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Assessment of Pollution in Agricultural Soil and Interrelationship between the Heavy Metals at Paspanga, Burkina Faso

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Abstract: *Agricultural soil quality deterioration resulting from increase in the level of heavy metals is becoming more and more pronounced, thus raising the question on safety status of human health and environment. Determination of concentration, calculation of contamination factor and pollution load index of heavy metal in agricultural soil including top (0-5cm) and sub (15-20cm) soils at Paspanga, Burkina Faso were undertaken. The soil samples were analysed for trace metals employing flame atomic absorption spectrometry (FAAS). The pollution was characterized using the quality indices as contamination factor (CF) and pollution load index (PLI). The decreasing order of metals observed in Paspanga top soil samples was Fe>Mn>Pb>Zn>Cr>Ni>Co>As>Hg whereas that of subsoil samples was Fe>Mn>Zn>Pb>Cr>Ni>Co>As>Hg. The levels of heavy metals analyzed were within the threshold limit set by the WHO. The concentrations of heavy metal in the top soil are higher than those in subsoil. The PLI indicates that the top and sub soil at Paspanga market garden (soil) were not polluted. The statistical study of heavy metal concentration in top and sub soil shows that there is correlation between: Nickel and Zinc (Ni-Zn), Manganese and Zinc (Mn-Zn), Lead and Arsenic (Pb-As), and Lead and Mercury (Pb-Hg).*

Keywords: *Heavy metals, concentration, contamination factor, pollution load index, correlation.*

I. Introduction

The world agricultural context (exacerbated competition, increasing requirements of the consumers, precaution principles), submits soils to different shapes of deterioration and pollution, due to agricultural, industrial and urban waste which use some big areas of land. Adding to that, there is the intensification of agriculture with more artificially productivity setting in culture of new surfaces, in bad conditions, without taking into account the soils potentialities and the fragilities. Otherwise, other wastes are also susceptible to be spread on the cultivated soils. Among the undesirable substances contained in these various waste, appear the "heavy metals" [1]. The biologic system needs the heavy metal but their lack or excess can lead to several messes. The heavy metals contamination of water, soil and air can lead to the contamination of the food and cause their accumulation in the biologic organism [2]. Conventional inorganic phosphorus fertilizers and organic fertilizers can be an important source of heavy metals in agricultural soil [3]. A heavy metal in soil can negatively affect crop growth and also interferes with plants metabolic functions, inhibition of photosynthesis, respiration and degeneration of main cell organelles [4]. The heavy metal can pollute ground water because of its rapid transfer in soil profiles. The potential accumulation and bioaccumulation of heavy metals in agricultural soils affects seriously food chain contamination [5]. In Ouagadougou, the sites of urban agriculture are present along the city hydrographic network (dams, gullies, central channel, temporary or permanent creeks etc.) and around the dismissals of waste waters [6]. Therefore an assessment and a better understanding of sources of heavy metals, their accumulation in the agricultural soil and their presence in water and plants can be particularly important questions on the evaluations of the risk.

The objective of this study was to assess and analyse the concentration, contamination factor, pollution load index of heavy metals and determination of correlation between the heavy metal in soil (0-5cm) and sub-soil (15-20cm) at Paspanga.

II. Materials and methods

II.1 Study Area

In this study, the soil samples were collected on ten (10) sites in Paspanga market garden. The market garden of Paspanga is situated in Ouagadougou on the outskirts of the dam number 3 of Tanghin with a surface of about 5.3 hectare. It is irrigated with water coming from the dam. The dams number 1, 2, and 3 of Tanghin have been constructed in 1934. The capacity of retention of these three restraints of water (dam’s n°1, 2, 3) is 5.235.500 m3 [6].

II.2 Samples and Sampling Techniques

The samples were collected from the market garden of Paspanga at two different levels: top-soil 0-5cm and sub-soil 15-20cm. The agricultural soil sample was collected at three or four different points on the diagonal profile of each site. The soils from the different points were mixed and kept in sterile glass bottles. The samples were collected from ten sites.

II.3 Laboratory Analysis

The soils samples were analysed for heavy metals such as cobalt (Co), chromium (Cr), iron (Fe), manganese (Mn), zinc (Zn), lead (Pb), nickel (Ni), cadmium (Cd), arsenic (As) and Mercury (Hg) using Atomic Absorption Spectrometer. The soil sample(1.5g) were weighed into a 100ml polytetrafluo-roethylene (PTFE) Teflon tube and concentrated acids of 6mL of concentrated nitric acid (HNO_3, 65%), 3mL of concentrated hydrochloric acid (HCl, 35%) and 0.25mL of Hydrogen peroxide (H_2O_2, 30%) were added to each sample. The samples were then loaded on the microwave carousel. The vessel caps were secured tightly using a wrench. The complete assembly was microwave irradiated for 26 minutes using milestone microwave Labstation ETHOS 900, INSTR: MLS-1200 MEGA. After digestion the Teflon tube mounted on the microwave carousel was cooled in a water bath to reduce internal pressure and allow volatilized material to re-stabilize. The solution was then diluted to 20 ml with distilled water and assayed for the presence of elements (Zn, Pb, Mn...) using VARIAN AA 240FS- Atomic Absorption Spectrometer in an acetylene-air flame. The metal final concentration was calculated using the following formula:

$$Final\ concentration = \frac{C_{metal} * D_{factor} * V_{nominal}}{Sample\ weight(g)}$$

Where C_{metal} is the concentration of the metal, D_{factor} is the dilution factor and $V_{nominal}$ is the nominal volume.
For soil samples: nominal volume=20ml and sample weight=1.5g.

II.4 Quantification of the soil pollution

In this study, the soil pollution degree and the contamination level were quantified using the Contamination Factor (CF) and Pollution Load Index (PLI) [7].

Contamination Factor (CF): The CF is the concentration of each metal in the soil divided by the background concentration of the metal (concentration in unpolluted soil).

$$CF = \frac{C_{heavy metal}}{C_{background}}$$

The background concentrations were calculated from the heavy metals concentration in unaffected soils of the studied area [8].
To classify the contamination levels, four categories were defined depending on the value of CF: low contamination for CF<1; moderate contamination for 1<CF<3: considerable contamination for 3<CF<6 and very high contamination for CF>6 [9][10].

Pollution Load Index (PLI): The pollution load index of sampling site was calculated using the contamination factor of the heavy metal. The PLI for a single site is the nth root of the product of the n CF values [4].

$$PLI = (CF_1 * CF_2 * CF_3 * .... * CF_n)^{1/n}$$

Where, n is the number of metals index which provides a simple, comparative means for assessing the level of heavy metal pollution.
A value of PLI < 1 denote perfection; PLI = 1 shows that only baseline levels of pollutants are present and PLI > 1 would indicate a deterioration of site quality [11][12].

III. Results and discussions

III.1 Heavy metals concentration

Table 1: Average concentration of heavy metals in soil and sub-soil at Paspanga

Paspanga		[Co]	[Cr]	[Fe]	[Mn]	[Zn]	[Pb]	[Ni]	[As]	[Hg]
Top-soil (0 à 5 cm)	Average	0.629	3.446	264.326	34.208	6.813	7.147	0.783	0.495	0.033
	Median	0.585	2.775	264.244	36.885	6.240	6.555	0.660	0.450	0.015
	Standard Deviation	0.290	3.035	2.697	11.185	2.593	2.244	0.358	0.287	0.021
	Minimum	0.075	1.680	260.585	13.725	4.860	4.845	0.345	0.165	0.015
	Maximum	1.155	12.495	270.621	51.360	14.265	11.205	1.500	0.900	0.060
Sub-soil (15 à 20 cm)	Average	0.198	1.846	254.276	24.754	5.172	4.493	0.453	0.150	0.016
	Median	0.180	1.950	260.735	28.755	5.205	4.035	0.450	0.150	0.015
	Standard Deviation	0.135	0.380	20.349	11.702	1.091	1.343	0.274	0.059	0.005
	Minimum	0.075	0.915	194.508	0.030	3.360	3.045	0.015	0.045	0.015
	Maximum	0.405	2.325	264.822	37.095	6.855	6.570	0.840	0.270	0.030

Table 1 show the average concentration, the standard deviation, the minimum and maximum concentration of the different heavy metals in the top-soil and sub-soil at Paspanga. For the top-soil, the average values of metal concentration were: 264.33ppm for Fe, 34.21ppm for Mn, 7.15ppm for Pb, 6.81ppm for Zn, 3.45ppm for Cr, 0.78ppm for Ni, 0.63ppm for Co, 0.50ppm for As and 0.03 ppm for Hg. For top-soil sample, the heavy metals showed this rank: Fe>Mn>Pb>Zn>Cr>Ni>Co>As>Hg. In sub-soil sample, the average values of metal concentration were: 254.28ppm for Fe, 24.75ppm for Mn, 5.17ppm for Zn, 4.49ppm for Pb, 1.85ppm for Cr, 0.45ppm for Ni, 0.20ppm for Co, 0.15ppm for As, and 0.02ppm for Hg. For sub-soil samples, the heavy metals showed this rank: Fe>Mn> Zn > Pb>Cr>Ni>Co>As>Hg. The concentration of cadmium in top-soil and sub-soil were less than the detection limit. The average concentrations of Cr, Zn, Pb, Ni and As detected in Paspanga soil samples were less than the WHO concentration limit [12][13]. The concentrations of metals for top-soil (0-5cm) were very larger than those for sub-soil (15-20 cm). At a depth of 15 to 20cm, the As concentration decreased 69.7% of its initial value obtained from the top-soil sample, while iron only decreases 3.8%. The concentration of iron in sub-soil was high and this can be lead to the ferruginous nature of soil [14]. The concentrations of Co, Hg, Cr, Pb and Ni at the depth (15-20cm) have a decrease percentage higher than 35% of the surface concentration and the concentration of Zn and Mn at depth have a decrease percentage less than 30%. Except iron, all the studied heavy metals showed a decrease percentage between 24.1 and 69.7% at a depth of 15 to 20cm.

III.2 Contamination factor

The study concerned ten (10) sites at Paspanga on which the samples of soils and sub-soil have been collected and analyzed.

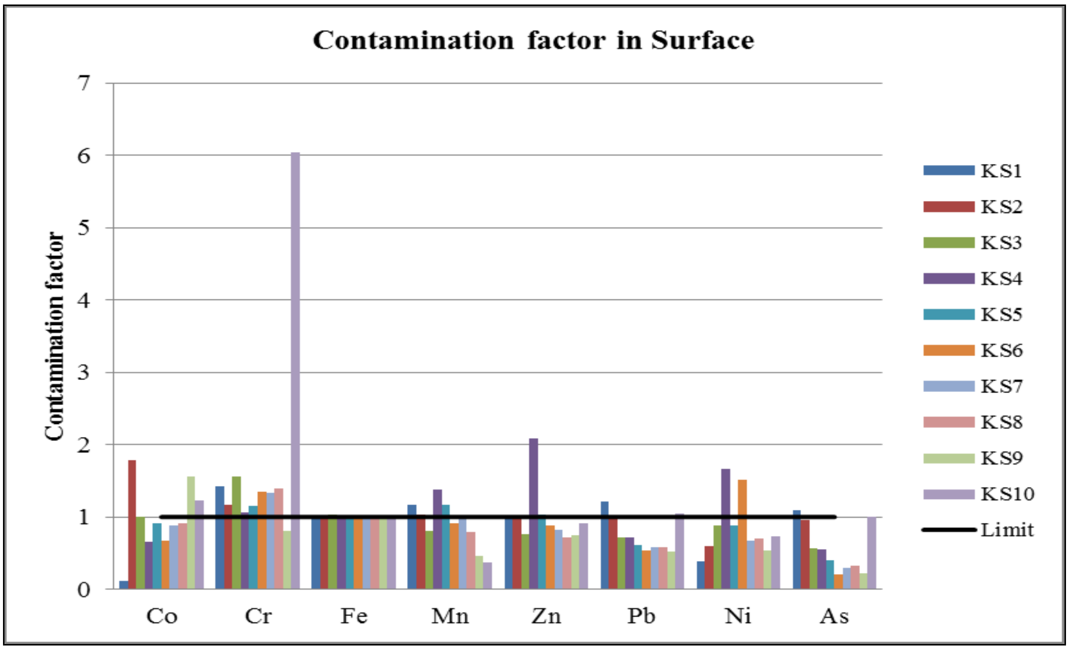

Figure 1: Variation of metals contamination factor of the top-soil for ten (10) sites

The figure 1 shows the heavy metal contamination factor for the top soil samples from Paspanga sites. The contamination factors of the cobalt vary between 0.12 and 1.79 for all the ten (10) sites of sampling with an average of 0.97. Therefore the sampling sites present a low contamination in Co. The chromium has a contamination factor that varies between 0.81 and 6.04 with an average of 1.73, the contamination is moderate. Iron has a low contamination because the factor of contamination for all the sites is appreciably equal to one. The manganese, zinc, lead, the nickel and arsenic have a low contamination because their average contamination factors are 0.91, 1, 0.75, 0.85 and 0.56 respectively. The concentration of the Cd in the samples is less than the detection limit and therefore the contamination factor is very low. In general, the results of this study show that the heavy metals contaminations on the top soil for the ten (10) sampling sites at Paspanga are low, except the chromium that has a moderate contamination.

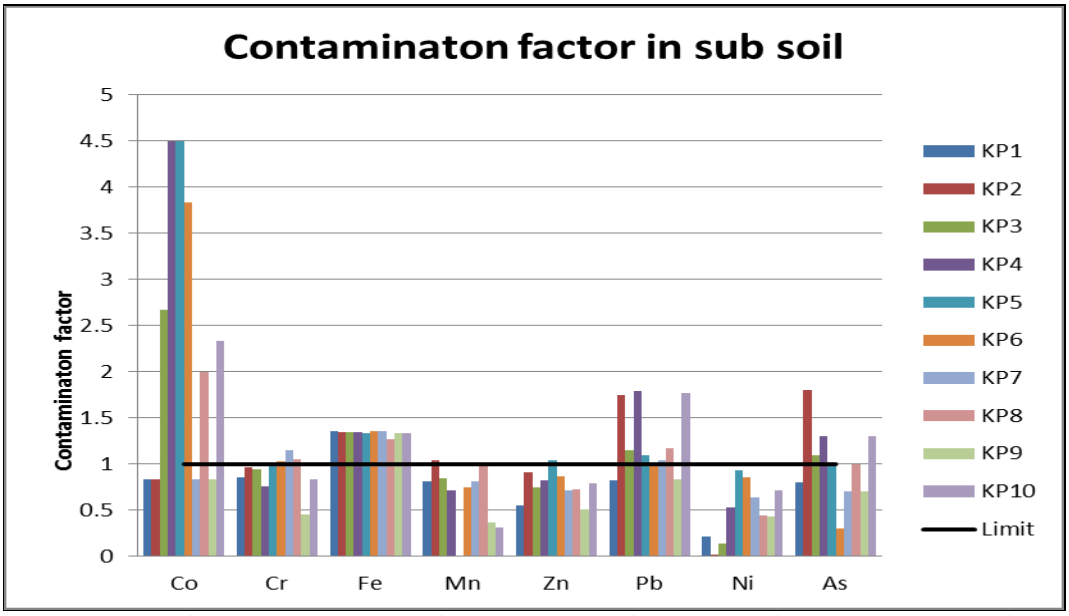

Figure 2: Variation of metals contamination factor at a depth of 15 to 20cm for the ten (10) sites of sampling

The figure 2 shows the heavy metal contamination factor on the sub-soil samples from Paspanga sites. The contamination factors of the cobalt vary between 0.83 and 4.5 with an average factor of 2.32, therefore the contamination is moderate. The contamination factor of the cobalt increased with depth. It can be explain by a low concentration of the cobalt in the background soil at a depth of 15-20cm. And it shows an important migration of the cobalt in depth. The same analysis is done for the lead that has low contamination in surface and a moderate contamination in depth. The iron presents a moderate contamination in depth what was not the case in surface. In conclusion the cobalt, iron and lead are more contaminated in depth than on surface.

III.3 Pollution Load Index

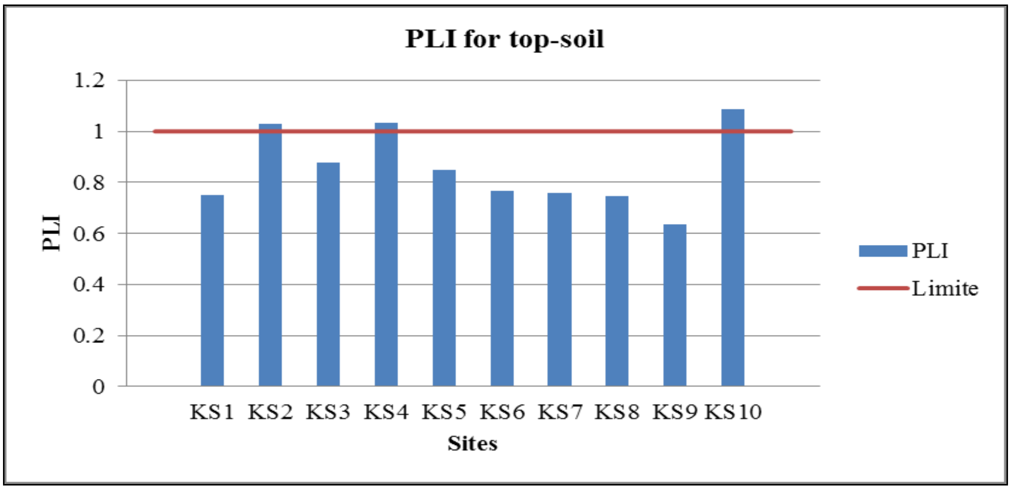

Figure 3: Pollution Load Index on surface at Paspanga

The figure 3 shows the evolution of the pollution load index for the top-soil samples from Paspanga sites. The pollution load index of the sites for the top-soil varies between 0.63 and 1.09 with an average of 0.85. Almost all the sites have a pollution load index less than one. This result indicates that the soils of Paspanga sites are not polluted. The figure 4 shows the evolution of the pollution load index in sub-soil of Paspanga sites. In the sub-soil of Paspanga, the pollution load index of the sites for the top-soil varies between 0.52 and 1.16 with an average of 0.85. The pollution load indexes are generally lower than one. It indicates that the sub-soil of Paspanga is not polluted. The results show that the studied sites are less polluted than the sites of Loumbila and the zone of market gardening situated behind the fence of the Yalgado-Ouedraogo teaching hospital [15].

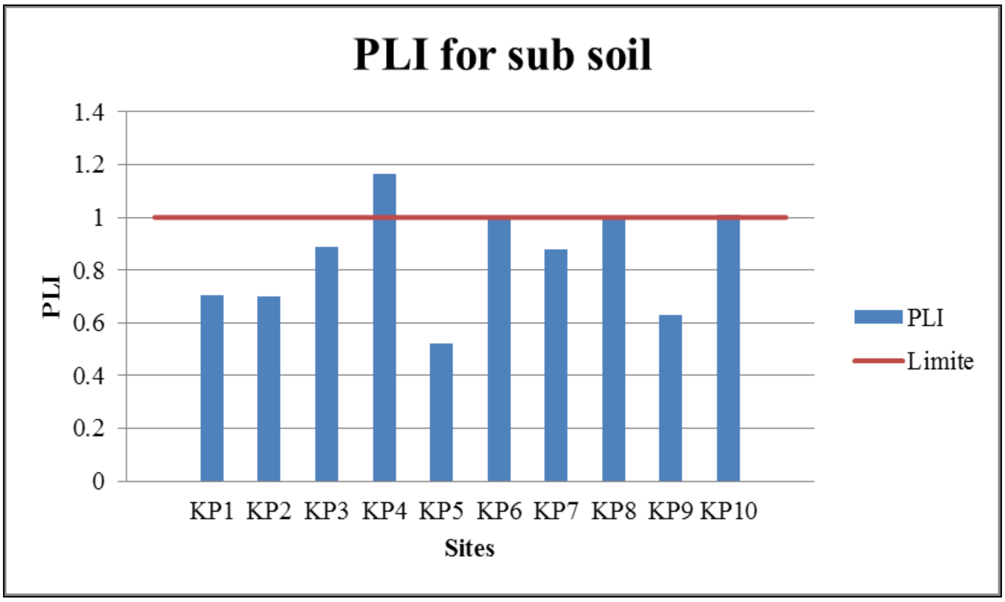

Figure 4: Pollution Load Index in sub soil at Paspanga

III.4 Statistically study

This study of interrelationship between the heavy metals has been done on the concentrations of ten (10) sites of Paspanga with the software SPSS 20. For the study of the interrelationship, the following classification has been used: interrelationship is low if the correlation coefficient is consisted between 0 and 0.5, moderate if it is consisted between 0.5 and 0.7 and high the correlation coefficient is greater than 0.7.

1. Correlation matrix of heavy metal for top soil sample

The table 2 shows the correlation matrix of the heavy metal for surface soil sample. The correlation coefficient allows the determination of the interrelationship between the heavy metals.

Table 2: The correlation matrix between different heavy metals for surface soil samples

	Ni	Co	Cr	Fe	Mn	Zn	Pb	As	Hg
Ni	1.000	-0.253	-0.126	0.122	0.382	0.640*	-0.337	-0.294	-0.381
Co	-0.253	1.000	0.119	-0.246	-0.515	-0.264	-0.126	-0.024	0.052
Cr	-0.126	0.119	1.000	0.086	-0.585	-0.116	0.374	0.382	0.172
Fe	0.122	-0.246	0.086	1.000	0.213	0.018	0.230	0.239	0.040
Mn	0.382	-0.515	-0.585	0.213	1.000	0.634*	0.103	0.094	0.183
Zn	0.640*	-0.264	-0.116	0.018	0.634*	1.000	0.119	0.144	-0.008
Pb	-0.337	-0.126	0.374	0.230	0.103	0.119	1.000	0.984**	0.839**
As	-0.294	-0.024	0.382	0.239	0.094	0.144	0.984**	1.000	0.853**
Hg	-0.381	0.052	0.172	0.040	0.183	-0.008	0.839**	0.853**	1.000

*Correlation is significant at the 0.05 level; ** Correlation is significant at the 0.01 level

The interrelationships between the heavy metal are mostly low. The elements correlated between them are: Nickel and Zinc (Ni-Zn), Cobalt and Manganese (Co-Mn), Chromium and Manganese (Cr-Mn), Manganese and zinc (Mn-Zn), Lead and Arsenic (Pb-As), Lead and Mercury (Pb-Hg) and Arsenic and Mercury (As-Hg). The correlation is significant at the 0.05 level between: Ni-Zn and Mn-Zn, the correlation coefficients are positive. This indicates significant influence of zinc on nickel and manganese. The increase of Zn concentration in surface can entail to the increase of Ni and Mn concentration. The correlation is significant at the 0.01 level between: Pb-As, Pb-Hg and As-Hg and the coefficients (p-value) are positive. There is however a strong correlation 0.984 between Pb and As ($p<0.05$) in the top-soil sample sites indicating significant influence of one metal on the other. It also suggests that, there is possibility of the metals having the same source, because the correlation coefficient between Pb and As is close to one. The correlation between Pb and Hg is strong in the top-soil sample indicating influence of Pb on Hg. There is possibility of Pb and Hg metals having the same source. Also there is possibility of As and Hg having the same source, because of the strong correction between them. There is significant influence of As on Hg. The correlation between Co-Mn and Cr-Mn are the negative coefficients. The increase of Mn concentration entails a reduction of Cr and Co concentration.

2. Correlation matrix of heavy metal for sub-soil sample

The table 3 shows the correlation matrix of the heavy metals for sub-soil samples for from the sites. The correlation coefficient allows determination of the interrelationship between the heavy metals.

Table 3: The correlation matrix between different heavy metals for sub-soil samples

	Ni	Co	Cr	Fe	Mn	Zn	Pb	As	Hg
Ni	1.000	0.385	0.225	-0.457	-0.406	**0.524**	-0.174	-0.439	-0.003
Co	0.385	1.000	0.075	0.258	-0.447	0.471	0.292	-0.062	**0.510**
Cr	0.225	0.075	1.000	-0.180	0.381	**0.522**	-0.010	-0.038	-0.276
Fe	-0.457	0.258	-0.180	1.000	-0.314	-0.416	0.177	-0.046	0.125
Mn	-0.406	-0.447	0.381	-0.314	1.000	-0.076	0.025	0.146	0.023
Zn	**0.524**	0.471	**0.522**	-0.416	-0.076	1.000	0.341	0.307	0.060
Pb	-0.174	0.292	-0.010	0.177	0.025	0.341	1.000	**0.789****	**0.513**
As	-0.439	-0.062	-0.038	-0.046	0.146	0.307	**0.789****	1.000	0.254
Hg	-0.003	**0.510**	-0.276	0.125	0.023	0.060	**0.513**	0.254	1.000

*Correlation is significant at the 0.05 level; ** Correlation is significant at the 0.01 level

The elements correlated between them are: Nickel and Zinc (Ni-Zn), Cobalt and Mercury (Co-Hg), Chromium and Zinc (Cr-Zn), Manganese and zinc (Mn-Zn), Lead and Arsenic (Pb-As), Lead and Mercury (Pb-Hg) and the coefficients are all positive. There is however a strong correlation 0.789 between Pb and As ($p<0.05$) in the sub-soil sample sites indicating significant influence of one metal on the other. It also suggests that, there is possibility of the metals having the same source, because the correlation coefficient between Pb and As. The correlations of heavy metals in the sub-soil samples are not significant at the 0.05 level.

3. Paired samples t-test

A paired t-test is used to compare two population means where you have two samples in which observations in one sample can be paired with observations in the other sample.

The paired samples test permitted to make a comparative study between the heavy metals mean concentrations in surface and in depth. The hypothesis outgoing H_0 is: there is no difference between the mean concentrations in surface and in depth. The considered tolerance is 5%. The interrelationship between the two levels (surface and depth) is not statistically significant when the p-value is superior to 0.05. For the probabilities less than 0.05, there is a difference between surface and depth mean concentration. The results show a significant difference between the surface and depth concentration for the heavy metals (Ni, Co, Mn, Pb, As and Hg) in the studied samples because the p-value are less than 5% (table 4). The concentration of the heavy metals in soils surface is significant higher than those in subsoil.

Table 4: Summary of Paired samples t-test

Difference Surface-Depth	**Paired Differences**					**t**	**df**	**p-value**
	Mean Difference	**Std. Dev.**	**standard Error Mean**	**95% confidence Interval of the difference**				
				Lower	**Upper**			
Ni	0.330	0.342	0.103	0.100	0.560	3.2	10	**0.009**
Co	0.431	0.354	0.107	0.193	0.669	4.04	10	**0.002**
Mn	9.454	14.001	4.221	0.048	18.860	2.24	10	**0.049**
Pb	2.654	2.310	0.696	1.102	4.205	3.81	10	**0.003**
As	0.345	0.258	0.078	0.171	0.519	4.43	10	**0.001**
Hg	0.016	0.023	0.007	0.001	0.032	2.39	10	**0.038**
Cr	1.600	3.073	0.927	-0.465	3.664	1.73	10	0.115
Fe	10.049	19.796	5.969	-3.250	23.348	1.68	10	0.123
Zn	1.640	2.573	0.776	-0.088	3.369	2.11	10	0.061

Std. Dev.: Standard deviation; df: degree of freedom

IV. Conclusion

This study has revealed that the concentrations of the heavy metals in the agricultural soils at Paspanga are lower than the WHO concentration limit. The concentration of the heavy metals decreases strongly at a depth of 15 to 20 cm. Iron presents the most elevated concentration in top and sub soil samples. The chromium is the only metal that has a moderate contamination in surface, and at a depth of 15 to 20 cm the cobalt presents a moderate contamination for the soil. The cobalt, iron and lead contaminate the sub-soil more than the top-soil. The Pollution load index of the sites at Paspanga is generally less than one, what permits to conclude that the quality of sites is not deteriorated. The statistical study of the elements concentrations in surface and in depth shows that there are a low number of metals that are correlated.

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