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Estimation of the Degree of Heavy Metal Pollution in Market Gardening Soils in Kadiogo Region, Burkina Faso

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The objective of this study is to estimate the degree of heavy metal pollution (As, Cr, Cu, Fe, Hg, Mn, Ni, Pb, Se, Tl and Zn) of market gardening soils in the Kadiogo region. This work provides reassurance about the quality of the studies soils in the central region of Burkina Faso. Thirty-two (32) market garden soil samples, including two (02) for the background, were measured using ICP-MS. Indeed, the results show that the average concentrations of heavy metals in the 0-20 cm soil profile respect the recommended limits. However, Contamination Factors (CF) and Pollution Load

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Index (PLI) show that certain soils are polluted. These indices reveal that the pollution of exploited soils differs not only from one site to another but also between the 0-10 cm and 10-20 cm levels. Thus, the most polluted soil on the surface (0-10 cm) is SK2 in Koubri with a PLI of 8.20 compared to 0.24 for STD1 in Tanghin-Dassouri. For the 10-20 cm horizon, the PLI values show that the soils PO5 (Pissy), PO1 (CHU-YO), PO2 (CHU-YO) and PK3 (Koubri) already polluted at the surface (0-10 cm) the rest in profile (10-20 cm). Also, we can emphasize that the presence of non-essential trace metal elements such as Pb, As and Hg constitute a threat to the health of consumers of market garden products from these sites. In addition, the low concentrations of metals in the soil samples suggest that this is diffuse pollution.

Keywords: Contamination; contamination factor (CF); heavy metals; non-essential metals; pollution; pollution load index (PLI).

1. INTRODUCTION

Heavy metals or trace metal elements (TMEs) are naturally present in the environment but also sometimes caused by human activities [1,2]. Through very complex physicochemical mechanisms, they can end up in the food chain [3,4] and be problematic for human health [5]; although some, called trace elements, are useful to the body in well-defined doses [6]. Indeed, the soil, which is in essence the node of several types of pollution [7,8] plays a fundamental role in the transfer of these contaminants to different compartments of the environment including water [9-11], air [12,13], and plants [14-16]. In order to help reassure ourselves of the quality of the soils exploited in Burkina Faso, four main supply zones for the capital of Burkina with market gardening products were selected: Ouagadougou (O), Boulbi (B), Koubri (K) and Tanghin- Dassouri (TD). In total, thirty-two (32) soil samples including two (02) for the background were taken in the 0-10 cm and 10-20 cm horizons including fourteen (14) in Koubri, ten (10) in Ouagadougou, four (04) in Tanghin-Dassouri and four (04) in Boulbi. These samples were analysed with ICP-MS in order to characterize and quantify eleven (11) metallic trace elements (As, Cr, Cu, Fe, Hg, Mn, Ni, Pb, Se, Tl, Zn). Also, the particle size and physicochemical parameters (pH, C.E, C.E.C, B.E, T.S and M.O) of the soils likely to influence the solubility and mobility of these contaminants [17] were determined at the laboratory of the National Soil Bureau in Burkina Faso (BU.NA.SOL) according to the current protocol [18].

2. MATERIALS AND METHODS

2.1 Study Area

The localities of Boulbi, Tanghin-Dassouri and Koubri are close to the city of Ouagadougou. They contribute enormously to the supply of market garden products to the capital, which has around 2.8 million inhabitants. Indeed, they are respectively located approximately 15 km, 24.6 km and 25 km from Ouagadougou. The geographic positions of the four study areas were recorded using GPS and recorded in Table 1.

2.2 Sampling, Preparation and Analysis

Thirty-two (32) soil samples including 16 in the 0-10 cm horizon and 16 between 10-20 cm were taken, processed and analysed with Perkin Elmer 9000 brand ICP/MS. Two soil samples per zone were taken to determine the particle size parameters. In total, sixteen sites were selected including 07 in Koubri, 05 in Ouagadougou, 02 in Tanghin-Dassouri and 02 in Boulbi. The samples were placed in plastic bags to ensure sealing against outside air and transported to the laboratory for analysis.

Table 1. Geographic coordinates of the zones

Area	Longitude	Latitude
Koubri	12°11'49.00"N	1°24'3.90"W
Ouagadougou Site 1	12º23’5,75’’N	1º30’33,78’’W
Ouagadougou Site 2	12º20’20,32’’N	1º35’10,12’’W
Tanghin-Dassouri	12°13'53.70"N	1°45'4.50"W
Boulbi	12°14'30.90"N	1°32'28.00"W

Fig. 1. Geographical location of study area

After drying, grinding and reduction into fine powder, the soil samples underwent mineralization according to the standards of the Bureau of Mines and Geology of Burkina (BU.MI.GE.B). The physicochemical analysis of the soil samples was carried out at the National Soil Bureau (BU.NA.SOLS) according to the methods of physical and chemical analysis of soils [18].

Formula (1) was used for the conversion of metal concentrations from mg/l to mg/kg [19]:

$$C_{sample(mg/kg)} = C_{sample(mg/l)} * V_{mineralisation(l)} / \text{Mass Dry}_{\text{test sample}} \quad (1)$$

C_{sample} is concentration of the sample; $V_{mineralisation}$: mineralisation volume;

2.3 Quantification of Soil Pollution

To estimate the degree of pollution of the soil samples, the Contamination Factors (CF), the degree of contamination (CD) and the Pollution Load Indexes (PLI) were respectively calculated by equations (2), (3) and (4) below [20,21].

2.3.1 Contamination Factor (CF)

The Contamination Factor makes is used to estimate the level of soil contamination [22]. It is the quotient of the concentration of the element measured in the soil ($C_{heavy\ metal}$) and the reference or background concentration ($C_{background}$) [22,23].

$$CF = \frac{C_{heavy\ metal}}{C_{background}} \quad (2)$$

2.3.2 Degree of Contamination (CD)

The Contamination Degree is the sum of the contamination factors (CF). A priori, it makes it possible to estimate the polymetallic contamination for each sampling point. It is expressed according to formula 3 [24,25].

$$CD = \sum_{i}^{n} (CF)_i \quad (3)$$

In table 2, the level of contamination is evaluated according to contamination factors (CF) and contamination degree (CD):

Table 2. Contamination level according to CF and CD [26]

CF values	CD values	Contamination intensity
$\mathbf{CF \leq 1}$	$CD \leq 8$	Low
$\mathbf{1 \leq CF \leq 3}$	$8 \leq CD \leq 16$	Moderate
$\mathbf{3 \leq CF \leq 6}$	$16 \leq CD \leq 32$	Considerable
$\mathbf{CF \geq 6}$	$CD \geq 32$	Very strong

2.3.3 Pollutant Load Index (PLI)

The pollutant load index is a powerful tool in the assessment of heavy metal pollution of soils [27]. It is determined by the formula 4:

$$\mathrm{PLI} = (\mathrm{CF}_1 * \mathrm{CF}_2 * \mathrm{CF}_3 * \ldots * \mathrm{CF}_n)^{1/n} \quad (4)$$

In this expression, CF_i is the contamination factor of the metal i considered and n=11 (number of heavy metals measured). Depending on the PLI value, we have the following cases: PLI < 1 (unpolluted soil), PLI = 1 (pollution reference level) and PLI > 1 (polluted soil) [22,25].

3. RESULTS AND DISCUSSION

3.1 Particle Size and Physicochemical Parameters

Table 3 below presents these parameters for soils B1, B2 form Boulbi; O1, O2 from Ouagadougou; K1, K2 from Koubri and TD1, TD2 from Tanghin-Dassouri.

The particle size results show variability in soil texture. Clay, which plays a major role in the adsorption of heavy metals in the soil, has a percentage of between 4,00 and 19,00%. These values are relatively low in all the soil samples analysed. However, the percentages of silt and sand are the highest with respective maximums of 26.50% (coarse silt) and 41.95% (fine sand). Almost all soils are sandy loam (LS) type. Indeed, the erosion which brings fine elements into the lowlands can well explain this soil texture. Also, the deep entrainment of clay by the phenomenon of leaching contributes to this state of the soil. A more advanced profile could lead us to the clay accumulation horizon.

The mobility and bioavailability of metal pollutants are very often controlled by certain physicochemical parameters of the soil [17,28,29]. Thus, the physicochemical characteristics of the soils were determined. These are the organic matter (O.M), the cation exchange capacity (C.E.C), the hydrogen potential (pH), the electrical conductivity (E.C), the sum of exchangeable bases (E.B), the saturation rate (S.R) and the real (Dr) and apparent (Da) densities. Indeed, we see that the relative densities of the samples are greater than the apparent densities. Also, the most porous soil is B_2 with a porosity of around 40.62% compared to 36.01% for sample K_1. The soil which contains more organic matter is the O_2 sample with 2.42% compared to 0.78% for K_2. Soil organic matter plays an important role in retaining trace metal elements on the surface and occasionally helps slow their progression towards deeper horizons. The most conductive ground is O_1 with 1.53 mS/cm compared to 0.17 mS/cm for TD_2. In addition, we note that with the exception of the soils of Tanghin-Dassouri, the samples from Boulbi, Ouagadougou and Koubri are acidic; which promotes the mobility of metallic trace elements [30]. Also, sample B_2 has the greatest cation exchange capacity of 6.40 compared to 2.49 for soil TD_2. Thus, B_2 has the highest retention capacity for cationic heavy metals than other samples [31].

TD_1 and TD_2 soils are basic unlike the others which are acidic in nature. With the exception of K_1 and K_2 soils which are irrigated with water of an alkaline pH, the others are watered with water of an acidic nature. The acidity of the water could partly explain that observed in the soils of Boulbi (B_1, B_2) and Ouagadougou (O_1, O_2). Acidity is much more pronounced in soils B1 and B_2 respectively with a pH of 4.60 and 4.37. Acidic pH leads to an increase in the solubility of heavy metals as well as their mobility in the soil [12,32]. On the other hand, a basic pH favors metal adsorption on the reducible fraction of sediments (iron and manganese oxides), after exchange of metal cations with H^+ ions on certain surface sites [33,34].

Table 3. Particle size characteristics of soils

	Percentage (%) of the different particle size fractions				
Site	**Clay**	**Fine silt**	**Coarse silt**	**Fine sand**	**Coarse sand**
B_1	14,00	7.50	26.50	26.20	25.80
B_2	19,00	5,00	21.80	18.10	36.10
O_1	11.50	10,00	17.95	36.85	23.70
O_2	9,00	2.50	19.40	31.60	37.50
K_1	9,00	7.50	21.15	31.85	30.50
K_2	9,00	5,00	17,00	31.15	36.95
TD_1	9,00	10,00	22.70	41.95	16.35
TD_2	4,00	7.50	18.15	38.30	32.05

Table 4. Physico-chemical parameters of soils

Site	pH_{eau} P/V : 1/2,5	Dr (g/cm^3)	Da (g/cm^3)	Porosity (%)	O.M (%)	S.R	E.B (méq/100 g)	C.E.C	E.C (mS/cm)
B_1	4.60	2.54	1.53	39.76	1.96	59.58	1.56	2.61	0.21
B_2	4.37	2.56	1.52	40.62	2.08	51.41	3.29	6.40	1.42
O_1	6.22	2.60	1.56	40,00	1.77	70.06	4.46	6.36	1.53
O_2	6.11	2.60	1.59	38.85	2.42	53.09	2.87	5.40	0.78
K_1	6.88	2.61	1.67	36.01	1.52	51.63	1.48	2.87	0.24
K_2	6.86	2.64	1.59	39.77	0.78	64.10	2.82	4.41	0.14
TD_1	7.41	2.51	1.56	37.85	1.14	81.30	2.84	3.49	0.23
TD_2	7.19	2.59	1.60	38.22	1.09	84.25	2.10	2.49	0.17

Table 5. Relationship between water-soil pH by site

Site	B_1	B_2	O_1	O_2	K_1	K_2	TD_1	TD_2	Max	Min
pH_{eau}	6.01	5.74	6.60	5.97	7.36	7.36	5.28	5.28	7.36	5.28
pH_{sol}	4.60	4.37	6.22	6.11	6.88	6.88	7.41	7.19	7.41	4.37

3.2 Average Concentrations of Heavy Metals by Study Area

Figs. 2 and 3 present the histograms of the average concentrations of heavy metals quantified in the 0-10 cm and 10-20 cm soil profiles.

The results show that the Fe and Cr contents are the highest. Indeed, the Ouagadougou sites are the most loaded with Fe (6023.47 ppb), followed by Boulbi (5974.50 ppb), Koubri (4150.97 ppb) and Tanghin-Dassouri (1513.10 ppb). The highest concentration of Cr is observed in Koubri (512.07 ppb) followed by Ouagadougou (61.81 ppb), Boulbi (49.19 ppb) and Tanghin-Dassouri (3.65 ppb). The histograms indicate that the soils of Ouagadougou contain more As, Fe and Ni, while a higher content of Cu, Hg, Se and Zn is observed in Boulbi; Cr and Pb in Koubri and Mn in Tanghin-Dassouri. Thus, we can conclude that the Tanghin-Dassouri sites are the least loaded with these heavy metals studied.

The results showed that Fe and Cr have the highest concentrations. Indeed, the Tanghin-Dassouri sites are the most loaded with Fe (5940.46 ppb), followed by Koubri (4918.28 ppb), Ouagadougou (4387.78 ppb) and finally Boulbi (1804.05 ppb). The highest Cr content is observed in the Koubri zone (766.16 ppb), then in Tanghin-Dassouri (125.40 ppb), in Ouagadougou (34.75 ppb) and in Boulbi (2.70 ppb). The histograms show that the Koubri soils are the most loaded with As, Cr, Cu and Mn; the soils of Tanghin-Dassouri in Ni, Fe and Zn and those of Ouagadougou in Pb and Se. The Boulbi zone turns out to be the least loaded in its 10-20 cm profile.

Generally, this study revealed that the average concentrations of heavy metals in the 0-20 cm profile of market gardening soils are lower than the recommended limits. These low levels of heavy metals suggest that the critical load of the soil has not yet been reached and that it continues to play its buffering role so that these micropollutants have difficulty migrating to depth. However, the presence of non-essential trace metal elements such as Pb, As and Hg in soils presents risks of contamination of groundwater resources and market garden products and therefore a serious threat to the health of consumers.

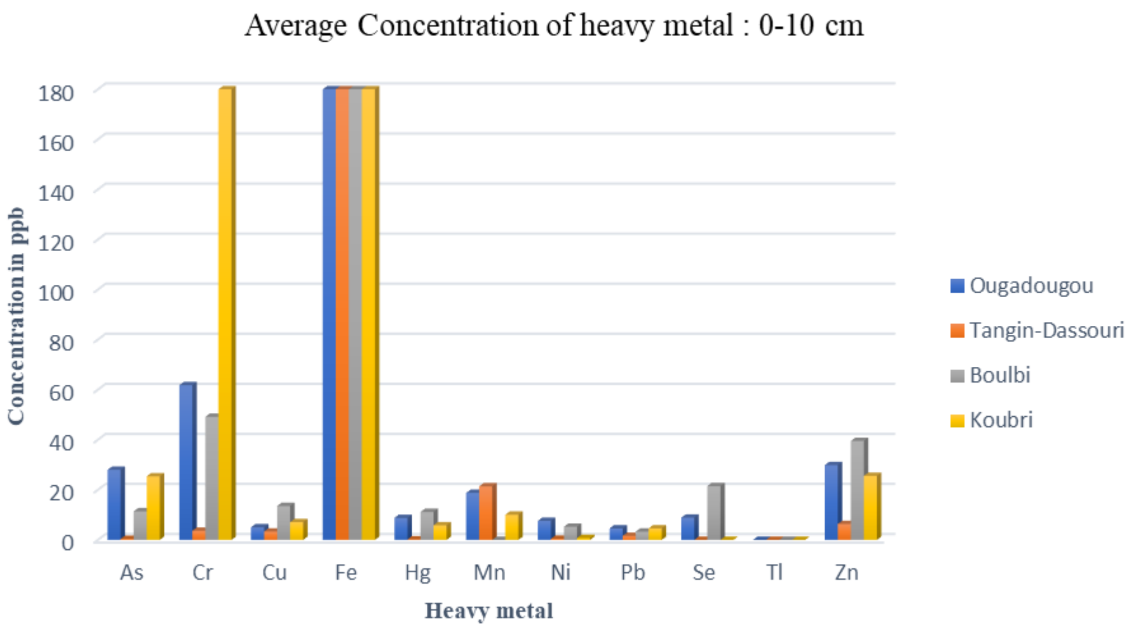

Fig. 2. Average concentrations of heavy metals in the 0-10 cm profile

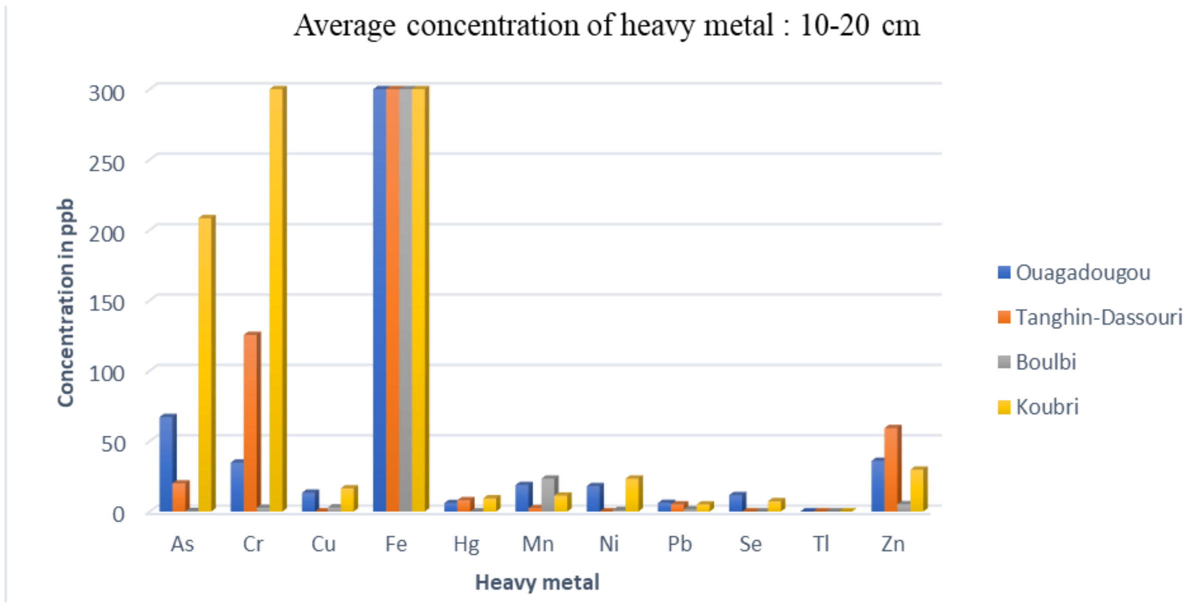

Fig. 3. Average concentrations of heavy metals in the 10-20 cm profile

3.3 Factors of Contamination of Market Gardening Soils in the Four Zones

To better compare with the limit values, we have determined the metal contamination factors and represent them on the histograms below.

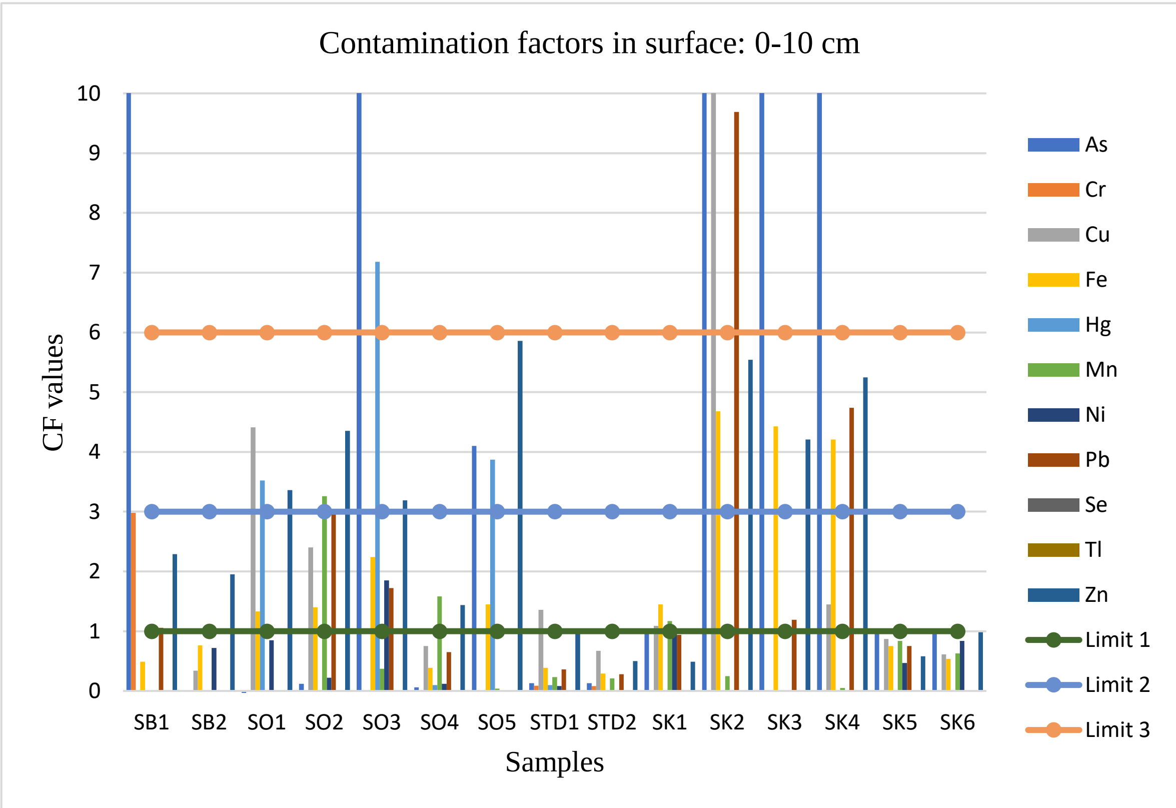

Fig. 4. Variations in contamination factors in the 0-10 cm soil profile

CFs are variable. Indeed, As is the element which contributes the most to the contamination of SB1 (Boulbi) and SK2, SK3, SK4 (Koubri) soils with respective values of 10.07; 333.70; 82.33 and 89.47. In the SO3 sample (Baskuy), it is the elements Cu and Hg which have a very high contamination contribution with CFs of around 14.51 and 7.18. Also, the result show that Hg and Zn have somewhat high contamination factors; which reflects their contribution to the contamination of samples such as SO1 (CHU) and SO5 (Pissy) for Hg and SK1, SK2, SK3, SK4 (Koubri), SO5 (Pissy) and SO3 (Baskuy) for Zn.

In this profile, these are As, Cr, Cu, Mn, Ni and Zn which contribute considerably to the contamination of the soil samples measured. Indeed, the contamination factors of arsenic are around 59.01 for PO2 (Koubri), 8.38 for PTD2 (Tanghin-Dassouri) and 46.28 for PK6 (Koubri). For Cr, we have respectively 51.18 and 11.14 for PK3 and PK6 (Koubri). For PO2 (CHU), the contamination factor is 21.14 for Cu and 7.38 for Ni. The CF of Zn are around 151.11 for PK2; 56.57 for PK3; 491.11 for PK4; 58.78 for PK5 (Koubri) and 6.54 for PTD1; 8.7 for PTD2 (Tanghin-Dassouri). Also, the contribution of Hg and Mn is considerable respectively on the PTD2 (Tanghin-Dassouri) and PO1 (CHU) sites.

3.4 Degree of Contamination (DC)

In the 0-10 cm profile, the samples SO3, SK2, SK3 and SK4 are highly contaminated. The most contaminated being the SK2 sample in Koubri with a CD of 368.37 compared to 2.16 for STD1 in Tanghin-Dassouri (less polluted). Also, samples SB1, SO1, SO2 and SO5 have degrees of contamination which show that their contamination is not negligible. The soils of Tanghin-Dassouri are the least contaminated while those of Koubri are the most contaminated with a peak of 368.37 as the degree of contamination.

In the 10-20 cm profile, there is strong contamination for samples PO2, PK2, PK3, PK4, PK5 and PK6. Soils K2, K3 and K4 which were heavily contaminated on the surface remain so at depth. On the other hand, PK5 and PK6 which were slightly contaminated on the surface are heavily contaminated at depth. The most polluted

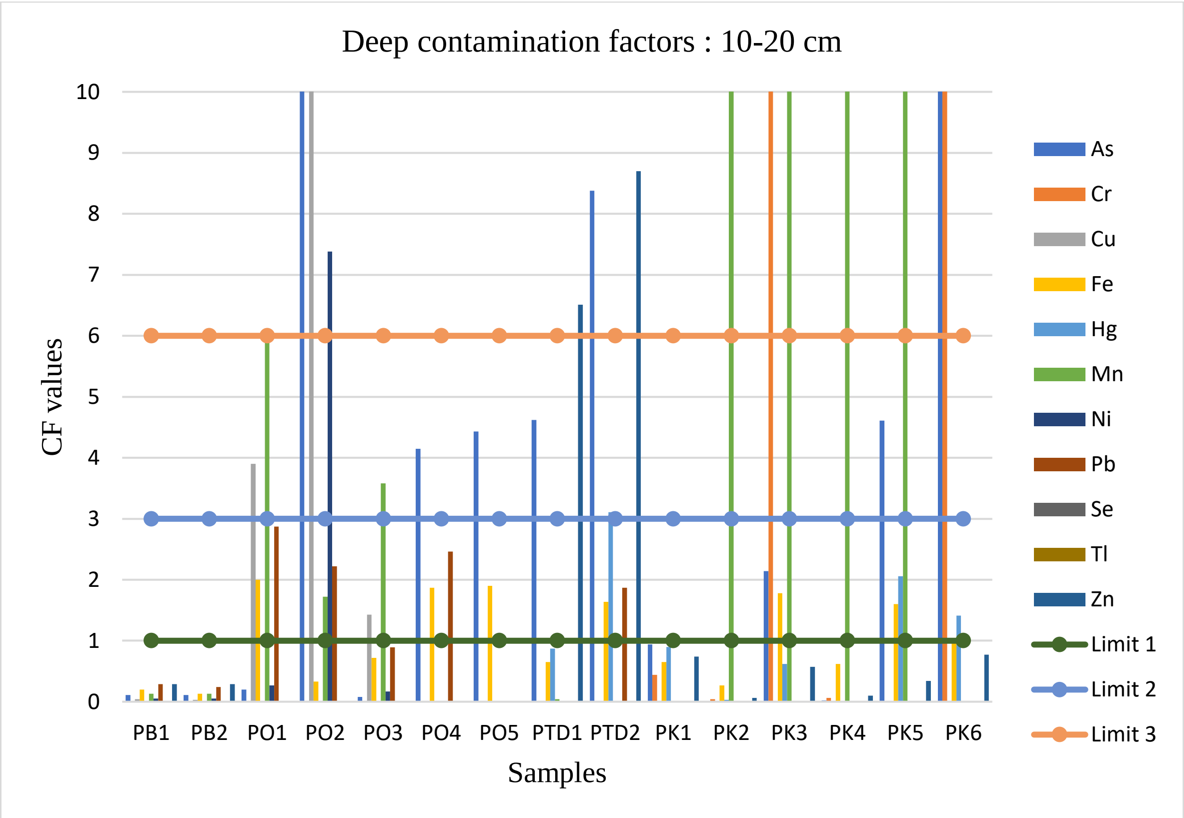

Fig. 5. Variations in contamination factors in the 10-20 cm soil profile

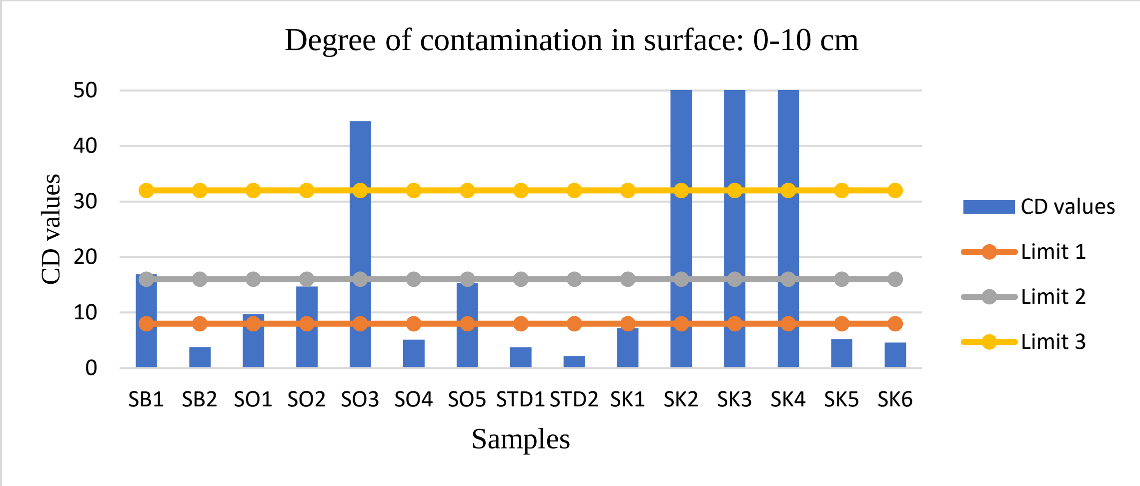

Fig. 6. Variations in contamination degrees in the 0-10 cm soil profile

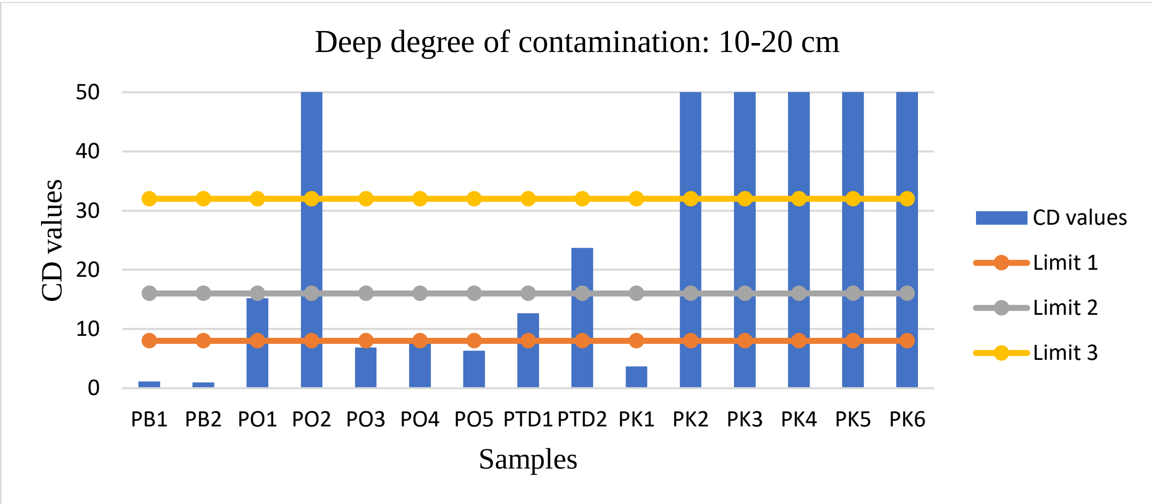

Fig. 7. Variations in degrees of contamination in the 10-20 cm profile of

sample is PK4 with a CD of 491.91 compared to 0.98 for PB2 in Boulbi (less polluted). Soils PO1, PO2, PTD1, PTD2, PK2, PK3, PK4, PK5 and PK6 which were contaminated on the surface remain contaminated at depth 10-20 cm to different degrees. The soils of Boulbi are the least contaminated in the 10-20 cm profile while those of Koubri remain the most contaminated in this profile. The only soil sample from Ouagadougou that is heavily contaminated is PO2.

3.5 Assessment of the Degree of Soil Pollution Using the Pollution Load Index (PLI)

Figs. 8 and 9 show the evolution of the Pollution Load Index of the soils studied in the 0-10 cm and 10-20 cm profiles.

Surface pollution differs not only from one area to another but also from one site to another in the same area. The most polluted soil in its 0-10 cm horizon is SK2 in Koubri with a PLI of 8.20 compared to 0.24 for STD1 in Tanghin-Dassouri (less polluted). It confirms the previous analysis with the degrees of contamination. Also, soils SO5 (Pissy), SO1 (CHU), SO2 (CHU), SO3 (Baskuy); SK3, SK4 (Koubri) and SB1 (Boulbi) are polluted with PLIs which are significantly greater than unity [21]. On the other hand, soils SK1, SK5, SK6 (Koubri); STD1, STD2 (Tanghin-Dassouri) and SO4 (Baskuy) have PLIs less than unity and therefore not polluted [21]. Also, the PLI values confirm that the Tanghin-Dassouri samples are the least polluted and those of Koubri the most polluted.

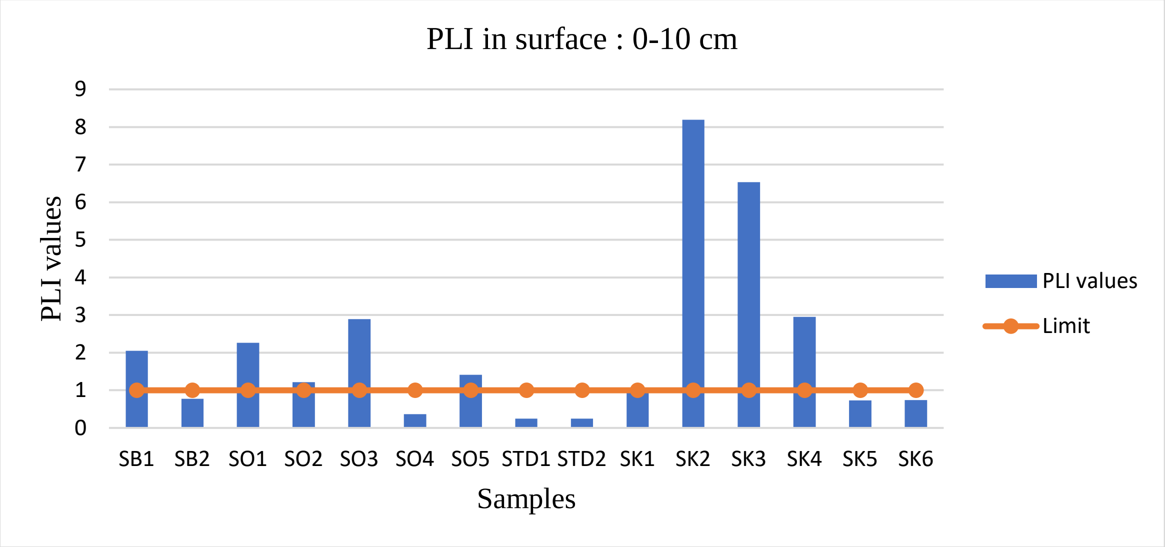

Fig. 8. Surface pollution index (0-10 cm)

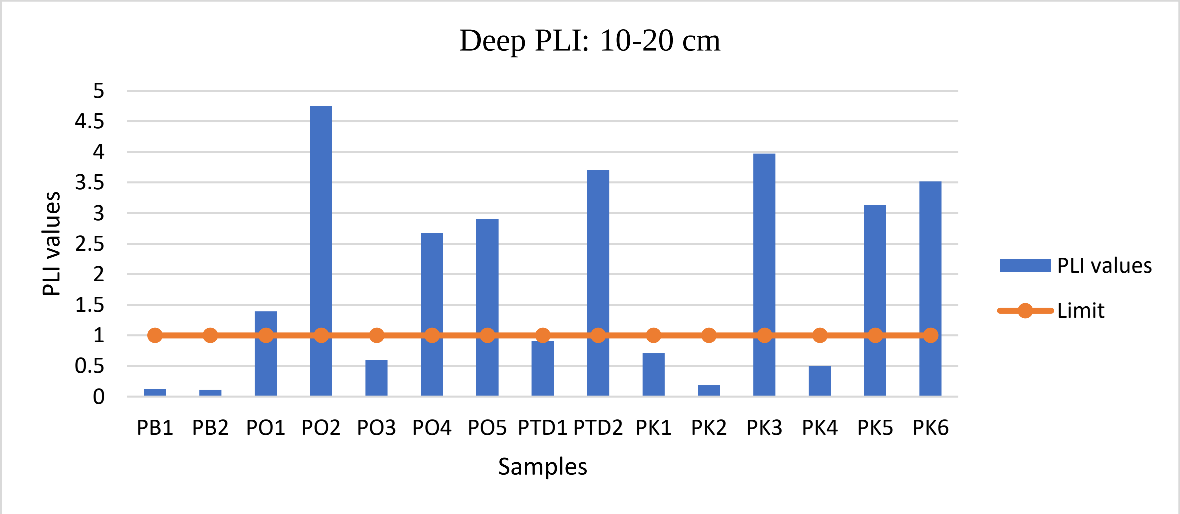

Fig. 9. Pollution index at depth (10-20 cm)

At a depth of 10-20 cm, the PLI values show that the PO5 (Pissy), PO2 (CHU) and PK3 (Koubri) soils already polluted on the surface remain so at depth. However, PTD2 (Tanghin-Dassouri), PK5, PK6 (Koubri) and PO4 (Ouagadougou) which were not polluted on the surface are polluted at the 10-20 cm profile. This situation is perhaps due to the considerable contribution of elements such as As, Cr, Hg and Zn. Also, this may be due to the fact that at the 0-20 cm horizon the soil is constantly disturbed by the practice of market gardening.

4. CONCLUSION

It can be noted that the average concentrations of heavy metals measured in soil samples are lower than the recommended standards. However, the evaluation of the degree of soil pollution, with mathematical models such as Contamination Factors, Contamination Degrees and Pollution Load Index (PLI), show that certain exploited soils are polluted; especially the soils of market gardening sites in the city of Ouagadougou. These tools reveal that the pollution of market gardening soils differs not only from one site to another but also between the 0-10 cm and 10-20 cm profiles. Thus, the most polluted soil in its 0-10 cm horizon is SK2 in Koubri with a PLI of 8.20 compared to 0.24 for SS4 in Tanghin-Dassouri. At depths of 10-20 cm, the PLI values show that the soils PO5 (Pissy), PO1 (CHU), PO2 (CHU) and PK3 (Koubri) already polluted at the surface remain so at depth. However, the low concentrations of metals in the soil samples suggest that this is diffuse pollution. In addition, can we remember that the presence of non-essential elements such as Pb, as and Hg constitutes a serious threat to the health of consumers of market garden products from these sites.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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