Original Research Article

Assessment of heavy metal concentration in soil and plant and Evaluation of Bioconcentration factor at LOUMBILA market gardening perimeters, Burkina Faso

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 heavy metal concentration in soils and plants from Loumbila market gardening, and calculation of bioconcentration factor were undertaken. Heavy metals copper (Cu), nickel (Ni), lead (Pb), chromium (Cr), cadmium (Cd) and zinc (Zn) were measured using atomic absorption spectrophotometer (AAS) model AANALYST 200 from PERKIN ELMER.

The soil where the pepper was grown, the concentration of chromium was 175 mg/kg, which is higher than the concentration limit which is 150 mg/kg. Also the concentrations of lead in the soils of onion (118 mg/kg), green bean (118 mg/kg), carrot (178 mg/kg) and pepper (135 mg/kg) were above the limit which is 100 mg/kg. The concentrations of chromium in Onion leaves (3.72 mg/kg), onions (4.65 mg/kg), lettuce (4.89 mg/kg), green beans (5.89 mg/kg) and bell peppers (3.56 mg/kg) were concentrations above the limit established by the FAO/WHO, which is 2.3 mg/Kg. The concentrations of lead in carrot, onion leaf, onion, lettuce, green bean and bell pepper were above the limit proposed by FAO/WHO.

The bioconcentration factors show that the onion leaf (0.731), onion (0.929), lettuce (0.876), green bean (0.987) and bell pepper (0.858) are the plants which accumulate zinc and the carrot (0.524) accumulates nickel. The bioaccumulation of the metals in the vegetable from Loumbila market gardening decreased in the order of Onion > lettuce > green bean > bell pepper > onion leaves > carrot.

Keywords: Heavy Metal, Concentration, Bioconcentration factor, soil, plant

I. Introduction

In countries witnessing rapid industrialization, one of the most pressing environmental issues challenging the global sustainable development agenda is environmental pollution due to toxic metals. Metal pollutants gain entry into the air, soil, and water bodies via natural and anthropogenic routes, including domestic and agricultural use, metals mining and smelting activities, and other industrial productions [1]. Rapid industrialization, inappropriate utilization and disposal of toxic trace metal containing wastes, excessive use of fertilizers and pesticides are the main causes of toxic trace metals in agricultural soils, which become hazardous to human and environmental health. The main heavy that contribute to environmental pollution, particularly in areas with high anthropogenic activities are lead (Pb), cadmium (Cd), nickel (Ni), cobalt (Co), iron (Fe), zinc (Zn), chromium (Cr). The capacities of heavy metal uptake and accumulation, mechanisms of metal concentration, exclusion and compartmentation vary among different plant species and also between various parts of plants [2, 3].

The problem of contaminated soil on the perimeters of market gardening is very worrying today in urban cities for emerging countries. Heavy metals such as lead, cadmium, copper, zinc and mercury cannot be biodegraded and therefore persist in the environment for long periods of time. The accumulation of heavy metals in the environment can affect human and animal health
[4]. Understanding the origin of heavy metal pollution, the phenomenon of accumulation in soils, and their possible interactions with soil constituents is a priority in many environmental studies. The accumulation of heavy metals in agricultural soils presents an increasing risk of food pollution and a potential risk to human health [5].

The use of waste water can increase the crop productivity, but also increases the contamination of heavy metals (Pb, Ni, Cd, Cu, Zn, Mn, Cr…) in the plants. The plants (Amaranthus , Fenugreek and Spinach) heavy metals concentrations depend on the soil concentration [6] [7]. The vegetable from the contaminated soil can accumulate some high concentration of heavy metal and cause some serious risk to human health [8]. As an example, [9] John et al. , show that the vegetable and the soil from Kaduna city are polluted by Pb, Cd and Cr [9]. The concentration of Pb in cabbage, (10.51), lettuce (10.19), green pepper (9.44), hot pepper (7.61) and ayoyo (9.05) from some parts of Accra were higher than the FAO/WHO maximum recommended limit of 0.30 mg/kg for Pb [10].

The concentration of cadmium (Cd), lead (Pb) and chromium (Cr) in vegetable species (Telferia occidentalis, Talinum triangulare, Ocimum gratissimum, Celosia argentea, and Amaranthus viridis) cultivated in Lagos farmlands and floodplains, were above standard limit [11]. Heavy metals in plants can accumulate in the human body and cause diseases such as Colon, stomach, liver, lung, bladder and kidney cancers [12] [13] [14].

Trace metal elements contained in wastewater are toxic and non-biodegradable substances that accumulate in the soil and, depending on biogeochemical conditions, can lead to soil degradation [15]. Studies show that even treated wastewater also contains heavy metals that can contaminate crops when used for irrigation [16].

Metal elements such as Fe, Zn, Mo, Cu, Co and Cr are known to be essential elements in the living organism. However, a high concentration can be potentially toxic [17].

Pollution can be due on the one hand to the use of wastewater for irrigation and on the other hand to the proximity of the production sites of major urban traffic axes and industries that emit heavy metals [18]. The accumulation of heavy metals in soil can be due to the irrigation water and thereafter contaminate the vegetable and fruit. Heavy metal concentrations in vegetable are different to those of the fruits that reveal the difference between their capacities of accumulation
[19].

The contamination of soils, plants and water by heavy metals constitutes an important public health issue which requires more information on the various sources of pollution and on the rate of contamination. Preliminary studies on heavy metal pollution in the market gardening areas of Ouagadougou and Loumbila have revealed a deterioration in soil quality [20]. Concentration values of certain metals (Cr, Mn, Ni and Hg) in irrigation water were found to be above standards. A high concentration of chromium was observed in tomato [21]. The alert resulting from this study on the potential risk of pollution of agricultural soils and transfer of pollutants into the food chain justifies the need to continue studies on the market gardening areas of Ouagadougou and Loumbila on other plants.

The bioconcentration factor (BCF) for the heavy metals in the leafy vegetables decreased in the order of Cd (5.85) > Hg (3.83) > Fe (0.31) > Zn (0.11) > Cr (0) = Ni (0). The capacity of leafy vegetables to accumulate Fe, Cd, Zn, Cr, Ni, and Hg decreased in the order of

Amaranthus spinosa > Corchorus olitorious > Brassica oleracea > Brassica rapa. In the non-leafy vegetables, the BCF decreased in the order of Hg (2.46) > Zn (0.12) > Fe (0.1) > Cd (0) = Cr (0) = Ni (0). The capacity of non-leafy vegetables to accumulate Fe, Cd, Zn, Cr, Ni, and Hg decreased in the order of Daucus carota > Raphanus sativus > Allium cepa ~ capsicum annuum. The low BCF for Cr and Ni in all vegetable species maybe due to their toxicity of the crops [22].
Based on the work carried out on heavy metals in plants in West Africa (Ghana, Nigeria, etc.) in general and in Burkina Faso in particular, this study focused on copper (Cu), chromium (Cr), zinc (Zn), lead (Pb), nickel (Ni), and cadmium (Cd) in the most consumed plants [10] [11] [20].
The objective of this study is to estimate the concentration of heavy metals (Cu, Cr, Zn, Pb, Ni, and Cd) in soil and vegetables at the Loumbila market gardening sites and evaluate bioconcentration factor.

II. Materials and methods

II.1. Study Area

In this study, the vegetables samples were collected in different agricultural areas at Loumbila market garden. Distance of 18 kilometers from Ouagadougou capital city of Burkina, Loumbila market garden is expanding around the dam. The dam is located at a longitude of 01˚24'07.4 West and a latitude of 12˚29'35.8 North with the water capacity of 42.2 million cubic meter. It is used by market gardeners to irrigate the plants [23].
Loumbila's market gardening areas have a much diversified production of vegetables, namely onion, tomato, okra, zucchini, African eggplant, eggplant, pepper, bell pepper, lettuce, cabbage, carrot, green bean, and potato. Market garden products from Loumbila can be found in most markets in the city of Ouagadougou or exported to neighboring countries. These reasons led to the choice of the Loumbila market gardening areas to carry out this study, by choosing the most consumed vegetables in the city of Ouagadougou.

II.2. Samples and Sampling Techniques

The samples of soils and vegetables were collected from the market garden of Loumbila.
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 plastic bags.

Sampling was carried out at regular intervals and over the entire plot for each type of sample. The different plants were sampled by separating the different plant tissues (roots, leaves, stems and fruits) of each plant using a ceramic knife to avoid contamination. To measure an average concentration, at the plot level, the samples were mixed by family and constitute an aliquot. Plant samples for analysis of heavy metal were placed in plastic bags.
The vegetables were washed up with tap water thoroughly to remove the attached dust particles, soil, unicellular algae, etc. Then they were washed with distilled water and finally with deionized water. The washed vegetables were dried at room temperature to remove surface water.

Carrot, onion leaves, onion, lettuce, green beam and bell pepper were collected during the vegetable sampling.

II.3. Laboratory Analysis

The soils and vegetables samples were analysed for heavy metals such as chromium (Cr), zinc (Zn), lead (Pb), nickel (Ni), cadmium (Cd), and Mercury (Hg) using Atomic Absorption Spectrometer, model PERKIN ELMER AANALYST 200.

Mechanical preparation consisted of sieving the soil samples through a certified 200 mesh (75 micron) sieve. The test portion used is one gram. The soils samples were weighed using a PA214C balance from OHAUS PIONEER, precision 10^{-4} gram and capacity 200g. The mineralization consisted in mineralizing the samples weighed by aqua regia (2.5 mL of HNO_3 + 7.5 mL of HCl) at controlled temperature (water bath at 90 ± 50°C) for one hour. The acids used are of the analytical type. The solution obtained is consequently brought to 100 mL by way of demineralized water with a conductivity of less than 2 µS / cm.
The vegetable sample (1 g) were weighed into a 100 ml volumetric flask and concentrated acids of 10.0 mL of concentrated sulfuric acid were added to each sample. The samples obtained after adding concentrated acid were gently on a hot plate, stirring occasionally until the powder completely dissolved in the solution (about 10 to 15 minutes). Then 10ml of distilled water was added and the whole was heated gently for a few minutes (5 to 10 mins). Finally, the solution was left to stand for it to settle well and the filtrate was taken for analysis.
The analysis results are valid on the basis of the performance of the analysis methods used (limit of detection and quantification, data of duplicates and reference materials inserted in the chemical preparation of the samples, selectivity of the method, the robustness of the method, data for control solutions, data for chemical blanks, etc.).

II.4. Bioconcentration factor

Bioconcentration factor (BCF) is defined as the ratio of the metal concentration in plant to the metal concentration in the soil. BCF measure the heavy metal accumulation efficiency in plants. When the BCF values greater than 1, indicates that the species is a hyperaccumulator of Heavy Metal [1-3 ; 22; 24-25].

$$\boldsymbol{BCF = \frac{heavy\ metal\ concentration\ in\ plant}{heavy\ metal\ concentration\ in\ soil}}$$

III. Results and discussions

III.1. Concentration of heavy metals in agricultural soils

Table 1 presents the concentrations of Cu, Ni, Cr, Cd, Pb and Zn in some market gardening soils at Loumbila. The soils were taken according to the plant produced. The soils for the production of onions, green beans, lettuce, carrots and bell peppers the subject of this study.

Table 1: Concentration of some heavy metals in the market gardening soils of LOUMBILA

	Concentration in ppm (mg/kg)					
	Cu	**Ni**	**Cr**	**Cd**	**Pb**	**Zn**
Soil of onion and green beans	**34**	**29**	**83**	**ND**	**118**	**79**
Soil of Lettuce	**35**	**24**	**69**	**ND**	**46**	**80**
Soil of bell pepper	**33**	**22**	**66**	**ND**	**82**	**82**
Soil of carrot	**34**	**21**	**62**	**ND**	**178**	**90**
Soil of pepper	**51**	**19**	**175**	**ND**	**135**	**107**
Average	**37.4**	**23**	**91**	**ND**	**111.8**	**87.6**
Limits values	**100**	**50**	**150**	**3**	**100**	**300**

The copper concentrations in the studied soils vary from 33 mg/kg to 51 mg/kg with an average of 37.4 mg/kg. The copper concentrations obtained in this study were all below the limit value for copper in agricultural soils.

The studied soils present nickel concentrations which were between 19 mg/kg and 29 mg/kg with an average of 23 mg/kg. The limit value for nickel in soils is 50 mg/kg, which is higher than the values obtained in this study.

On the soil where the pepper was grown, the concentration of chromium was 175 mg/kg, which is higher than the concentration limit which is 150 mg/kg. The other soils had chromium concentrations below the limit. This high concentration of chromium in soil can lead to a high concentration of chromium in the pepper.

In all soil samples analyzed in this study, the cadmium concentration was below the detection limit.

The concentration of zinc in soils varies between 79 mg/kg and 107 mg/kg with an average of 87.6 mg/kg. The zinc concentrations in the studied soils were below the limit of 300 mg/kg.

The results of this study show that the concentrations of lead in the soils of onion, green bean, carrot and pepper were above the limit which is 100 mg/kg. These high lead concentrations in soils can lead to high concentrations of lead in onions, green beans, carrots and peppers. Lead concentrations in lettuce and pepper soils were below the limit.

The mean concentration of heavy metals in the agricultural soils samples from Loumbila market gardening decreased in the order Pb > Cr> Zn > Cu > Ni > Cd.

III.2. Concentration of heavy metals in some plants

Table 2 presents the concentrations of Cu, Ni, Cr, Cd, Pb and Zn in carrot, onion leaf, onion, lettuce, green bean and bell pepper sampled from some soils of Loumbila.

Table 2: Concentrations of heavy metals in the studied plants

	Concentration in ppm (mg/kg)					
	Cu	**Ni**	**Cr**	**Cd**	**Pb**	**Zn**
Carrot	**17.6**	**11**	**1.3**	**ND**	**27.02**	**42.95**
Onion leaves	**16.4**	**11.16**	**3.72**	**ND**	**10.48**	**57.72**
Onion	**19.81**	**10.05**	**4.65**	**ND**	**11.52**	**73.37**
Lettuce	**16.9**	**5.09**	**4.89**	**ND**	**15.44**	**70.1**
Green bean	**16.06**	**8.58**	**5.89**	**ND**	**4.09**	**78**
Bell pepper	**19.65**	**7.01**	**3.56**	**ND**	**1.73**	**70.39**

Average	**17.74**	**8.82**	**4.00**	**ND**	**11.71**	**65.42**
FAO/WHO safe limit	**40**	**-**	**2.3**	**0.2**	**0.3**	**20**

The concentrations of copper in the studied plants vary from 16.06 mg/Kg to 19.81 mg/Kg. All measured concentrations in the studied plants were below the limit established by the FAO/WHO.
The concentrations of chromium in the studied plants vary from 1.3 mg/Kg to 5.89 mg/Kg. Onion leaves, onions, lettuce, green beans and bell peppers have chromium concentrations above the limit established by the FAO/WHO, which is 2.3 mg/Kg. Carrots have a chromium concentration lower than the limit established by the FAO/WHO. Consumption in large quantities of onion leaf, onion, lettuce, green bean and pepper from the study area can be the cause of diseases such as stomach cancer, intestine, … [14].
Concentrations of lead in carrot, onion leaf, onion, lettuce, green bean and bell pepper were above the limit proposed by FAO/WHO. The high concentrations may be due to the high concentrations of lead observed in crop soils. The lettuce growing soil had a lead concentration below the limit whereas the lettuce leaves have a lead concentration above the FAO/WHO limit. This high concentration of lead in lettuce leaves may be due to the fact that lettuce is accumulating lead. Consumption in large quantities of these products from the study area can be the cause of cardiovascular disease (hypertension), kidney damage [12], liver disease [14].
The concentrations of zinc in carrot, onion leaf, onion, lettuce, green bean and pepper were higher than the limit proposed by the FAO/WHO although the concentrations in the soils were lower. These high concentrations of zinc in carrots, onion leaves, onions, lettuce, green beans and bell peppers show that the studied plants were hyper-accumulators of zinc.
The mean concentration of heavy metals in the edible portions of the vegetables decreased in the order Zn > Cu > Pb > Ni > Cr > Cd.

III.3. Soil-plant concentration

Figure 1 presents a histogram comparing the concentrations of copper, nickel, chromium, cadmium, lead and zinc in the carrot and its cultivation soil.

Figure 1: Concentration of heavy metals in the carrot and its cultivation soil

The concentration of lead was the highest in carrot cultivation soil, while zinc is the metal with the highest concentration in carrot. Carrots accumulate less chromium than the other heavy metals studied.
Figure 2 presents a histogram comparing the concentrations of copper, nickel, chromium, cadmium, lead and zinc in lettuce and its growing soil.

Figure 2: Concentration of heavy metals in lettuce and its growing soil

Zinc has a high concentration in lettuce and in its growing soil. Chromium has a fairly high concentration in soil, while its concentration in lettuce is the lowest. This reflects a high absorption of zinc and a low absorption of chromium by lettuce.

Figure 3 presents a histogram of the concentrations of heavy metals in green beans and their cultivation soil.

Figure 3: Concentration of heavy metals in green beans and their growing soil

Lead has a high concentration in green bean soil but a low concentration in green bean. Zinc has a high concentration in green beans and very close to the soil concentration. This reflects a high absorption of zinc and a low absorption of lead by the green bean.

Figure 4 presents a histogram of the concentrations of heavy metals in the pepper and its cultivation soil.

Figure 4: Concentration of heavy metals in bell pepper and its growing soil

Zinc has a high concentration in the pepper and in its cultivation soil. Lead has a fairly high concentration in soil, while its concentration in pepper is the lowest. This reflects a high absorption of zinc and a low absorption of lead by the bell pepper.

Figure 5 presents a histogram comparing the concentrations of copper, nickel, chromium, cadmium, lead and zinc in the onion, these leaves and its cultivation soil.

Figure 5: Concentration of heavy metals in onion, onion leaves and growing soil

Onion growing soil has a high lead concentration and a low nickel concentration. Onion leaves have a high zinc concentration and a low chromium concentration. Onion has a high zinc concentration and a low chromium concentration. This reflects a high absorption of zinc and a low absorption of chromium by the onion and these leaves. The onion accumulates more copper, chromium, lead and zinc than these leaves. As for onion leaves, they accumulate more nickel.

The results of soil and plant concentrations show that zinc is the heavy metal that accumulates the most in onion leaf, onion, lettuce, green bean and pepper. Lead and chromium accumulate less in most studied plants.

III.4. Bioconcentration factor

Table 3: heavy metal Bioconcentration factor

	Cu	Ni	Cr	Pb	Zn
Carrot	**0.518**	**0.524**	**0.021**	**0.152**	**0.477**
Onion	**0.583**	**0.347**	**0.056**	**0.098**	**0.929**
Onion leaves	**0.482**	**0.385**	**0.045**	**0.089**	**0.731**
Lettuce	**0.483**	**0.212**	**0.071**	**0.336**	**0.876**
Green Bean	**0.472**	**0.296**	**0.071**	**0.035**	**0.987**
Bell pepper	**0.595**	**0.319**	**0.054**	**0.021**	**0.858**

Table 3 presents the bioconcentration factors of copper, nickel, chromium, lead and zinc in carrot, onion leaf, onion, lettuce, green bean and bell pepper.

The carrot has a bioconcentration factor which varies from 0.021 to 0.524. The most accumulative metal in the carrot was nickel.

The bioconcentration factor ranges from 0.056 to 0.929 in onion and ranges from 0.045 to 0.731 in onion leaves. The most accumulative metal in the onion and in the leaves is zinc, which has a bioconcentration factor close to one in the fruit. This reflects a strong transfer of zinc from the soil to the plant.

In lettuce, the bioconcentration factor ranges from 0.071 to 0.876. The most accumulating metal in lettuce was zinc.

Green beans have a bioconcentration factor that varies from 0.035 to 0.987. The most accumulative metal in the green bean is zinc, which has a bioconcentration factor roughly equal to one. This reflects a strong transfer of zinc from the soil to the green bean.

The bioconcentration factor varies from 0.021 to 0.858 in bell pepper. The most accumulative metal in bell pepper was zinc.

The bioconcentration factors show that the onion leaf, onion, lettuce, green bean and pepper are the plants which accumulate zinc and the carrot accumulates nickel.

The bioaccumulation of the metals in the vegetable from Loumbila market gardening decreased in the order of Onion > lettuce > green bean > bell pepper > onion leaves > carrot.

IV. Conclusion

This study has revealed that the concentrations of lead in the soils of onion, green bean, carrot and pepper are above the limit which is 100 mg/kg. These high lead concentrations in soils can lead to high lead concentrations in onions, green beans, carrots and peppers. Lead concentrations in lettuce and pepper soils are below the limit.

The values of the bioaccumulation show that the onion leaf, onion, lettuce, green bean and bell pepper were the plants which accumulate zinc and the carrot accumulates nickel.
The mean concentration of heavy metals in the agricultural soils samples from Loumbila market gardening decreased in the order Pb > Cr> Zn > Cu > Ni > Cd. The mean concentration of heavy metals in the edible portions of the vegetables decreased in the order Zn > Cu > Pb > Ni > Cr > Cd. For the individual vegetables, the bioaccumulation of the metals in the edible parts decreased in the order of Onion > lettuce > green bean > bell pepper > onion leaves > carrot.

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