0.33*	2.85**	2.82
S10	3.32***	14.3****	0.73*	10.3****	3.15***	0.57*	7.27****	5.67
S11	0.53*	6.14****	0.53*	1.40**	1.57**	0.24*	1.27**	1.67
S12	0.33*	1.80**	0.40*	0.81*	1.08**	0.23*	0.47*	0.73

S13	0.16*	1.26**	0.35*	0.24*	0.66*	0.29*	0.22*	0.45
S14	0.24*	4.22***	0.50*	0.37*	1.08**	0.60*	0.38*	1.59
S15	0.28*	3.06***	0.60*	0.39*	1.29**	0.62*	0.40	0. 95
S16	0.24*	3.52***	0.59*	0.37*	1.37**	0.72*	0.23*	1.01
S17	0.19*	1.67**	0.38*	0.35*	1.27**	0.71*	0.18*	0.68
S18	0.27*	2.85**	0.41*	0.30*	0.91*	0.39*	0.14*	0.75
S19	0.11*	1.53**	0.26*	0.28*	1.03**	0.13*	0.13*	0.50
S20	0.16*	2.43**	0.35*	0.39*	1.27**	0.20*	0.19*	0.71

* Low contamination (FC<1)

** Moderate contamination (1<FC<3)

*** Significant contamination (3<FC<6)

**** High contamination (FC>6)

The contamination factor was used to express the contamination level by each metal in sediments. Soil S10 has the highest heavy metal content with a contamination factor of over 6 especially for lead, manganese and zinc. For the index pollution (PLI), on the 20 soils samples, 10 samples have a pollution index greater than 1 of which S10 with the highest (PLI=5.6). These results are similar to those of [20,21] where PI greater than 1 were obtained on soils in urban and peri-urban areas. Contrary to the results of [22], soil samples subjected to urban solid waste have a PLI< 1.

3.3. Principal Component Analysis of heavy metals and correlation study between metal for soil and plant sample

3.3.1. Soils

The principal component study of heavy metals in soil and the correlation matrices between metals are shown in table 2 and figure 5:

Table 2. Correlation matrix between heavy metals in samples soils

Variables	Fe	Cr	Ni	Cd	Mn	Zn	Cu	Pb
Fe	1							
Cr	0,01	1						
Ni	0,08	0,58	1					
Cd	0,31	0,26	0,62	1				
Mn	0,18	0,23	0,68	0,7	1			
Zn	0,05	0,17	0,59	0,73	0,91	1		
Cu	0,05	0,21	0,69	0,74	0,91	0,98	1	
Pb	0,06	0,16	0,61	0,75	0,91	0,99	0,99	1

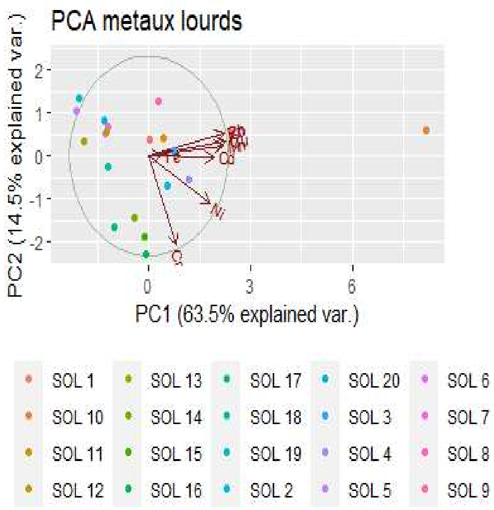

Figure 5. Principal component analysis of heavy metals in plants.

For the correlation study, the linear correlations are all positive. A single group has been identified for consisting of Mn, Cu, Pb and Zn. The correlation coefficients between these chemical elements are very high especially for Cu and lead with r2= 0.99. These results agree with those of [23] where Cu and Pb have a strong correlation which confirms that a single mechanism governs between these two metals, this mechanism could be that of adsorption.

In the correlation, the first component (dim 1), contributing with 63,5 % inertia and 14,5 % for the second component. The figure shows a variation in concentrations as a function of the distance of the sampling point from the landfill and the metal element. The closer the soil is to the landfill, the higher is the heavy metal content. This is the case for soil S10, which is very close to the landfill site, almost all heavy metal values are at maximum. These results are similar to those of numerous authors [16,20,21,24-26], who have shown that heavy metal concentrations in soils vary according to the metal element and the sampling site.

3.3.2. Plants

The application of principal component analysis for heavy metals in edible plants and heavy metal correlation matrices is illustrated in table 3 and figure 6:

Table 3. Correlation matrix between heavy metals in plants

Variables	Ni	Cd	Pb	Cr	Cu	Zn	Fe	Mn
Ni	1							
Cd	0,5	1						
Pb	0,46	0,84	1					
Cr	0,36	0,82	0,92	1				
Cu	0,21	-0,05	-0,28	-0,36	1			
Zn	0,27	0,43	0,14	0,14	0,65	1		
Fe	0,3	0,27	0,13	0,07	0,06	-0,07	1	
Mn	0,11	-0,15	-0,26	-0,21	0,26	0,04	0,35	1

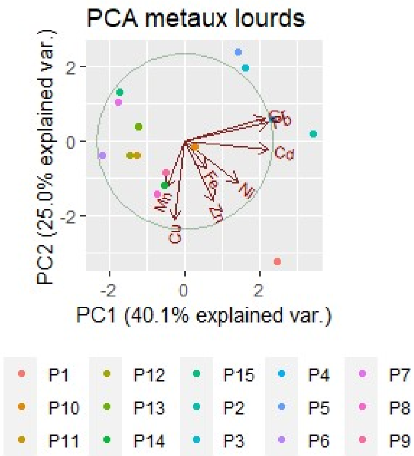

Figure 6. Principal component analysis of heavy metals in plants.

Lead and chromium are the chemical elements correlated with each other with a very high correlation coefficient (r2= 0.92 and r2=0.82). The 15 samples were contaminated with heavy metals, especially Fe, Cr, Cd, Ni and Zn. The nickel contents are well above the threshold value (1.5 mg/kg). High concentrations are observed in squash samples (9.05 mg/kg) and lettuces (9.5 mg/kg). Taros also accumulate nickel very well, with a high concentration of 8.36 mg/kg. As with nickel, high cadmium contamination was observed in the 15 edible plant samples. The highest level is found in squash at 4.1 mg/kg, 80 times higher than the recommended value (0.05 mg/kg), while high levels are also found in taro (3.97 mg/kg) and beans (3.9 mg/kg). For chromium, the heavy metal concentrations observed in taro (12.63 mg/kg), squash (15.53 mg/kg), petsay (14.67) and beans (12.18) are well above the acceptable limit value (1.5) mg/kg. The edible plant samples located near or far from the landfill are all contaminated with heavy metals.

IV. Conclusion

The study highlighted the pollution of receiving environments (water, soil, vegetation) from the Andralanitra landfill. High levels of metal contamination were observed in several soil samples, indicating the penetration of leachates produced by the stored waste. It also showed the accumulation of metals by several plants, especially leafy vegetables, which accumulate more heavy metals. Metallic pollution of plants can come from the soil in which they are grown or from irrigation water. Because heavy metals can cause serious illnesses such as cancer, the risks to human health from eating edible plants contaminated by heavy metals are very high. According to the results obtained, measures must be taken to limit heavy metal contamination, such as soil treatment.

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