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Research Article

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Bioaccumulation of Metallic Trace Elements by Vegetables Grown in the Industrial Zone of Lome, Southern Togo

Housséni AHOUDI*, Hodabalo D. SOLITOKE, Gnon TANOUAYI, Kamilou OURO-SAMA, Tchaa E.E. BADASSAN, Kissao GNANDI

Laboratoire de Gestion, Traitement et Valorisation des Déchets, Faculté des Sciences, Université de Lomé, BP: 1515 Lomé, Togo
Département de Géosciences, Facultés des Sciences, Université de Lomé, BP: 1515 Lomé, Togo.
Email: ahoudih@yahoo.fr

Abstract The objective of this study was to determine the contents of Mercury (Hg), Cadmium (Cd), lead (Pb), and arsenic (As) in the edible parts of leafy, fruits and rooat vegetables grown in the industrial zone of Lomé and assess the health risks faced by consumers. For this purpose 16 species of vegetables and their soils exposed to industrial, road other urban pollution was sampled in three sites of the study area and sixteen others control samples in rural zone (klobatèmé) for the determination of Cd, Hg, Pb and As. Five samples of each species were sampled in each site to form one sample par site. The physicochemical parameters were analysed using standard methods of the French association Standardisation (AFNOR) and the Cd, Hg, Pb and As by atomic Absorption Spectrometer and inductively coupled plasma mass spectrometer. It appears that conductivity values of Hanoukopé, Kotokoudji-Amoutivé, Bê and East Lagoonare higher than the standard (500 µs/cm), the organic matter contents of the study area are all lower than those of the reference area and pH values are above 6,5 – 7,5 recommended by the World Health Organisation (WHO). Some of these sandy soils are polluted only by As, but their leafy vegetables are polluted by As and Pb, root vegetables by Pb. In the fruit vegetables only cucumber was polluted by Cd and As. The study shows that fruit organs concentrate less metals than leaves and roots. The hazard indices associated with vegetables consummation show no health effect on consumers.

Keywords Vegetables, pollution, heavy metals, hazard indices, consumers

1. Introduction

In Lomé Urban and peri-urban market gardening plays an important role in supplying the city with vegetables and provides employment for a significant portion of the population [1]. Market gardeners often develop their activities along roadsides and around urban dwellings and public buildings such as industrial units exposing them to the anthropogenic pollution due to lack of agricultural growing spaces. Vegetables that are known to provide to the human and animal beings the essential trace element such as calcium, magnesium, potassium, iron and proteins became exposed to anthropogenic pollutants. However, these vegetables if they are polluted by microorganisms, and heavy metals are sources of heavy metals uptake and human adverse health effects [2]. In Lomé, the market gardening area is also the most important industrial and an intense road traffic zone. Leafy, fruit and root vegetables grown in that area and their soils are directly exposed to the atmospheric deposits of gases from industrial activities and vehicular emissions which occur due to complete and uncomplete combustion of gasoline containing heavy metals and other pollutants. Vegetables are also exposed to other trace metals sources like the application of pesticides and inorganic fertilisers, urban garbage, the surface run-off and the use of wastewater to irrigate vegetables by market gardeners [4-5]. Vegetables grown in Lomé market gardening are contaminated with heavy metals such as As, Cd, Pb and Hg from all sources by atmospheric deposits and soils bioaccumulation [4], [6]. One of the properties of green leafy vegetable is the accumulation of heavy metals in their tissues without exhibiting any toxicity symptoms [7]. Elements like As, Cd, Hg and Pb are nonessential and have no beneficial role in plants, animals, and human beings and have no nutritional function, as they are highly toxic [8]. These vegetables are the most consumed by the population of Lomé and are also exported to the countries of sub-region. This study aims to determine the contents of heavy metals in vegetables for food safety and in their soils in order to establish the quality of soils and assess health risks faced by consumers.

2 Material and methods

2.1 Study area

The study zone is in the costal area of Lomé, southern Togo. It is located in the industrial zone between latitudes 6°06'49.06'' and 6°08'53'' North and longitudes 1°12'1.49'' and 1°12'14.12'' East. The vegetable production areas are experiencing a decrease in their areas due to land pressure linked to the construction of public buildings, economic activities and the extension of the autonomous port of Lomé. This situation led to the displacement of market gardeners to the eastern areas of Lomé [9]. These market gardens zones like the whole city of Lomé enjoys a subequatorial or Guinean climate with two rainy seasons and two dry seasons. The most important economic activities in that area are industrial activities specialised in agribusiness, plastics manufacturing, iron and steel industry, cement manufacturing, cosmetics and an oil refinery. To these activities we find a harbour that is the lung of the Togolese economy and whose imports of second-hand goods from Europe and the United States of America pose serious problems of environmental pollution. This zone is also the market gardening zone of Lomé which supplies all the city and some cities of the sub-region with vegetables.

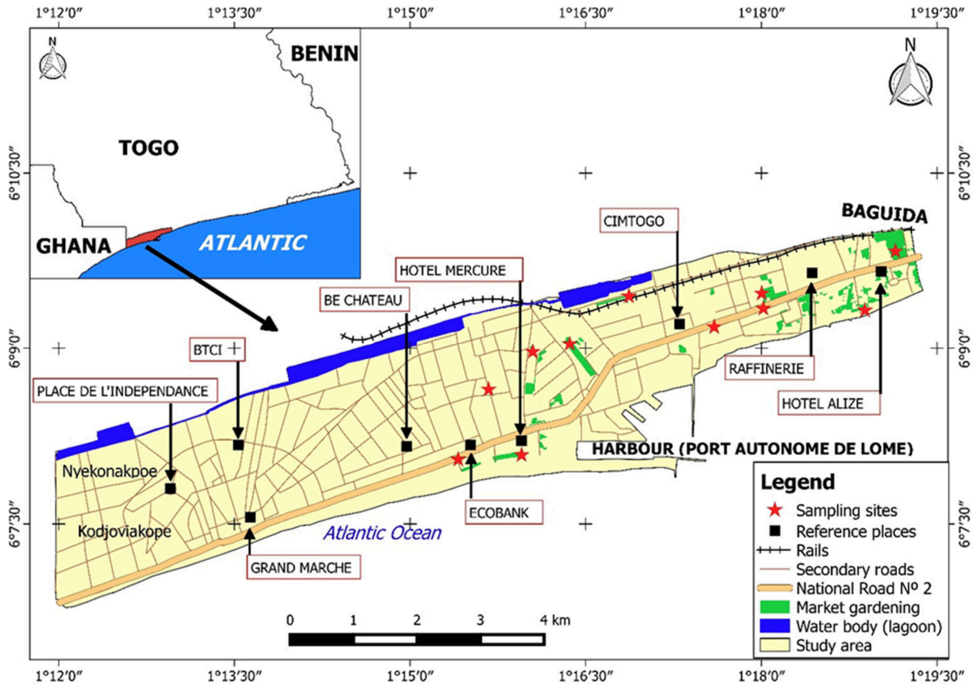

Figure 1: Locating map of the study area showing the sampling sites

2.2 Vegetables and soil sampling

The vegetables sampling was carried out in November 2017, just at the end of the rainy season and a few days before the harvest. A total of sixteen species of commonly grown vegetables were randomly sampled throughout three sites of the study area to form three samples per vegetable. In each site, 5 vegetables were collected to form a composite sample of the same vegetable and put in polyethylene bags. At the same time soils samples were collected at a depth of 0–20 cm, at the same place as the vegetables. The samples were put in the ice chest and transported to the laboratory. Other vegetables samples and their soils were collected in rural zone (Klobatèmé) at 10 km to the study area to serve control samples.

2.3 Laboratory Analysis

In the laboratory, vegetable samples were first thoroughly washed with tape water followed by distilled water before cutting them to small pieces with aplastic knife. The vegetables are separated into different organs (leaves, fruit, stems and roots) before being dried at 40°C, and crushed. About 3 g of vegetable powder were weighed and digested in 6 ml HNO_3 (65%) and 12 ml H_2O_2 (30%) [10], for 30 min using a hot plate.

The soil samples were dried at room temperature before being sieved and crushed. About 0.3 g of soil were digested by aqua regia (1 mL HNO_3 65% m/m, 3 mL HCl 37%m/m) [9]. All the digested samples are filtered in polypropylene tubes and adjusted to 10 mL with distilled water. Each sample was tested three times and their average is retained as the final result.

Soil samples of 1 g was mixed with 2.5 g distilled water in polyethylene centrifuge tube. After shaking for 1 min, the mixture was allowed to stand for 2 hours and the pH and electrical conductivity were measured in the supernatant solution [11].

The parameters measured in soil samples were the pH, electrical conductivity, organic matter contents, the grain size of the soil and the contents of Cd, Hg, Pb and As.

The pH and the electrical conductivity were measured by a multimeter, type knick Portamess and the concentrations of Cd, Hg, Pb, and As were determined by the atomic absorption spectrometer, Thermo Electron S Series.

2.4 Data analysis

Comparison of the concentration of different metal trace element contents of vegetables and soils was done with statistica version 6 and Microsoft Excel 2013 software.

Health risk assessment

The human health risk assessment posed by heavy metals from consumption of vegetables polluted by anthropogenic activities was made by comparing the concentration of heavy metals Tolerable Daily Intakes (TDIs) and the Reference Dose (RfD). The daily intake of heavy metals through the consumption of vegetables was calculated as the following equation:

$$EDI = \frac{C \times DVC}{BW}$$

EDI = Estimated Daily Intake (mg/day), C = Heavy metal concentrations in the vegetable (mg/kg), DVC = Daily vegetable consumption, BW is the Body Weight (kg).

Daily vegetable consumption was obtained through estimations from a survey conducted on urban vegetable consumption in the study area.

The hazard index (HI) was calculated to determine the overall risk of exposure to all of the heavy metals via the ingestion of a particular vegetable crop [12]. To get HI, the hazard quotients (HQ) need to be obtained.

HQ = DIR/RfD,

DIR = Daily Ingestion Rate or Estimated Daily Intake (mg/day),

RfD = Reference Dose

HI is the sum of all the HQs of all the elements in each vegetable crop. HI < 1 indicates that the predicted exposure is unlikely to pose potential health risks. However, a hazard index >1 does not necessarily indicate that a potential adverse health effects will result, but only indicates a high probability of posing health risks.

Quality Assurance

Appropriate quality assurance procedures and precautions were taken to ensure the reliability of the results. Samples were carefully handled to avoid any contamination. Glassware was properly cleaned, and reagents were of analytical grades. Distilled water was used throughout the study. For the quality control, repeated analysis of the samples against internationally certified standard reference material Seronorm TM Trace Elements controls (SERO AS, Billingstad, Norvège) were used, and the results were found below 10% of the certified values.

3. Results

Spatial variation of the pH, electrical conductivity and organic matter in the study area

Figure 1 shows that in the study zone, the pH varies from 7.52 to 8.48 pH units and these values are all higher than those of the reference zone (Klobatèmé), which is 7.23. It is found that all pH values are above 6,5 – 7,5 recommended by WHO. This shows the alkaline character of the soils in the study area. Figure 2 shows that in the study area, the electrical conductivity varies from 105.979µS/cm to 230529.236 µS/cm where those of Hanoukopé, Kotokoudji-Amoutivé, BE and East Lagoon are higher than the standard (500 µs/cm). It is found that the organic matter contents of the study area (Figure 3) are all lower than those of the reference area with a high value in the East lagoon.

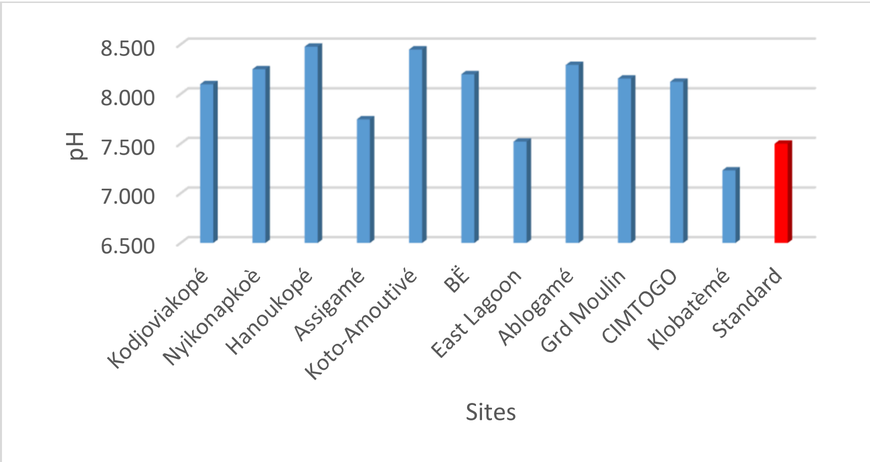

Figure 1: Spatial variation of the pH

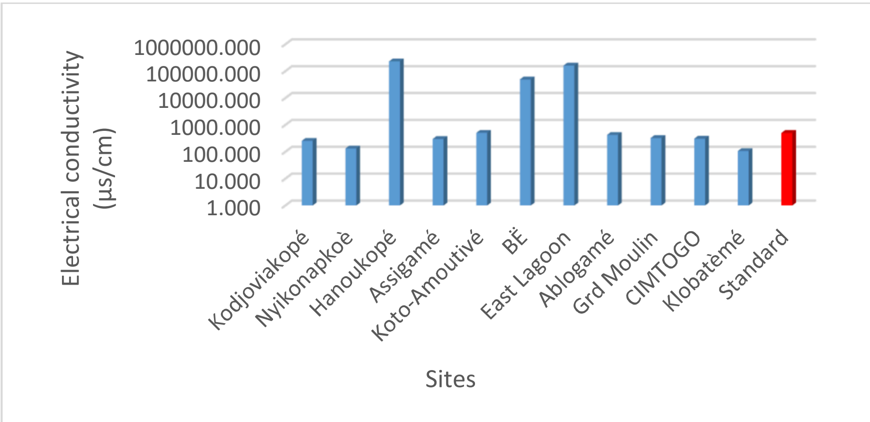

Figure 2: Spatial variation of electrical conductivity

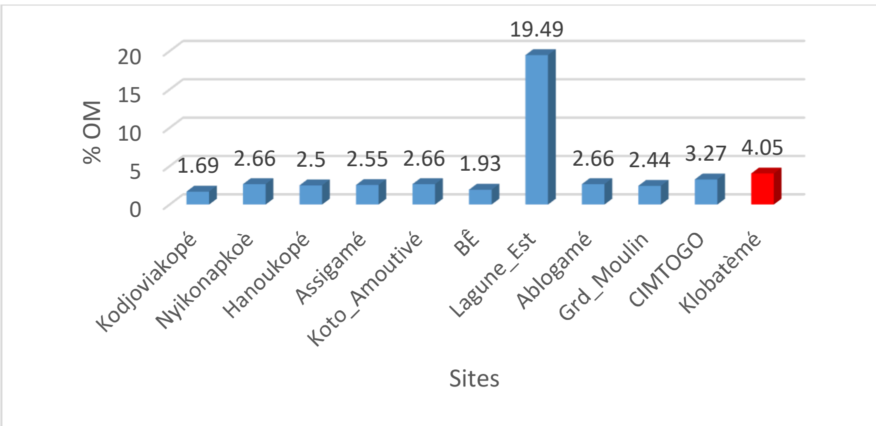

Figure 3: Percentage of organic matter (OM)

3.1 The grain size of the soil

The grain size expressed by the average grain size, and presented as a percentage of the total weight of the material shows that throughout the study area, the percentages of silt plus clay vary from 2% to 8%, the sand from 83% to 97%, and the grave from 0% to 15%, and this characterises a sandy soil.

3.2 - Heavy metal content in soils of vegetable plots

The concentrations of heavy metals in soil samples from vegetable plots presented in Figure 4 show that as concentrations of cabbage, spinach, onion, beetroot and turnip soil samples are higher than its Canadian Soil Quality Standard which is 19 000µg/kg. So these soils are polluted by the As. All other contents of As are below to this Canadian standard. All concentrations of Cd, Hg and Pb are also below their respective Canadian standards. This shows that the soils of vegetable plots are not polluted by these three heavy metals.

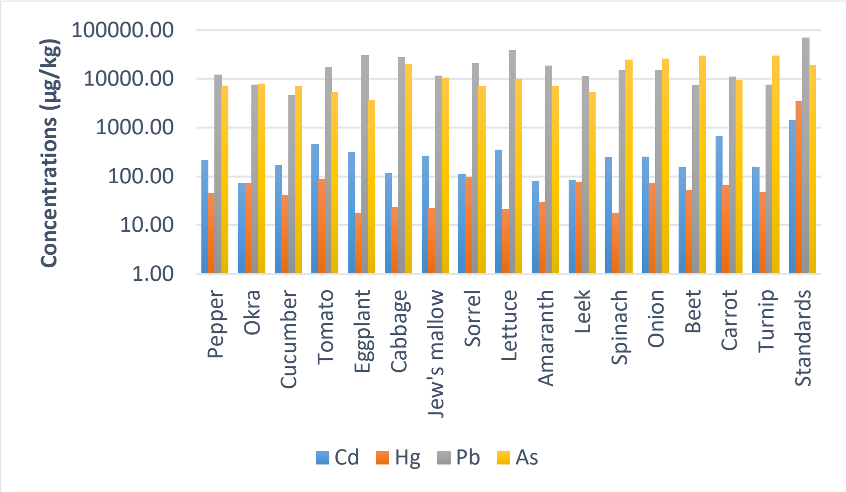

Figure 4: Heavy metal content in soils of vegetable plots

The metallic trace element contents in leaves of leafy vegetables presented in figure 5 show that all cadmium levels of these vegetables are below the European union (EU) cadmium standard (1400 µg/kg). This shows that these leafy vegetables are not polluted by this metal compared to its EU standard. However, Cd content of all leafy vegetables of the study zone compared to those of controls are higher than them indicating their pollution. The concentrations of Hg in the leek (39.08 ± 17.04 µg/kg) and in the eggplant (34.79 ± 5.47 µg/kg) of the study zone are all higher than its EU standard which is (30 µg/kg) thus indicating these vegetables pollution. The other Hg concentrations, higher than those of the controls, remain below the EU standard indicating a simple contamination. The Pb concentrations of all vegetables in the study area are all above its EU standard (100 µg/kg), and the concentrations of the controls with the exception of the leek, indicating their Pb pollution. It is found that all the as content of these leafy vegetables are higher than those of the controls and the EU standard. This shows a pollution of these leafy vegetables from the study area by As.

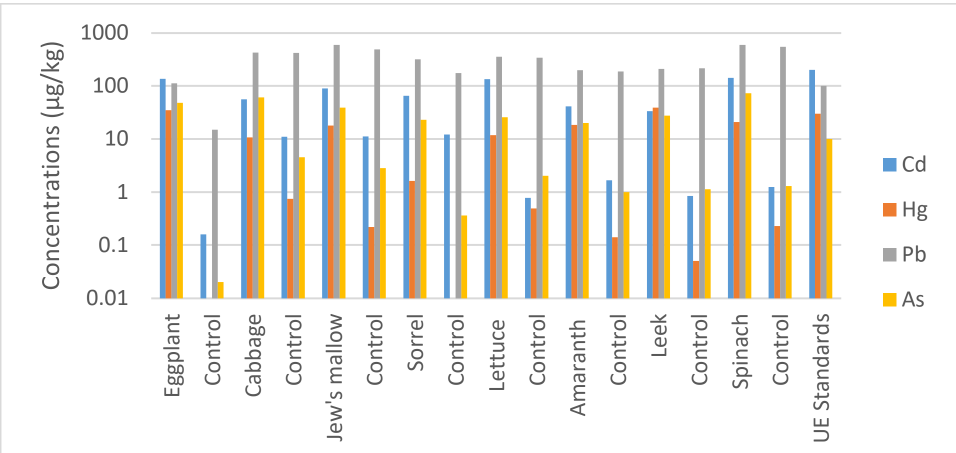

Figure 5: Metallic trace elements content in leaves of leafy vegetables

Figure 6 shows that Cd concentrations in fruit of fruit vegetables in the whole study area are higher than the controls but remain lower than its EU standard (50 µg/kg) except in cucumber where it exceeds this standard showing cucumber pollution by Cd. For Hg, all its concentrations in these fruits vegetables are higher than the controls but remain below the EU standard (50 µg/kg) thus indicating a simple contamination of these vegetables by Hg. Pb levels are all higher than the controls except in cucumber where the concentration of control is higher than that of the cucumber in the study area. However, all the Pb contents are lower than the EU standard, which indicates a contamination of these vegetables. It can be seen that for As, only the concentration in cucumber is higher than the EU standard for As indicating its pollution by this element. No metal is determined in the chilli pepper and okra controls unlike cucumber and tomato controls.

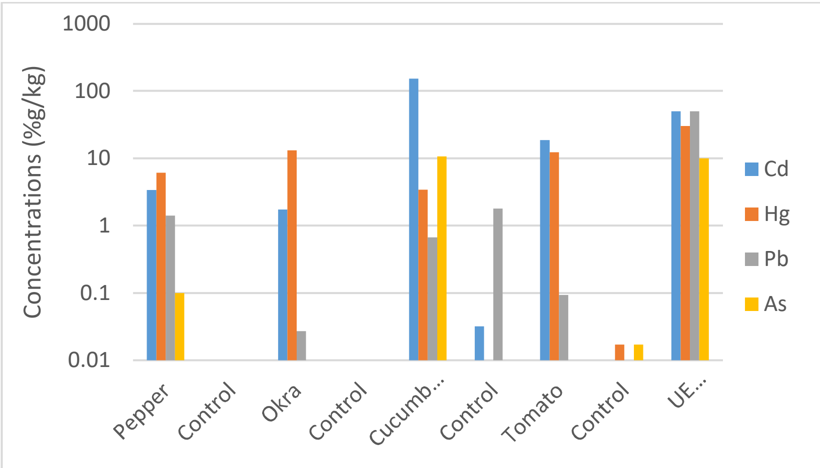

Figure 6: Metallic trace elements content in Fruit of fruit vegetables

Figure 7 shows that all Cd contents in the reserve organs of the vegetables of the study area are higher than the controls but remain below its EU standard, thus indicating a simple contamination of these reserve organs by this Cd. For Hg all its concentrations in the reserve organs of the vegetables in the study area are all higher than the controls but only the concentration in the carrots is higher than the EU standard (30 µg/kg). This indicates carrot pollution and the contamination of other reserve organs of other vegetables. As for Pb, all its concentrations in the reserve organs of the vegetables in the study area are higher than those of their controls and the EU standard for roots and bulbs vegetables, this shows a strong pollution of these vegetables by the Pb. For As all its concentrations in the reserve organs of root vegetables are lower than its EU standard. This shows a contamination of the vegetables in the study area by the As as compared to the controls. However there is an absence of As in the reserve organs of control vegetables.

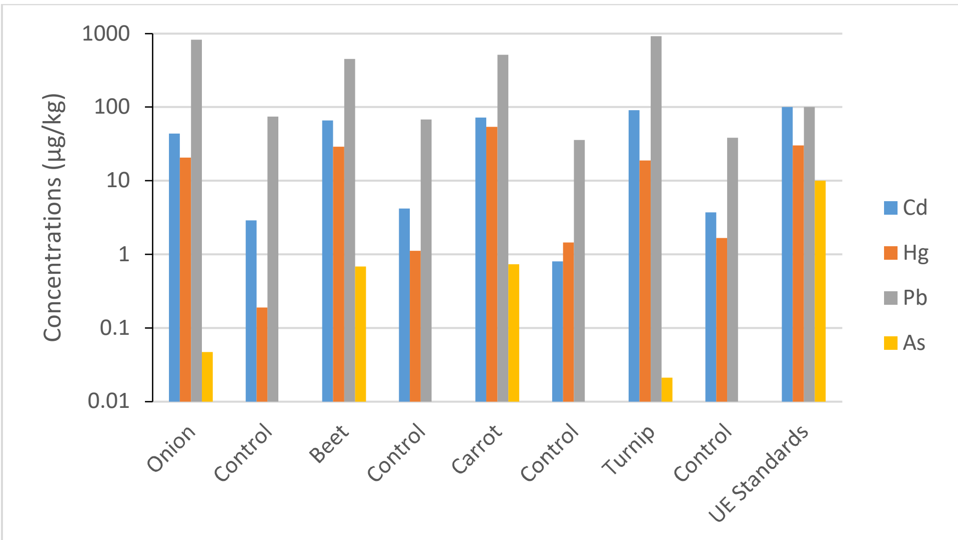

Figure 7: Metallic trace element contents in reserve organs of root vegetables

With regard to these heavy metal contents in these vegetables, the hazard quotients (HQ) are calculated in order to predict the health risks faced by consumers. These HQ presented tables are all less than 1 indicating no adverse health effects.

Table 1: Hazard quotients for threshold effects for leafy vegetables

Vegetables/metals	Cd	Hg	Pb	As	QD SUM
Eggplant	118.3E-3	96.4E-3	20.5E-3	131.7E-3	366.9E-3
Cabbage leaf	73.5E-3	44.7E-3	119.1E-3	254.1E-3	491.5E-3
Jew's mallow	29.8E-3	19.1E-3	41.9E-3	41.2E-3	132.0E-3
Sorrel of Guinea	2.2E-3	171.4E-6	2.2E-3	2.4E-3	7.0E-3
Lettuce	31.2E-3	8.7E-3	17.5E-3	19.1E-3	76.6E-3
Amaranth	1.4E-3	2.0E-3	1.4E-3	2.1E-3	6.9E-3
Leek	222.7E-6	832.8E-6	294.6E-6	586.1E-6	1.9E-3
Spinach	21.2E-3	9.9E-3	18.9E-3	35.0E-3	84.9E-3

Table 2: Hazard quotients for threshold effects for fruit vegetables

Vegetables/metals	Cd	Hg	Pb	As	QD SUM
Pepper	54.0E-6	97.7E-6	5.0E-6	5.3E-6	162.0E-6
Okra	3.1E-3	2.4E-3	10.8E-6	896.9E-6	6.4E-3
Cucumber	778.8E-6	17.4E-6	758.0E-9	181.3E-6	978.2E-6
Tomato	13.2E-3	8.6E-3	14.5E-6	nd	21.8E-3

nd: not determined

Table 3: Hazard quotients for threshold effects for root vegetables

Vegetables/métaux	Cd	Hg	Pb	AS	QD SUM
Onion	2.8E-3	4.4E-3	11.7E-3	10.0E-6	18.8E-3
Beetroot	13.7E-3	20.1E-3	20.9E-3	470.9E-6	55.1E-3
Carrots	19.5E-3	48.6E-3	31.1E-3	661.1E-6	99.9E-3
Turnip	1.5E-3	1.0E-3	3.3E-3	1.1E-6	5.7E-3

4. Discussion

Soils of the Gulf of Guinea coastal are developed on littoral sands very poor in vegetation cover [9]. They are characterised by low humidity, due to their low water retention and low levels of vegetation cover [9]. These factors explain their low organic matter contents, which has the ability to trap metallic trace elements and limit their bioavailability. The particle size analysis shows the low percentage of clays (2% to 8%), and graves (0% to 15%), but a high percentage of sands (83% to 97%). According to the texture triangle of food and agriculture organisation (FAO) that determines the textural class of soils, the study area has predominantly sandy soils. These conditions characterise the sandy character of the coastal soils of the Gulf of Guinea. The low organic matter content of the soil and clays shows that these parameters have no influence on trace metals uptake in these soils. However, the salinity of these soils limits this bioavailability. The salinity of soils can be linked to basic cations (Mg^{2+}, Ca^{2+}, Na^{+}, K^{+}) which are the results of urban pollution. This salinity causes the precipitation of metallic cations including heavy metals and thus limits their mobility and bioavailability for vegetables. In these soils, the pollution of cabbage, spinach, onion, beetroot and turnip soil plots by As can be explained by the usage of pesticides, chemical fertilisers, and dry depositions of industrial and road dust containing heavy metals on vegetables and their soils. The levels of As above EU standard in these market garden soils show that this pollution is linked to agricultural activities, industrial and road traffic emissions containing this trace metal.

The pollution of all leaves of the vegetables by As and Pb, and the leaves of leek and eggplant by Hg, and the contamination of other leafy vegetables by Cd and Hg is the results of the use of chemical pesticides and fertilisers [13], [14], containing trace metals to protect plants and increase their yields [15]. This pollution is aggravated by the presence of several industries in the study area which contribute to vegetables crops pollution by heavy metals through industrial and traffic emissions (Cement plants, vehiculars and motorcycles). In these leafy vegetables, pollution factors range from 1,11 to 5,91 for Pb, and 2 to 7,29 for As. Several studies have shown that proximity to industrial activities increases the contamination of the soil, as well as crops cultivated in these soils [3]. The market gardening zone is also the industrial zone of Lomé with a strong road traffic which emits large quantities of dust containing metallic pollutants which eventually settle on soils and vegetables [4]. After deposits of dust on aerial parts, heavy metals have the capacity to enter directly in the vegetable through stomata [14]. It is shown that 50% of the lead found in aerial parts of plants grown on contaminated soil near industrial areas, came from atmospheric lead contained in industrial emissions [17]. Another fraction of soil heavy metals is absorbed by the vegetables through the roots. In the fruits of fruit vegetables, only the content of arsenic and Cd in cucumber are higher than their EU standards showing this fruit pollution. Many studies showed that cucurbits are classified as accumulators of heavy metals explaining this pollution. This study shows that fruit vegetables accumulate less heavy metals than other vegetables and for this reason they can be privileged in urban market gardening. Pollution of roots and bulbs vegetables by Pb shows that this metal is absorbed from soils and its presence in the soils is the results of industrial and road emissions deposits and chemical fertiliser applications [18]. The pollution factors for lead range from 4,52 to 9,18 showing the important accumulation of Pb in root and bulb vegetables. Pb accumulation in the roots and bulbs organs can be explained by their role of accumulator organs, thus these metals are a concern for public health. The bioaccumulation of heavy metals is different for different plant species because the mechanisms of elemental uptake by plants are not the same for all plant species [19].

The student test at the significance level $\alpha = 0.05$ showed a significant difference in concentration of Cd, Hg, Pb and As between the vegetables of the study area and their controls. This shows the pollution of leafy vegetables by arsenic and Pb, cucumbers by Cd and arsenic, carrots by Hg, and root vegetables by Pb.

The calculation of the hazard quotients (HQ) for threshold effects of the consumption of vegetables polluted by heavy metals has shown hazard quotients fewer than 1. This indicates that consumption of these vegetables have no adverse health effects on consumers.

5. Conclusion

The results of the study shows the impact of anthropogenic agents on abundances of heavy metals in soils and their vegetables. The results show the pollution of some soils of the market gardening by As and the contamination of all the area by Cd, Hg and Pb. The leafy vegetables are the most polluted par As and Pb, followed by roots and bulbs vegetables which are polluted by Pb. In fruit vegetables, only cucumber is polluted by Cd and As indicating that these vegetables are the least polluted. This shows that fruit vegetables accumulate little heavy metals and can be favoured in urban market gardening compared to other vegetables. This study shows that heavy metal accumulation in vegetables depends on the types of metal and the type of vegetables. Despite these heavy-metal contents in vegetables, the calculation of hazard quotients has shown that the consumption of these vegetables is without short-term health risks. However, the synergistic effect of heavy metals on the health of consumers cannot be neglected in the long run. In view of the heavy metal content in vegetables, this study clearly highlights the necessity to continue the evaluation of their levels for protection of environment and consumers.

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