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Spatial distribution of metallic trace elements in the soils of Mayanga market garden sites in Brazzaville (Congo)

Jean de Dieu NZILA [1,2], Salisou YALLO MOUHAMED [1,3], Noël WATHA-NDOUDY [1,3], Diane Prudence NGUILA-NTSOKO [1,2], Narelle Valia GAKOSSO [1,2], Oldain Cédrick BANZOUZI NTONDÉLÉ [1,2], Jean-Pierre KAMPÉ [1], Dieudonné LOUEMBÉ [1], Victor KIMPOUNI [1,2]

(1) Institut national de Recherche Forestière. BP 177 Brazzaville. E-mail : jddnzila@yahoo.fr
(2) École Normale Supérieure (ENS), BP 237 Brazzaville (Congo).
(3) Faculté des Sciences et Techniques, BP 69 Brazzaville (Congo).

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ABSTRACT

Objective: This study focused on the assessment of trace metal element (MTE) contamination risks of soils in the Brazzaville vegetable belt, subject to intensification of cultural practices and urban expansion.

Methodology and results: To determine the MTEs (Pb, Cd, Cr, Cu and Ni), 54 composite soil samples were collected systematically from 54 plots of 1 ha each at the three sites of Mayanga vegetable sector (Bikakoudi, Wayako and Mahouna). The concentrations of MTE vary between 50 and 125 mg.kg-1 for Pb, between 10 and 15 $mg.kg^{-1}$ for Ni, between 30 and 40 $mg.kg^{-1}$ for Cu and between 0.4 and 0.8 $mg.kg^{-1}$ for the Cd. The order of accumulation of MTE in the soils is Pb > Cu > Ni > Cr > Cd. The Pb and Cd contents at the Bikakoudi site are 2 to 3 times higher than the values allowed by the European standard of European Commission Director General Environment (ECDGE, 2004) while the other trace elements have contents lower than the accepted amount (40 $mg.kg^{-1}$ for Pb, 20 $mg.kg^{-1}$ for Cu, 15 $mg.kg^{-1}$ for Ni, 30 $mg.kg^{-1}$ for Cr and 0.4 $mg.kg^{-1}$ for Cd). The contamination of certain plots is linked to the use of household waste sludge and to road and railway traffic that are close to these sites. The pollution indices show that nearly 40% of plots studied, on the Bikakoudi site, have low pollution values, to be monitored in order to limit the contamination risk of crop.

Conclusion and application of results: The Bikakoudi site is the most exposed to the risks of pollution by MTEs. However, the potential ecological risk factor is very low for all the MTEs studied. In the future, studies should focus on speciation of MTEs and their transfer to cultivated plants.

Keywords: Congo, Brazzaville, soils, urban market gardening, MTE mapping, pollution index.

INTRODUCTION

In developing countries, urban market gardening is helping to feed the growing urban populations, particularly in sub-Saharan Africa (Belantsi & Torreilles, 1999; FAO, 2012). As the soils in this zone are relatively poor in nutrients (Jones *et al.,* 2013), there is an intensification of cultivation practices characterized by the elimination of fallow, regular and unsustainable inputs of organic fertilizers (sludge and compost from household waste, livestock manure, agro-industrial by-products, sewage sludge), mineral fertilizers and the use of various pesticides (Denissov, 1977; Girard *et al.,* 2005; Compaoré & Nanéma, 2010). These practices, far from being ecological, not only contribute to

improving yields, but also contaminate the soil with metallic trace elements (MTE) contained in these fertilizers (Setyorini *et al.,* 2002; Houot *et al.,* 2009; Siti Norbaya *et al.,* 2014). Indeed, regular use of fertilizers results in an accumulation of MTE in the surface horizons (ploughing horizon) and their transfer into crops or groundwater (Mbarki *et al.,* 2008; Tankari Dan-Badjo *et al.,* 2014; Hodomihou *et al.,* 2016). Brazzaville's market-garden belt provides at least 80% of the vegetables sold in the city markets. Unfortunately, with rapid population growth, agricultural production is relatively low due to land constraints and low soil fertility (Denis, 1974; Gaye, 1986; Schwartz 1986; Samba & Moundza, 2007; FAO, 2012). The massive spreading of household waste sludge and mineral fertilizers to improve the fertility of sandy soils and increase yields could induce significant risks of soil contamination by MTEs (Matondo & Miambi, 1990; Boland, 2002; Ntangou, 2006). Furthermore, as a result of urban expansion, the proximity of physical communication infrastructures (road and rail traffic) to market gardening sites could also contribute to soil contamination by the fallout from exhaust gases from vehicles and locomotives rich in MTEs (Sétra, 2004; Tremel-Schaub et Feix, 2005; Meng *et al.,* 2014; Tankari Dan-Badjo *et al.,* 2014). Thus, the objective of this article is to determine the contents of MTEs (Pb, Cd, Cu, Cr and Ni) in the soils of market garden sites in Mayanga, which is part of the Brazzaville market garden belt, in order to assess the risks of crop /environment contamination and ecological impacts.

MATERIAL AND METHOD

Location and characteristics of study sites: The Mayanga market gardening cooperative, set up in 1990 by Agri-Congo society, is located in southwest of Brazzaville, between 4° 15' and 4° 16' south latitude and 15° 11' and 15° 12' east longitude, on the right bank of Djoué river. The climate of the Mayanga sector, similar to that of Brazzaville, is of the lower-Congo or Guinean-Sudanese type, characterized by two seasons: a rainy season from October to May with a decrease from January to February, and a dry season from June to September. The annual rainfall is about 1 400 mm. The average temperature is about 25°C with thermal amplitudes not exceeding 5°C (Samba-Kimbata, 1978). The original vegetation that covered the site of Brazzaville city and its surroundings consisted of forests and savannahs. Savannahs are divided into two subgroups: the first, characterized by *Hypparhenia diplandra* and *Bridelia ferruginea*, grows on more clayey soils, while the second in *Loudetia demeusii* and *Hymenocardia acida* is typical of sandy soils (Makany, 1976). The forests, of mesophilic and tropophilic types, more or less degraded and secondarized, are found in the hilly areas bordering Brazzaville city while the gallery forests border the rivers (Makany, 1976). The Mayanga sector comprises three sites (Figure 1) which were the subject of this study: Bikakoudi (28 ha), Wayako (12 ha), and Mahouna (6 ha).

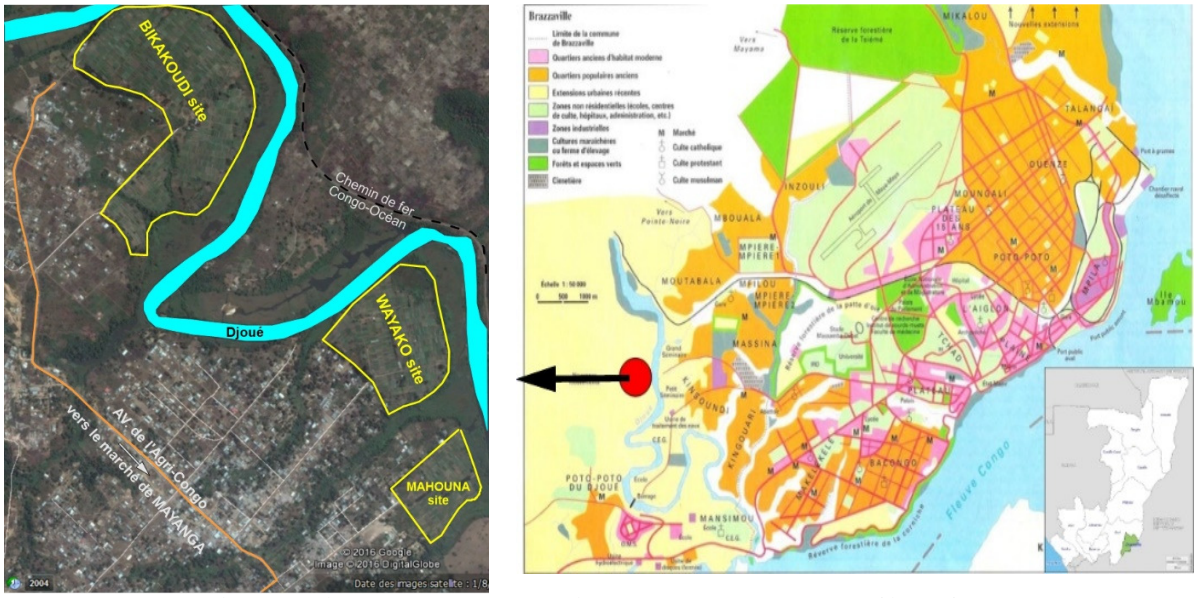

Figure 1: Location of the Agri-Congo vegetable sector from Mayanga to Brazzaville (Congo).

Pedological characteristics of the sites: The soils of Bikakoudi and Wayako market garden sites derived from sands of the Batéké plateaux and those of Mahouna site were developed on arkosique sandstones from the Inkisi series (Desthieux, 1993; Alvarez *et al.,* 1995). They are divided into three types: Arenosols, which dominate the sites of Bikakoudi and Wayako, Ferralic Arenosols, observed on the site of Mahouna and Fluvisols, which are found at the bottom of the slope. Arenosols are chemically poor, with a sandy texture overall profile, without coarse, porous elements and an unclear structure. Ferralic Arenosols have a sandy texture on the surface and sandy-clayey in depth, with a relatively well-developed structure and porosity. Fluvisols develop along the Djoué River and are associated with Arenosols and Ferralic Arenosols (Denis, 1974; Gakosso, 2015; Nguila Ntsoko, 2015).

Sample collection: Sampling is carried out systematically using a 100 m square mesh grid with plough boards to a depth of 20 cm (Roberto & Fabriozo, 2009; Girard *et al.,* 2011; Tankari Dan-Badjo *et al.,* 2014). In each plot, five samples are taken and mixed to form a composite sample (Figure 2). The samples are then packed in polyethylene bags.

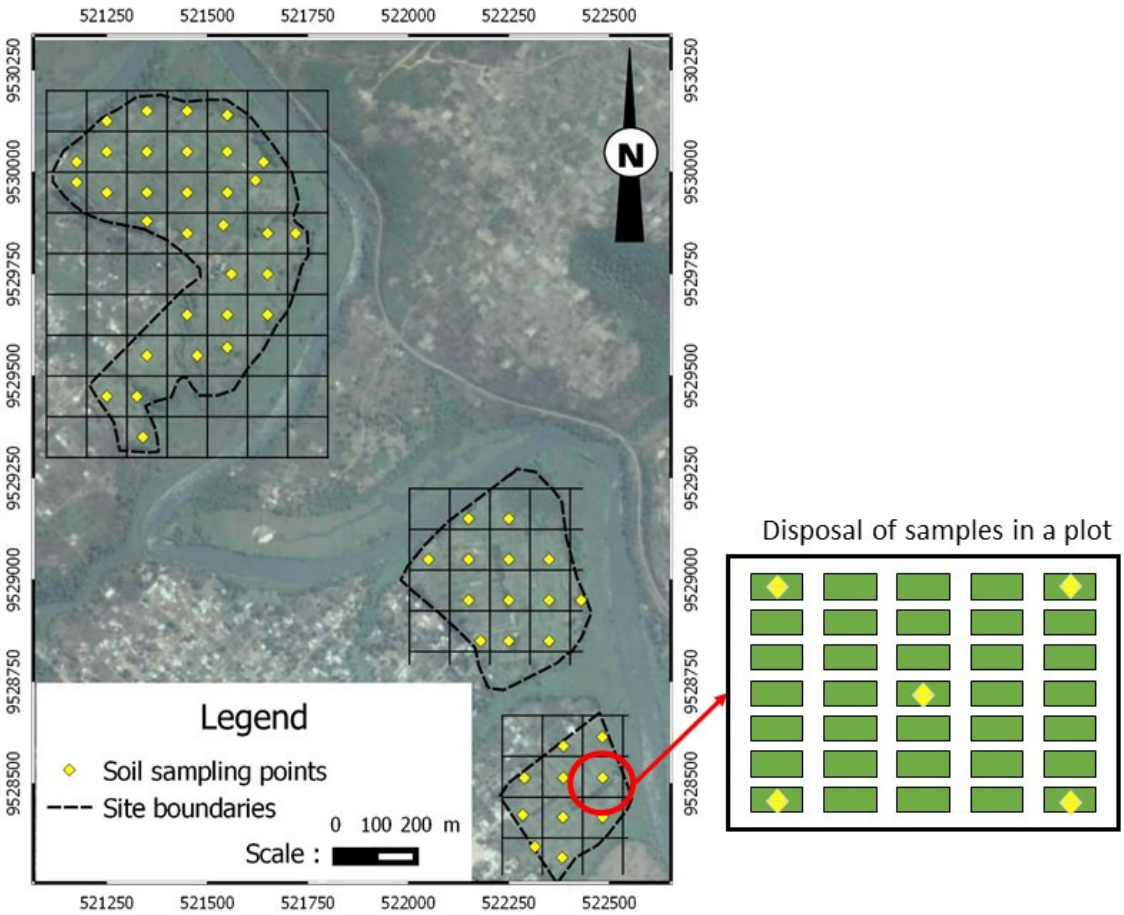

Figure 2: Location of soil sampling points

Sample preparation and metal analysis: The samples are dried in the laboratory at room temperature (25°C) for two weeks before being sieved through a 2 mm mesh sieve. For the determination of the MTEs, the samples were mineralized with aqua regia and hydrofluoric acid. The MTEs assay was performed by atomic emission spectrometry with inductively coupled plasma (ICP-AES).

Data processing: The statistical analysis of the data was done using Excel and SPSS software. For soil contamination maps, each sampling point is georeferenced and processed by QGIS software. The spatial distribution of the contents of each MTE was obtained by weighted inverse distance interpolation (IDW) (Valladares *et al.,* 2009) for the determination of the pollution risk; the pollution index (PI) of each sample was calculated based on the following formula:

$$IP = \frac{\sum\left(\frac{Ci}{Si}\right)}{n}$$

where Ci is the concentration of the considered MTE of each sample, Si is the normative threshold content of the considered MTE and n is the total number of studied MTEs (Funtua *et al.,* 2014; Meng *et al.,* 2014; Tankari Dan-Badjo *et al.,* 2014; Karimi & Nazari, 2015). The thresholds used for our study are those of the German Soil Protection Ordinance (BBSchV, 1999 cited by ECDGE, 2004). According to this standard, the limit contents of MTEs allowed in sandy soils are 40 $mg.kg^{-1}$ for Pb; 0.4 $mg.kg^{-1}$ for Cd; 15 $mg.kg^{-1}$ for Ni; 30 $mg.kg^{-1}$ for Cr; and 20 $mg.kg^{-1}$ for Cu. There are three IP classes: IP < 0.5 (unpolluted soils), 0.5 ≤ IP < 1 (slightly polluted soils) and IP ≥ 1 (polluted soils). To assess the environmental risks of each MTE present in soil, the ecological risk factor (Er) was calculated for each site based on Häkanson's (1980) MTE toxicity coefficients. It is based on the following formula:

Eri = IPi .Ti

With IPi = pollution index of each MTE and Ti its toxicity coefficient.

The toxicity coefficient values set by Häkanson for each MTE are as follows (Häkanson, 1980; Banu *et al.,* 2013; Wang *et al.,* 2013; Mugoša *et al.,* 2016): 2 for Cr and Ni; 5

for Cu and Pb; 30 for Cd. To distinguish the different contents of potential ecological risk, five classes are used: Eri < 40 (low), 40 ≤ Eri < 80 (moderate), 80 ≤ Eri < 160 (moderate), 160 ≤ Eri < 320 (considerable) and Eri ≥ 320 (very high). Pearson's correlation was applied to soil MTE contents to look for sources of contamination (Banu *et al.,* 2013; Mugoša *et al.,* 2016).

RESULTS

Average contents of MTEs in soils: Overall, the order of MTEs accumulation in soils is Pb > Cu > Ni > Cr > Cd; the Bikakoudi site has the highest average MTE contents (Figure 3). Mean Pb contents vary between 13 and 30 mg.kg^{-1}, with the lowest and highest values observed at the Mahouna and Bikakoudi sites respectively. The same trend is observed with Cu and Ni whose contents are from 2 to 10 mg.kg^{-1} and 3 to 7 mg.kg^{-1} respectively. In the soils of Bikakoudi, Pb, Cu and Ni contents are 2 to 5 times higher than in the Mahouna site, which recorded the lowest contents of these MTEs.

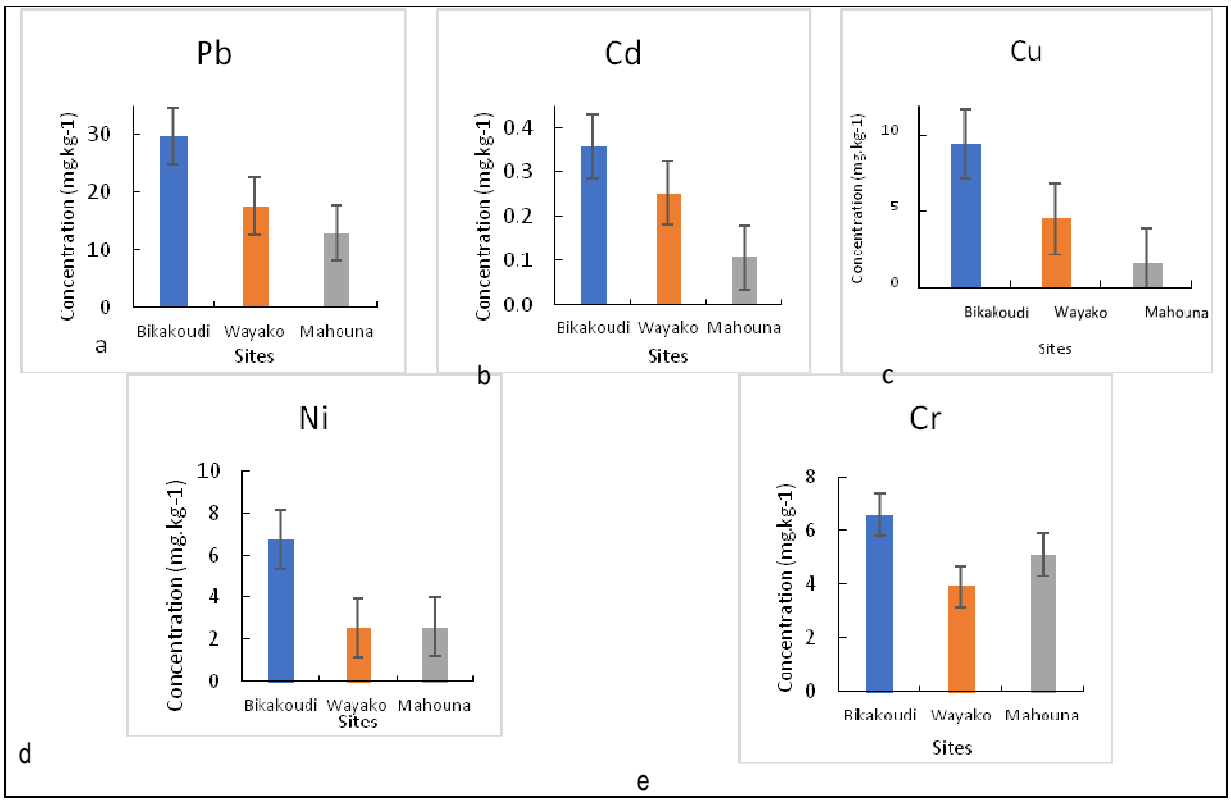

Figure 3: Average MTE contents in soils in the Mayanga sector

The contents of Cr and Cd vary respectively between 4 and 7 mg.kg^{-1} and between 0.1 and 0.4 mg.kg^{-1}, with the lowest contents observed in the Wayako site soils and the highest in the Bikakoudi site soils. For the latter two MTEs, the difference in concentrations between sites is not too great (< 1.5). The contents of Pb, Cu, Ni and Cr are well below the thresholds set by the German Soil Protection Ordinance (BBSchV, 1999 cited by ECDGE, 2004) in sandy soils for these elements which are respectively 40 mg.kg^{-1} for Pb, 20 mg.kg^{-1} for Cu, 15 mg.kg^{-1} for Ni and 30 mg.kg^{-1} for Cr. On the contrary, Cd contents in Bikakoudi soils are close to the limit value of 0.4 mg.kg^{-1}.

Spatial distribution of MTEs in soils: The spatial distribution of MTEs in the vegetable soils of Mayanga shows that 80% of the surface area of Bikakoudi site has soil contents below the accepted limit (40 mg.kg^{-1}) while 8% of the surface area of the site reveals Pb contents between 40 and 75 mg.kg^{-1} and only 2% of the surface area is affected by the highest Pb concentrations, between 75 and 125 mg.kg^{-1}. On the Wayako site, 2.5% of the area has soils with Pb contents between 4 and 75 mg.kg^{-1} while the Mahouna site has 2.3% of its area

where soils have contents between 40 and 100 mg.kg^{-1} (Figure 4a). Concerning Cu, the soils of Bikakoudi site have contents below the limit value (40 mg.kg^{-1}) nevertheless; it is observed that 8% of the surface of the site has soils with higher contents of Cu, between 20 and 40 mg.kg^{-1}. At the Wayako and Mahouna sites, 100% of their areas have low Cu contents, below 20 mg.kg^{-1} (Figure 4b). The spatial distribution of Cd concentrations shows that the highest concentrations (0.4 to 0.8 mg.kg^{-1}), higher than the standard (0.4 mg.kg^{-1}), are observed over 26% of the surface area of Bikakoudi site. 100% of the areas of Wayako site have Cd contents below 0.40 mg.kg^{-1} but 92% of the areas have contents between 0.20 and 0.40 mg.kg^{-1}, therefore close to the threshold used. 98% of the areas of Mahouna site have Cd contents below 0.20 mg.kg^{-1}; on the remaining 2% of the site, the highest contents (0.60 to 0.80 mg.kg^{-1}) of Cd were observed, far exceeding the accepted threshold (Figure 4c). With a threshold set at 15 mg.kg^{-1}, the highest Cr concentrations are found over an area of nearly 4% of Bikakoudi site, while all the points at the Wayako site and 92% of the points at Mahouna have Cr concentrations of less than 10 mg.kg^{-1} (Figure 4d). Although the contents of Ni vary from one site to another, they are well below the standard of 15 mg.kg^{-1}. The total area of Wayako site has Ni contents below 5 mg.kg^{-1}, while the highest contents close to the threshold (10 to 15 mg.kg^{-1}) are observed on 8% of the areas of Bikakoudi and Mahouna (Figure 4e).

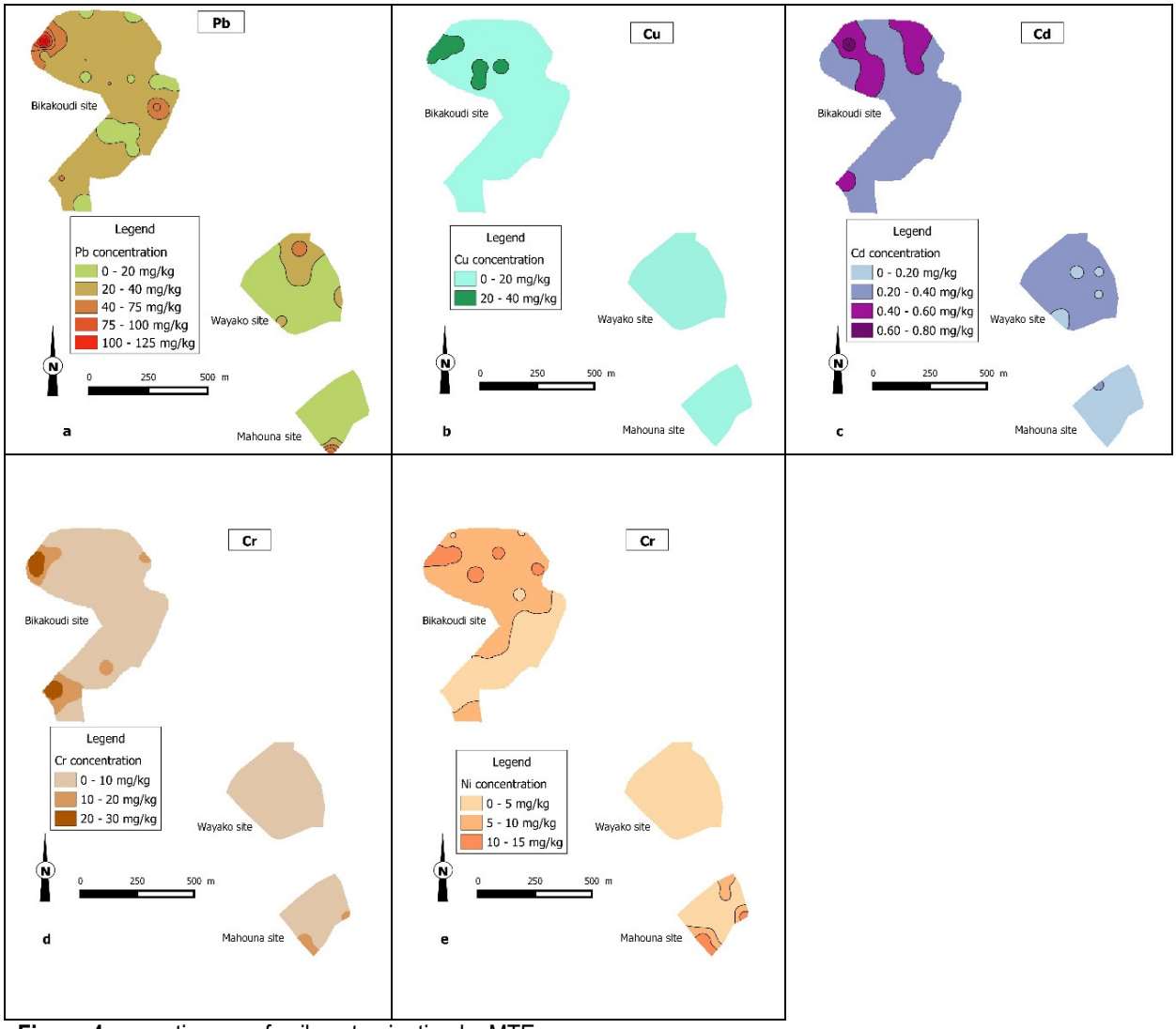

Figure 4: synoptic map of soil contamination by MTEs

Environmental risks: The spatial distribution of the overall pollution index (PI) shows that 44% of Bikakoudi sites are unpolluted, 50% of the plots are slightly polluted and 6% of the site area is polluted, with an IP > 1 (Figure 5). At the Wayako and Mahouna sites, soils are slightly polluted at 8% and 10% of the area respectively. The soils of Bikakoudi site thus present high risks of environmental pollution. The potential ecological risk factors (Er) are generally low (< 40) for all MTEs however, Cd has the highest values compared to the other four MTEs (Table 1).

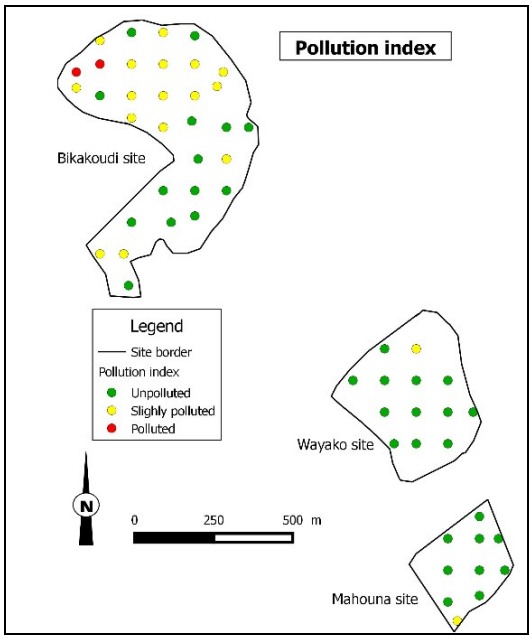

Figure 5: Spatial distribution of the MTE pollution index in the sites studied

Table 1: Ecological risk factors for contamination according to sites

Sites	Toxicity Coefficients of MTEs (Er_i)				
	Pb	Cd	Ni	Cr	Cu
Bikakoudi	3.7	28.5	0.4	0.9	1.2
Mahouna	1.6	8.5	0.2	0.7	0.2
Wayako	2.2	20.2	0.2	0.5	0.6

Identification of sources of contamination: All the MTEs studied have positive correlations between them but with different contents of significance (Table 2). Positive correlations at 1% significance level exist between Ni-Pb, Ni-Cd, Ni-Cu and Ni-Cr, but the strongest coefficients (r > 5) are between Ni-Cd and Ni-Cu. This indicates that the MTEs studied could have common origins but are distributed at different contents for each source.

Table 2: Correlation between MTE accumulated in Mayanga market gardening soils (n=55)

Metal	Pb	Cd	Ni	Cr	Cu
Pb	1				
Cd	0.25	1			
Ni	0.45**	0.56**	1		
Cr	0.38**	0.17	0.38**	1	
Cu	0.47**	0.47**	0.67**	0.32*	1

**. Significant correlation from 0.01; *. Significant correlation from 0.05.

DISCUSSION

Variation in spatial distribution of MTEs in soils: Spatial variation in MTEs contents from one point to another on the same site is a characteristic of anthropogenic contamination because soils should theoretically have the same metal concentrations due to their common geological origin (Sétra, 2004; Tankari Dan-Badjo *et al.,* 2014; Hodomihou *et al.,* 2016). Three factors explain this spatial variation in MTEs: farming practices, farm ages, and the existence of anthropogenic activities, sources of MTEs, around market gardening sites (Boland, 2002; Smith, 2009; Wang *et al.,* 2013; Mugoša *et al.,* 2016). Because MTE concentrations are cumulative and persistent in soils, Bikakoudi site, in operation since 1990, has accumulated more MTE than the other sites put into operation 7 years later. The existence of polluted areas at Bikakoudi and Mahouna sites could be explained by the high input of poorly sorted muck of household waste (82 t/ha) rich in MTE (Girard *et al.,* 2005; Mbarki *et al.,* 2008; Compaoré & Nanéma, 2010; Alackys Ampossi, 2018). At Bikakoudi site, land use has gradually evolved from north to south of the site, which would explain the pollution gradient showing decreasing contents of MTE from north to south of the site (Elbana *et al.,* 2013; Meng *et al.,* 2014; Tankari Dan-Badjo *et al.,* 2014).

Soil contamination sources: The correlation between the accumulated MTEs in Mayanga vegetable soils shows that Cu has the same significant correlation with Pb and Cd (r = 0.47), but the latter two are not significantly correlated (r = 0.25). This observation suggests that agricultural practices are not the only sources of contamination. With urban expansion around sites, human activities, such as road and railway traffic, can contribute to soil contamination by MTEs (Sétra, 2004; Salah *et al.,* 2013; Meng *et al.,* 2014; Siti Norbaya *et al.,* 2014; Tankari Dan-Badjo *et al.,* 2014; Mugoša *et al.,* 2016). Nevertheless, due to the age of the farms and the low doses of mineral fertilizers applied (1.2 t/ha), the MTE contents in all sites are still at an acceptable level according to the accepted limit thresholds for soils (ECDGE, 2004; Girard *et al.,* 2005; Siti Norbaya *et al.,* 2014; Tankari Dan-Badjo *et al.,* 2014).

Environmental risk assessment of MTEs: A comparative analysis of the MTE contents at the sites reveals that Bikakoudi is the site most exposed to the risks of environmental pollution and the very high risk of crops bioaccumulation. The bioaccumulation phenomenon would be favoured by the soils physico-chemical characteristics (low acid pH and CEC, sandy texture) which make them very sensitive to the mobility of MTE (Manouchehri & Bermond, 2010; Ondo, 2014; Hodomihou *et al.,* 2016; Yallo Mouhamed, 2016). Furthermore, because MTEs are persistent in the natural environment, over time they can accumulate in soil and become potentially toxic to living organisms (Girard et al. 2005; Khan et al. 2007; Smith 2009; Elbana et al. 2013; Uriah & Shehu 2014; Mugoša et al. 2016). For this reason, precautions must be taken to prevent the risk of MTEs accumulation in the market gardening soils of Brazzaville.

CONCLUSION

The determination of MTEs in the market gardening sector of Mayanga showed that the soils of Bikakoudi and Mahouna sites accumulated Pb in high contents (from 100 to 125 $mg.kg^{-1}$), largely exceeding the thresholds allowed by the standard used (40 $mg.kg^{-1}$). There are also Cd contents above the accepted threshold (0.4 $mg.kg^{-1}$) on certain plots at the Bikakoudi site. The spatial distribution of the MTEs shows that the northern areas of Bikakoudi site and the southern areas of Mahouna site are the most contaminated. The sources of contamination of these sites would be the intensification of farming practices and atmospheric inputs from MTE by human activities and road and rail transport. In relation to the calculated pollution index, Bikakoudi site is the most exposed to the risks of pollution by MTEs. However, the potential ecological risk factor is very low for all the MTEs studied. However, precautions must be taken, through the practice of reasoned fertilization techniques, to limit the risk of accumulation of these MTEs in the soil. In the future, studies should continue on these sites, focusing on speciation of MTEs and their transfer to cultivated plants.

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REFERENCES

Alackys Ampossi IB, 2017. Influence des fertilisants sur la mobilité des éléments traces métalliques (ETM) dans les sols maraichers de Kombe (Brazzaville, Congo). Mémoire de Master. Université Marien NGouabi. 57p.

Alvarez P, Maurin JC et Vicat JP. 1995. La formation de l'Inkisi (Supergroupe Ouest-Congolien) en Afrique centrale (Congo et Bas-Zaïre): un delta d'âge Paléozoïque comblant un bassin en extension. Journal of African Earth Sciences 20(2): 119 - 131.

Banu Z, Chowdhury SA, Hossain D and Nakagami K., 2013. Contamination and Ecological Risk Assessment of Heavy Metal in the Sediment of Turag River, Bangladesh: An Index Analysis Approach. Journal of Water Resource and Protection 5: 239 - 248. http://dx.doi.org/10.4236/jwarp.2013.52024

BBSchV, 1999. Bundes - Bodenschutz- und Altlastenverordnung (BBodSchV); 16. Juli 1999; BGBl., Teil I, Nr.36, p. 1554

Belantsi R et Torreilles JC, 1999. Appui au développement agricole périurbain au Congo. In : Agriculture périurbaine en Afrique Subsaharienne. Actes de l'Atelier International, 20-24 avril 1998, Montpellier (France). Moustier *et al.* (Eds), CIRAD, 53-62.

Boland J, 2002. L'agriculture urbaine : cultiver des légumes en ville, Agromisa, série-agrodok n°24. 96p.

Compaoré E et Nanéma LS, 2010. Compostage et qualité du compost de déchets urbains solides de la ville de Bobo-Dioulasso, Burkina Faso. Tropicultura 28(4) : 232 - 237.

Denis B, 1974. Notice explicative de la carte pédologique Brazzaville-Kinkala au 1/200000. ORSTOM, Paris. 108p.

Denissov L, 1977. Principe d'agriculture tropicale. Mir, Moscou. 240p.

Desthieux F, 1993. Carte géologique de la République du Congo au 1 : 1.000.000. Ministère des Mines et de l'Energie, Congo. 32p.

ECDGE, 2004. Heavy metals and organic compounds from wastes used as organic fertilizers. Final Report. Project ENV.A.2./ETU/2001/0024. July 2004. 3, European Commission Director General Environment (Ed.), 244 p.

Elbana TA, Ramadan AM, Gaber MH, Bahnassy MH, Kishk FM and Selim HM, 2013. Heavy metals accumulation and spatial distribution in long-term wastewater irrigated soils. Journal of Environmental Chemical Engineering 1 : 925 - 933. https://doi.org/10.1016/j.jece.2013.08.005

FAO, 2012. Pour des villes plus vertes en Afrique. Premier rapport d'étape sur l'horticulture urbaine et périurbaine. FAO, Rome, 111p.

Funtua MA, Agbaji EB et Pam AA, 2014. Heavy metals contents in soils and some crops irrigated along the bindare stream Zaria- Kaduna state, Nigeria. American Chemical Science Journal 4(6) : 855-864. http://doi.org/10.9734/ACS/2014/11858

Gakosso V.N. 2015. Caractérisation morphologique des sols utilisés pour le maraîchage dans les sites de Kombé et de Wayako à Brazzaville. Mémoire de master, Université Marien NGouabi, Brazzaville, 90p.

Gaye A, 1986. Note sur le maraîchage à Brazzaville. Actes du Colloque « Journée d'étude sur Brazzaville », 25-28 avril 1986, Brazzaville, Congo. ORSTOM et AGECO, Brazzaville, pp. 257-271.

Girard MC, Schvartz C et Jabiol B, 2011. Etude des sols : description, cartographie, utilisation. Dunod, Paris, 404p.

Girard MC, Walter C, Rémy JC, Berthelin J et Morel JL, 2005. Sols et environnement. Dunod, Paris, 684p.

Hakanson L, 1980. An ecological risk index for aquatic pollution control a sedimentological pollution control. A sedimentological approach. Water Research 4: 975 - 1001. https://doi.org/10.1016/0043-1354(80)90143-8

Houot S, Cambier P, Deschamps M, Benoit P, Bodineau G, Nicolardot B, Morel C, Linères M, Le Bissonnais Y, Steinberg C, Leyval C, Beguiristain T, Capowiez Y, Poitrenaud M, Lhoutellier C, Francou C, Brochier V, Annabi M et Lebeau T, 2009. Compostage et valorisation par l'agriculture des déchets urbains. Innovations Agronomiques 5 : 69-81.

Hodomihou NR, Feder F, Masse D, Agbossou KE, Amadji GL, Ndour-Badiane Y et Doelsch E, 2016. Diagnostic de contamination des agrosystèmes périurbains de Dakar par les éléments traces métalliques. Biotechnol. Agron. Soc. Environ. 20(3) : 1 - 11.

Jones A, Breuning-Madsen H, Brossard M, Dampha A, Deckers J, Dewitte O, Gallali T, Hallett S, Jones, R, Kilasara M, Le Roux P, Micheli E, Montanarella L, Spaargaren O, Thiombiano L,

Van Ranst E, Yemefack M, Zougmoré R (eds.), 2013. Soil Atlas of Africa. European Commission, Publications Office of the European Union, Luxembourg, 176p.

Karimi M and Nazari A, 2015. Contamination assessment and spatial distribution mapping of heavy metals in agricultural soils of south Hossein Abad copper indice (Neyriz, Iran). Journal of Biodiversity and Environmental Sciences 6(5): 513 - 524.

Khan S, Cao Q, Zheng YM, Huang YZ and Zhu YG, 2007. Health risks of heavy metals in contaminated soils and food crops irrigated with wastewater in Beijing, China. Environmental Pollution 1(7) : 1 - 7. http://doi.org/10.1016/j.envpol.2007.06.056

Makany L, 1976. Végétation des plateaux Téké (Congo). Collection travaux Université de Brazzaville, 301p.

Manouchehri N. et Bermond A. 2010. Mobilité et biodisponibilité des Éléments Trace Métalliques (ETM) du sol : Approches physicochimiques. AgroParisTech – Chimie Analytique 13 : 66-70

Matondo H et Miambi E. 1998. Utilisation agricole des composts d'ordures ménagères dans la ceinture maraîchère de Brazzaville (Congo). Tropicultura 8: 128 - 130.

Mbarki S, Labidi N, Mahmoudi H, Jedidi N and Abddely C, 2008. Contrasting effects of municipal compost on alfalfa growth in clay and sandy soils: N, P, K content and heavy metals toxicity. Bioresource Technology 99: 6745 - 6750. http://doi.org/10.1016/j.biortech.2008.01.010

Meng F, Ding N and Sun YJ, 2014. Assessment of heavy metal pollution in Chinese suburban farmland. Journal of Environmental Study 23(6): 2351 - 2358.

Mugoša B, Đurovic´ D, Vukovic´ MN, Barjaktarovic´-Labovic´ S and Vrvic´ M, 2016. Assessment of Ecological Risk of Heavy Metal Contamination in Coastal Municipalities of Montenegro. Int. J. Environ. Res. Public Health 13(393) : 1 - 15. http://doi.org/10.3390/ijerph13040393

Nguila Ntsoko DP, 2015. Caractérisation morphologique des sols utilisés pour le maraîchage dans le site de Bikakoudi à Brazzaville (Congo). Mémoire de Master de l'Enseignement des Sciences de la Vie et de la Terre, Université Marien Ngouabi, École Normale Supérieure, 90 p.

Ntangou M, 2006. Impact de la fertilisation minérale et organique sur la production des légumes feuilles sur le sol sableux de la ville de Brazzaville (Congo). Mémoire de Master de l'Enseignement des Sciences de la Vie et de la Terre, Université Marien Ngouabi, École Normale Supérieure, 43p.

Ondo J.O. 2011. Vulnérabilité des sols maraîchers du Gabon (région de Libreville) : acidification et mobilité des éléments métalliques. Thèse de doctorat. Université de Provence, France. 304p.

Roberto M and Fabriozo S, 2009. Dioxins trace elements bioindicators and biodiversity in soils. Institut for environment and substainability (E.U), 192p.

Salah E, Turki A and Noori S, 2013. Heavy Metals Concentration in Urban Soils of Fallujah City, Iraq. Journal of Environment and Earth Science 3(11): 100 - 112.

Samba G et Moundza P, 2007. Brazzaville, croissance urbaine et problèmes environnementaux. CRTH, Brazzaville, 15p.

Samba-Kimbata JM, 1978. Le climat du bas Congo. Thèse de Doctorat 3e cycle, Université de Bourgogne, Dijon, Tome 1, 280 p.

Schwartz D, 1986. Les sols des environs de Brazzaville et leur utilisation. ORSTOM, pp. 37-56.

Sétra, 2004. La pollution des sols et des végétaux à proximité des routes : Les éléments traces métalliques (ETM). Sétra, Bagneux, 12p.

Setyorini D, Prihatini T et Kurnia H, 2002. Pollution of soil by agricultural and industrial waste. *http://www.fftc.agnet.org/htmlarea_file/library/20110804163924/eb521.pdf*

Siti Norbaya M. R., Sharizal H., Mohd Lias K., Nor Shahrizan Mohd H. 2014. Analysis and pollution assessment of heavy metal in soil, Perlis. The Malaysian Journal of Analytical Sciences, 18, 1, 155-161.

Smith S.R. 2009. A critical review of the bioavailability and impact of heavy metals in municipal solid waste composts compared to sewage sludge. Environment International, 35, 142–156. http://doi.org/10.1016/j.envint.2008.06.009

Tankari Dan-Badjo A, Guéro Y, Dan Lamso N, zakaria ibrahim O, Ambouta JMK, feidt C, Echevarria G et Sterckeman T, 2014. Spatialisation de la pollution par les éléments traces métalliques des sols de la vallée de Gounti Yena, Niamey (Niger), Annales de l'Université Abdou Moumouni, XVII (A) : 179 - 191.

Tremel-Schaub A et Feix I, 2005. Contamination des sols : Transferts des sols vers les plantes. ADEME Édition, Anger, 413p.

Uriah LA and Shehu U, 2014. Environmental risk assessment of heavy metals content of municipal solid waste used as organic fertilizer in vegetable gardens on the Jos Plateau, Nigeria. American Journal of Environmental Protection 3(6, 2): 1 -13. http://doi.org/10.11648/j.ajep.s.2014030602.11

Valladares GS, Antônio de Camargo O, Porto de Carvalho JR, Cia Silva AM, 2009. Assessment of heavy metals in soils of a vineyard region with the use of principal component analysis. Sci. Agric. 66(3): 361 - 367. http://dx.doi.org/10.1590/S0103-90162009000300011

Wang J, Liu W, Yang R, Zhang L and Ma J, 2013. Assessment of the potential ecological risk of heavy metals in reclaimed soils at an opencast coal mine. Disaster advances 6(3) : 366-377.

Yallo Mouhamed S, 2016. Caractérisation morphologique et teneurs en éléments traces métalliques des sols de la ceinture maraîchère de Brazzaville (Congo) : secteurs de Mayanga et de Kombé. Mémoire de Master, Université Marien NGouabi. 57p.