International Journal of Physics, 2021, Vol. 9, No. 4, 211-217
Available online at http://pubs.sciepub.com/ijp/9/4/4
Published by Science and Education Publishing
DOI:10.12691/ijp-9-4-4

Influence of Arsenic, Chromium, Mercury and Lead Concentrations in Irrigation Water on the Evolution of Heavy Metals Concentration in Soil

Bambara Telado Luc[1,*], Derra Moumouni[2], Kaboré Karim[3], Ousmane I. Cissé[4], Francois Zougmoré[4]

[1]Physics and chemical, Department, Institute of Sciences, Ouagadougou, Burkina Faso
[2]Physics Department, University Norbert Zongo, Koudougou, Burkina Faso
[3]Physics Department, Virtual University, Ouagadougou, Burkina Faso
[4]Physics Department, University Joseph KI-ZERBO, Ouagadougou, Burkina Faso
*Corresponding author: telado.luc.bambara@gmail.com

Received May 17, 2021; Revised June 21, 2021; Accepted July 01, 2021

Abstract The market gardening in developing countries plays a huge important socioeconomic role in confronting the challenge of eradicating hunger, improving food security and the social daily life of the population. However, the quality of agricultural soils and irrigation is important to guarantee a good quality of market garden products. The purpose of this study was to investigate the concentration of metals (Cr, Pb, As and Hg) in irrigation water and soils from Loumbila, Goudrin et Paspanga, and simulate concentration evolution over the time in soil, in order to evaluate the potential impact of irrigation water. The research was conducted in four sites characterized by intensive market gardening performed. The results show that the concentrations of Cr, Pb, As and Hg in soils were lower than the recommended limit. The average heavy metals concentration in the irrigation waters from Loumbila was 0.116 ± 0.028 mg/L for Cr, 0.272 ± 0.004 mg/L for Pb, 0.016 ± 0.004 mg/L for As and 0.034 ± 0.002 mg/L for Hg. The average concentrations of the irrigation waters of Paspanga 1 were 0.016 ± 0.004 mg/L for Cr, and 0.092 ± 0.001 mg/L for Pb. The concentrations of Cr, Pb, As and Hg detected in the waters of Paspanga 2 were below the limit accepted by FAO. In Goudrin irrigation water only lead was detected with average concentrations of 0.086 ± 0.006 mg/L. The average concentrations of Cr, and Hg in irrigation water from Loumbila were above the accepted limit established by the FAO. The heavy metal concentration in irrigation water contribute to increases the heavy metal concentration in soil.

Keywords: *heavy metal, concentration, influence, irrigation water, simulation*

Cite This Article: Bambara Telado Luc, Derra Moumouni, Kaboré Karim, Ousmane I. Cissé, and Francois Zougmoré, "Influence of Arsenic, Chromium, Mercury and Lead Concentrations in Irrigation Water on the Evolution of Heavy Metals Concentration in Soil." *International Journal of Physics*, vol. 9, no. 4 (2021): 211-217. doi: 10.12691/ijp-9-4-4.

1. Introduction

Heavy metals occur naturally in the ecosystem with large variations in concentrations. In modern times, anthropogenic sources of heavy metals, activities of humans, have introduced some of these heavy metals into the ecosystem. The presence of heavy metals in the environment is of great ecological significance due to their toxicity at certain concentrations, translocation through food chains and non-biodegradability which is responsible for their accumulation in the biosphere [1].

Irrigation water contaminated with industrial wastewater has caused significant heavy metal contamination in soils and crops. If soil is irrigated with wastewater, heavy metal concentration will be high in the edible parts of growing plants [2,3]. Due to unplanned industrialization and urbanization in the country, wastewater contaminated with heavy metals is continuously released into irrigation canals, thus soil and crops are contaminated with heavy metals, and many people consume the contaminated crops after they have been transported and sold in retail markets, and thus face the risk of health problems [3,4].

The use of heavy metal-contaminated water in agricultural field's leads to soil pollution and gradually enriching the soil. Many studies have revealed that the presence of iron (Fe), lead (Pb), mercury (Hg) reduce soil fertility and agricultural output [5].

Heavy metals can accumulate in the soil at toxic levels due to the long-term application of wastewater [6].

Water is an important resource that can cause nuisance in receiving environments and health risks for populations who are in permanent contact with or who consume agricultural products irrigated with this water. Water, rich in organic matter and fertilizing elements, however contain undesirable chemical elements, in particular metallic pollutants, which can accumulate in the soil and, depending on the biogeochemical conditions [7]. Agricultural soils can be contaminated via atmospheric deposition of heavy metals from factories, vehicle exhaust, and other sources; application of chemical and organic fertilizers, irrigation water and pesticides; and tanning stones that contain high levels of heavy metals [8,9].

The accumulation of heavy metals in agricultural soils deteriorate the food quality and of increases potential health risks [5,10].

In Ouagadougou, urban agriculture sites meet along the city's hydrographic network (dams, ditches, central canal, temporary or permanent backwaters, etc.) and even all around wastewater discharges [11]. Therefore an estimation of the water concentration influence on the soil concentration and a study the evolution of the concentration heavy metals in the soil can be particularly important questions for the assessments of agricultural soils contamination.

2. Materials and Methods

2.1. Study Area

In this study, four areas were chosen for the collection of agricultural soil and water samples, which are the market gardening areas of Loumbila, Goudrin and Paspanga 1 and 2.

Located 18 km northeast of Ouagadougou, the capital of Burkina Faso, Loumbila market gardening area stretches along the dam. Loumbila dam is located at longitude 01° 24'07.4 West and 12° 29'35.8 North and with a capacity of 42.2 million m^3. It is used by market gardeners for watering their plants [12].

The Goudrin market garden area is a perimeter developed for market gardening and located at the following geographical position: longitude 01° 27'25.39 West and latitude 12° 22'56.44 North. It is fed by a borehole and has an area of approximately one (1) hectare.

The Paspanga 1 market garden area is located in Ouagadougou behind the Yalgado Ouedraogo Teaching Hospital with an area of approximately one hectare. It is irrigated with water from a traditional well dug about 2 meters from the hospital's wastewater pipe.

The Paspanga 2 market gardening area is located in Ouagadougou on the outskirts of Tanghin dam number 3 with an area of approximately 5.3 hectare. It is irrigated with water from the dam. The retention capacity of the three dams of Ouagadougou is 5,235,500 m^3 [11].

In this study, eighteen (18) soil samples (4 in Loumbila, 2 in Goudrin, 2 in Paspanga 1 and 10 in Paspanga) and eight (8) water samples (2 in Loumbila, 1 in Goudrin, 2 in Paspanga 1 and 3 in Paspanga 2) were used.

2.2. Determination of Heavy Metal in Samples

The heavy metal concentration in this study were determined by atomic absorption spectrometry. The study focuses on chromium, lead, arsenic and mercury.

The vegetable sample(0.5g) were weighed into a 100ml polytetrafluo-roethylene (PTFE) Teflon tube and concentrated acids of 6.0 mL of concentrated nitric acid (HNO_3, 65%) and 1.0 mL of Hydrogen peroxide (H_2O_2,30%) were added to each sample. The samples were then loaded on the microwave carousel. The vessel caps were secured tightly using a wrench. The complete assembly was microwave irradiated for 25 minutes using milestone microwave Labstation ETHOS 900, INSTR: MLS-1200 MEGA.

The soil sample(1.5g) were weighed into a 100ml polytetrafluo-roethylene (PTFE) Teflon tube and concentrated acids of 6mL of concentrated nitric acid (HNO_3, 65%), 3mL of concentrated hydrochloric acid (HCl, 35%) and 0.25mL of Hydrogen peroxide (H_2O_2, 30%) were added to each sample. The samples were then loaded on the microwave carousel. The vessel caps were secured tightly using a wrench. The complete assembly was microwave irradiated for 26 minutes using milestone microwave Labstation ETHOS 900, INSTR: MLS-1200 MEGA.

After digestion the Teflon tube mounted on the microwave carousel were cooled in a water bath to reduce internal pressure and allow volatilized material to re-stabilize. The solution was then diluted to 20 ml with distilled water and assayed for the presence of elements (Zn, Pb, Mn...) using VARIAN AA 240FS- Atomic Absorption Spectrometer in an acetyleneair flame. The metal final concentration was calculated using the following formula:

$$C_f \text{ (mg/kg)} = \frac{C_m * D_f * V_m}{S_w \text{ (g)}} \quad (1)$$

With C_f: Final concentration; C_m: metal concentration; D_f: dilution factor; V_m: nominal volume; S_w: sample weight.

2.3. Simulation of the Heavy Metal Concentration Evolution in Soil

MATLAB R2009b software was used in this study for the simulation of heavy metal concentration evolution in soil. The pollutant concentration in the soil was calculated.

At time t, the pollutant concentration in the soil is given by the following differential equation [13]:

$$\frac{dC_{sol}(t)}{dt} = -k * C_{sol} + D_S \quad (2)$$

In this study, the assumption was the soil deposits come only from water used for irrigation. Based on this assumption:

$$D_S = \frac{C_{water} * Q_{water}}{\Pr . R_0} \quad (3)$$

With: C_{water} (M of pollutant. L^{-3}): pollutant concentration in irrigation water

Q_{water} (L^3 / L^2): quantity of water supplied per year for the irrigation of 1 m^2 of soil

Pr (L): root depth (0.3m)

R_0 (M.L^{-3}): mass of dry soil per m^3 of soil in place (1500 kg / m^3)

In this study, the amount of water supplied per year for the irrigation of 1 m^2 of soil was determined by carrying out an investigation of the studied areas. The investigation allowed us to determine the average amount of water used per day, the area of irrigated perimeters, the number of seasons and the duration of a season. From the information collected during the investigation, the quantity of water supplied was calculated for each areas and the average was calculated [14].

The heavy metals concentration in the soil was determined using the following formula:

$$C_{soil}(t) = \frac{C_{water} * Q_{water}}{\Pr.R_0.\lambda_m} * (1 - \exp(-\lambda_m * t)) + C_{soil}(0) \quad (4)$$

With λ_m (T^{-1}): decay constant by migration in the soil.

The values of the decay constant by migration in the soil for some metals are given in Table 1.

Table 1. values of the decay constant by migration in the soil

Heavy Metal	Decay constant by migration in the soil in s^{-1}
Arsenic (As)	$2{,}2.10^{-10}$
Chromium (Cr)	$6{,}6.10^{-10}$
Mercury (Hg)	$2{,}2.10^{-10}$
Lead (Pb)	$1{,}2.10^{-12}$

Source: http://archives.invs.sante.fr/publications/2005/dechets/pdf/annexe8.pdf.

3. Results and Discussions

3.1. Concentrations of Cr, Pb, As, and Hg in the Water and Soils of the Study Areas

Table 2. Average concentration of heavy metals in the soil and water in the study areas

Sites	Samples	[Cr]	[Pb]	[As]	[Hg]
Loumbila	Soil (mg/kg)	2.98	5.7525	1.35	0.06
	Water (mg/l)	0.116	0.272	0.016	0.034
Paspanga 1	Soil (mg/kg)	5.79	5.94	1.34	0.06
	Water (mg/l)	0.016	0.092	0.004	0.004
Paspanga 2	Soil (mg/kg)	3.446	7.147	0.495	0.033
	Water (mg/l)	75.10^{-5}	0.0168	75.10^{-5}	75.10^{-5}
Goudrin	Soil (mg/kg)	2.667	1.893	1.567	0.073
	Water (mg/l)	0.004	0.086	0.008	0.004
Recommended limit [15,16,17]	Soil (mg/kg)	150	100	40	-
	Water (mg/l)	0.1	5	0.1	0.001

Table 2 gives the average concentration of heavy metals in the soils and waters from Loumbila, Goudrin and Paspanga. These results show that the concentrations of Cr, Pb, As and Hg in soils were lower than the recommended limit (150ppm for Cr, 100ppm for Pb, 40ppm arsenic) [18].

The average heavy metals concentration in the irrigation waters from Loumbila was 0.116 ± 0.028 mg/L for Cr, 0.272 ± 0.004 mg/L for Pb, 0.016 ± 0.004 mg/L for As and 0.034 ± 0.002 mg/L for Hg. The results obtained show that the mean concentrations of Cr, and Hg were above the accepted limit established by the FAO [19]. Loumbila irrigation water can be the contamination source of soil and / or plant in Cr, and Hg.

The average concentrations of the irrigation waters of Paspanga 1 were 0.016 ± 0.004 mg/L for Cr, and 0.092 ± 0.001 mg/L for Pb. Arsenic and Mercury were of very low concentration. The concentrations of chromium and lead were below the limit accepted by the FAO [19].

The concentrations of Cr, Pb, As and Hg detected in the waters of Paspanga 2 were below the limit accepted by FAO [19].

In Goudrin irrigation water only lead was detected with average concentrations of 0.086 ± 0.006 mg/L. This Pb concentration detected in the waters of Goudrin was below the FAO limit [19].

These values were used to simulate the concentration of metals in the soil as a function of time under the influence of irrigation water.

3.2. Influence of Water Concentration in Soil Concentration

In this part, the influence of irrigation water on the soil concentration was determined using equation 4. The study was carried out in the Loumbila and Paspanga areas. In this case, the assumption was that water input per square meter is the same on both perimeters. And also that the only source of soil contamination is from the water used for irrigation.

The lead concentration in water and in soil samples from Loumbila and Paspanga was used to make the calculation. Initially the Pb concentration in the soil of Paspanga was greater than that of Loumbila. The lead concentration in water from Loumbila was greater than that of Paspanga. By performing on twenty years simulation, the Pb concentration at both sites increases under the influence of the water concentration. It can be seen on Figure 1 that after fourteen years the two soil concentrations are roughly equal. After 14 years, the concentration at the Loumbila site is higher than that of Paspanga, whereas it was lower before 14 years (Figure 1).

In conclusion, the use of water with high concentration of heavy metal very quickly influences the soil concentration. Over the twenty years, the Pb concentration in Loumbila soil will increase by 7% while that of Paspanga will increase by 2.4%.

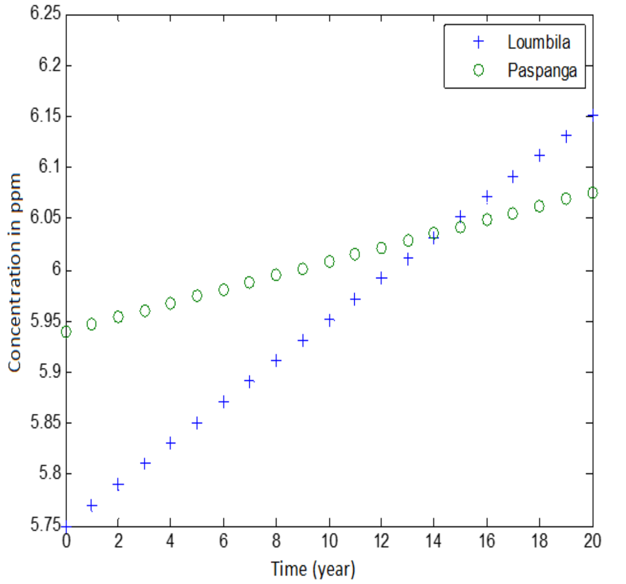

Figure 1. Evolution of the lead concentration over time in sol from the Loumbila and Paspanga

In conclusion, the concentrations of heavy metals in soils will change more rapidly in areas where irrigation water is more contaminated. Irrigation water contaminated cause significant heavy metal contamination in soils.

3.3. Study of the Evolution of the Concentration of Heavy Metals in the Soil

This study focused only on chromium, lead, arsenic and mercury. For the study of the evolution of the concentration of heavy metals in the soil over time, the simulation was done using equation (4) for calculating the concentrations of heavy metals with MATLAB software. To do this simulation, the average concentrations of heavy metals detected in the different study areas and the amount of water used per square meter were needed. To determine the amount of water used per square meter, an investigation of people cultivating market gardens was carried out. This investigation concerned twenty-six (26) people working in the market gardening areas in the city of Ouagadougou. The questions in this investigation were more oriented towards determining the area, the amount of water used throughout the perimeter, the use of fertilizers and pesticides. Secondary questions were asked of respondents to determine the amount of water such as: the number of cultivation culture board used by the person, the length and width of a culture board. From the answers obtained from the secondary questions, the surface area and the quantity of water used were calculated. Finally, the amount of water used per square meter was calculated by dividing the area by the amount of water used. The average of the quantity of water used per square meter for the 26 people investigated was used for the simulation of the concentration of metals in the soil. The amount of water per square meter found was 33.34 liters per square meter.

The evolution curves of the concentrations of heavy metals (Cr, Pb, As and Hg) in the Loumbila, Goudrin, Paspanga 1 and 2 soils are given in Figure 2 to Figure 5.

Figure 2 shows that the chromium concentration in the different study areas increases over time. This increase in the chromium concentration in the different areas is due to the significant chromium concentration in the water and the large water volume used per square meter of soil. The increase is much faster between zero and ten (10) years and becomes slow between ten (10) and twenty (20) years. After twenty (20) years the increase in concentration begins to become stable. The rate of increase is much greater at Loumbila and it may be related to the high concentration of Cr in the water. The concentration of chromium in water influences its concentration in the soil over 20 years and ultimately does not impact the soil after 20 years. After 20 years, the chromium concentration in the four study areas will remains below the limit imposed by the WHO. So the pollution coming only from the water used to irrigate is not enough to lead to pollution of market gardening soils. But it contributes to a degradation of soil quality.

The change in the concentration of lead over time in the different study areas is given in Figure 3. The Figure 3 shows an increase in the concentration of lead in the four areas. This increase in lead concentration varies depending on the area and the level of contamination of the water used. All these curves have two parts: one part where the concentration increases between zero and twenty years and another where the concentration is constant after 20 years.

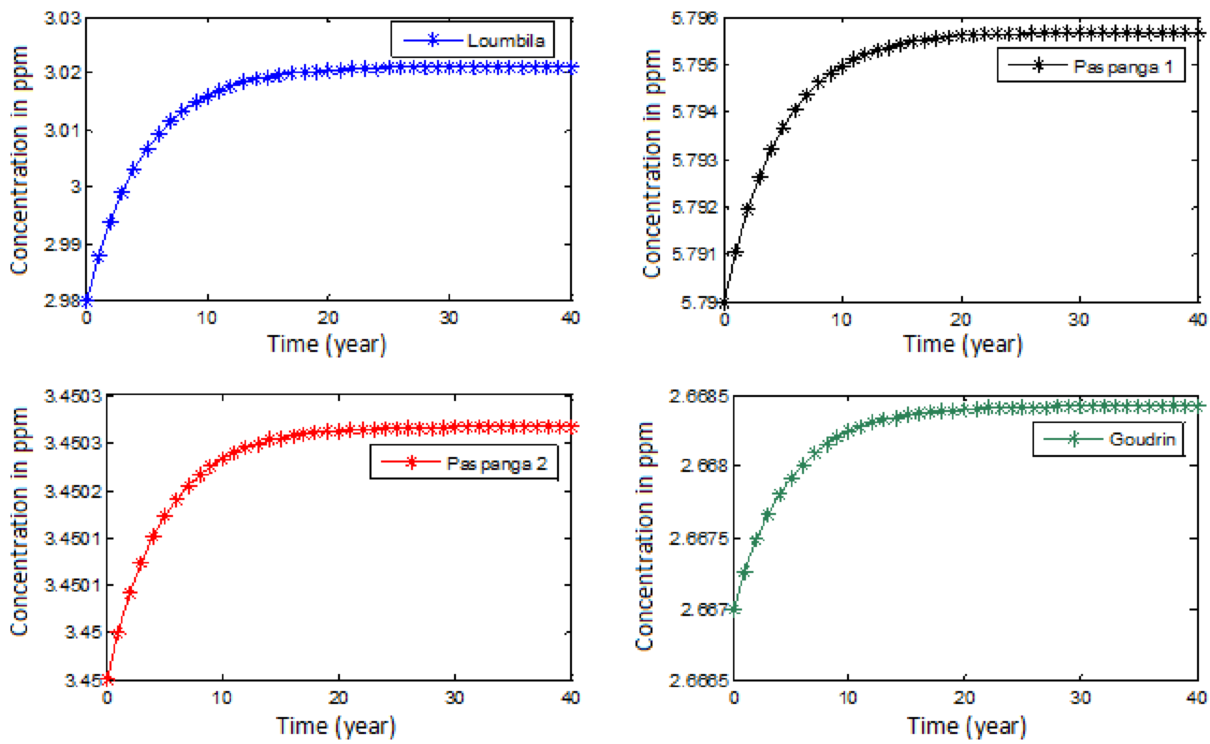

Figure 2. Evolution of chromium concentration in Loumbila, Goudrin and Paspanga 1 and 2 soils

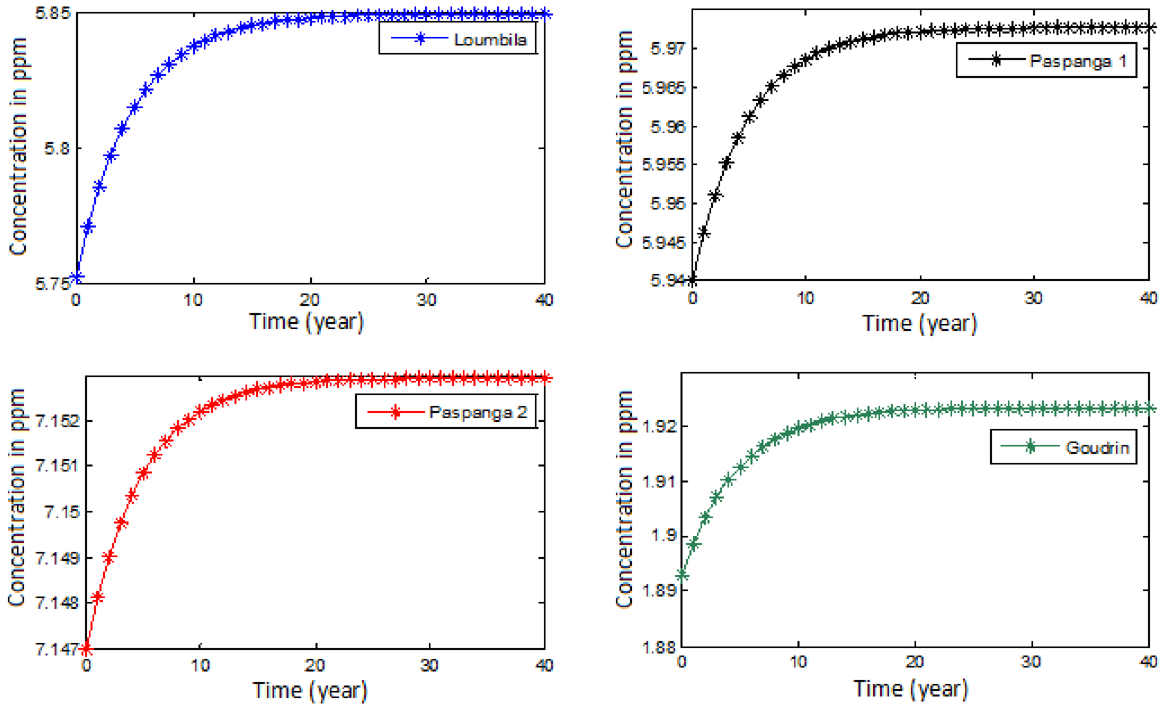

Figure 3. Evolution over time of the lead concentration in soils from Loumbila, Goudrin and Paspanga 1 and 2

This shows that after twenty years the concentration of water used to irrigate the soil no longer has any effect on the evolution of the soil concentration. The maximum lead concentrations after 40 years are as follows: 5.85ppm in Loumbila, 5.975 in Paspanga 1, 7.153ppm in Paspanga 2 and 1.922ppm in Goudrin. After 40 years, the lead concentrations in the four study areas are still below the limit imposed by the WHO. So the soil in the study areas will no longer be polluted with lead after 40 years if the source of pollution is only irrigation water of the same concentration as that detected in our study.

Figure 4 shows that the arsenic concentration in the different study areas increases over time. The Figure 4 shows an increase of the arsenic concentration in all studies areas. But this increase is very low and this is due to the low concentration of arsenic in the irrigation water of the areas. The concentration in soil become constant after twenty years.

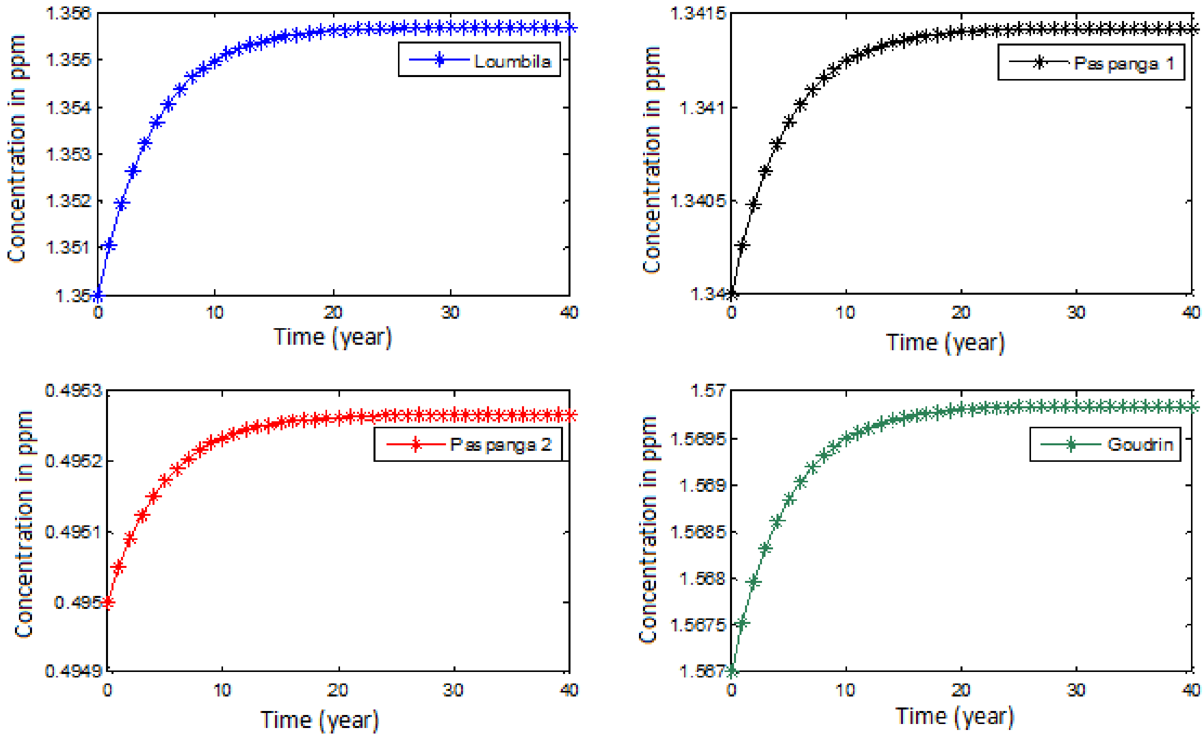

Figure 4. Evolution over time of arsenic concentration in soils from Loumbila, Goudrin and Paspanga 1 and 2

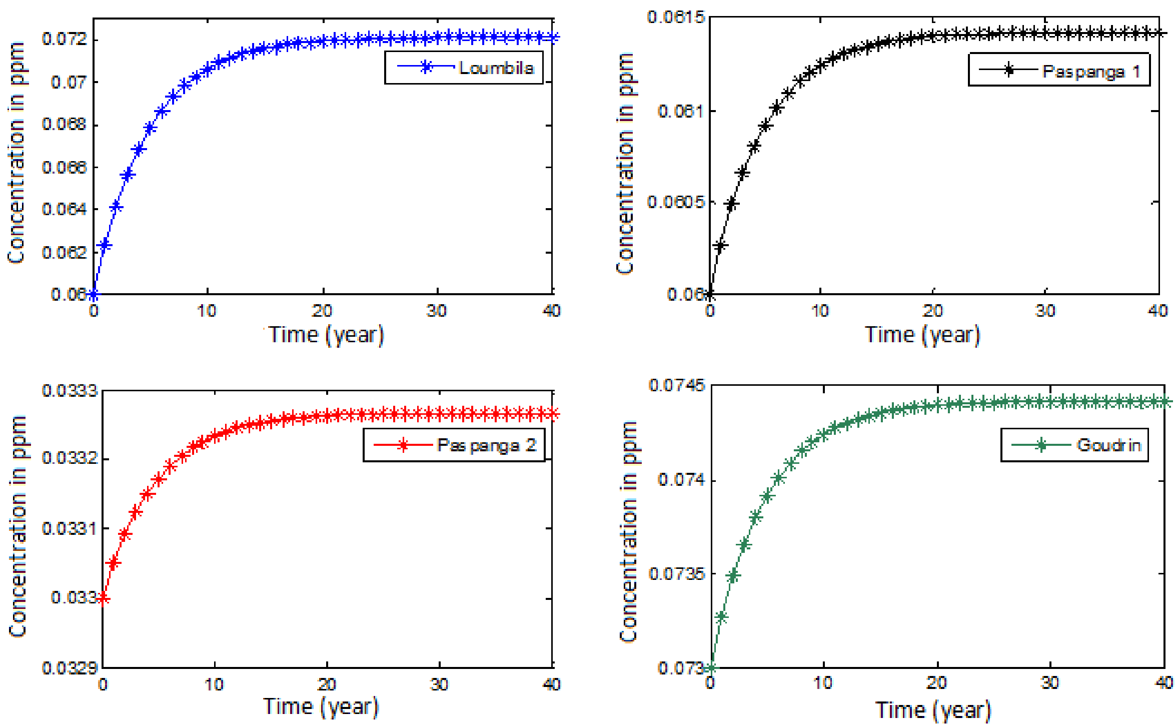

Figure 5. Evolution over time of the mercury concentration in soils from Loumbila, Goudrin and Paspanga 1 and 2

After 40 years, the arsenic concentration in soil from the four studies areas remains below the limit imposed by the WHO. So the pollution coming only from the water irrigation is not sufficient to cause pollution of market gardening soils. But it contributes to a degradation of soil quality.

The evolution of the mercury concentration over time in soil from Loumbila, Goudrin and Paspanga 1 and 2 is given by Figure 5. This figure shows an increase in the mercury concentration over the four areas. This increase of mercury concentration varies depending on the area and the level of contamination of the irrigation water. All these curves have two parts: one part where the concentration increases between zero and twenty years and another where the concentration is constant after twenty years. This shows that after twenty years the concentration of irrigation water no longer has any effect on the soil concentration evolution. The maximum mercury concentrations after 40 years were: 0.072ppm in Loumbila, 0.0615 in Paspanga 1, 0.0333ppm in Paspanga 2 and 0.0745ppm in Goudrin. After 40 years, the mercury concentrations in soils from Loumbila, Goudrin and Paspanga 1 and 2 are still below the limit imposed by the WHO. So the soil from Loumbila, Goudrin and Paspanga 1 and 2 will not be polluted with mercury after 40 years if the source of pollution is only irrigation water of the same concentration as that detected in our study.

Conclusion: The concentration of chromium, lead, arsenic and mercury increases with time until reaching a maximum value and becomes constant. The heavy metal concentration in irrigation water contribute to increases the heavy metal concentration in soil. In the study areas, the concentration of Cr, Pb, As and Hg in water from Loumbila, Goudrin, Paspanga 1 and 2 is not able to increase the soil concentration up to recommended limit.

4. Conclusion

This study revealed that the heavy metals concentrations in agricultural soils and irrigation water from Loumbila, Goudrin and Paspanga were the limits set by WHO. The heavy metals concentration in water influences that of the soil and the concentrations in soils will evolve more quickly in areas where irrigation water is more contaminated. The 40-years simulation of arsenic, chromium, mercury and lead concentration in soil from Loumbila, Goudrin and Paspanga sites show that the concentration increases slightly because of low concentration of heavy metals in irrigation water. This growth leads us to concentrations below the limits set by WHO after forty years and this if the pollution comes only from water at low concentrations. Although the concentration of chromium in Loumbila water exceeds the imposed limit, it does not allow the soil concentration to exceed the norm. This study shows that the contribution of water alone cannot lead to heavy metal pollution in agricultural soils.

References

[1] Opaluwa, O. D, Aremu, M. O, Ogbo, L. O, Abiola, K. A, Odiba, I. E, Abubakar, M. Ma. and Nweze, N.O, 2012. Heavy metal concentrations in soils, plant leaves and crops grown around dump sites in Lafia Metropolis, Nasarawa State, Nigeria. Pelagia Research Library, Advances in Applied Science Research, 2012, 3 (2): 780-784.

[2] Arora, M.; Kiran, B.; Rani, S.; Rani, A.; Kaur, B.; Mittal, N. Heavy metal accumulation in vegetables irrigated with water from different sources. Food Chem. 2008, 111, 811-815.

[3] Minhaz Ahmed, Masaru Matsumoto, Akinori Ozaki, Nguyen Van Thinh and Kiyoshi Kurosawa, 2019. Heavy Metal Contamination of IrrigationWater, Soil, and Vegetables and the Difference between Dry and Wet Seasons Near a Multi-Industry Zone in

Bangladesh. Water 2019, 11, 583, Licensee MDPI, Basel, Switzerland, Published: 20 March 2019.

[4] Ikeda, M.; Zhang, Z.W.; Shimbo, S.; Watanabe, T.; Nakatsuka, H.; Moon, C.S.; Matsuda-Inoguchi, N.; Higashikawa, K., 2000. Urban population exposure to lead and cadmiumin east and south-east Asia. Sci. Total Environ. 2000, 249, 373-384.

[5] Musa J. J., H. I. Mustapha, J. D. Bala, Y. Y. Ibrahim, M. P. Akos, E. S. Daniel, F. M. Oguche and I. A. Kuti, 2017. HEAVY METALS IN AGRICULTURAL SOILS IN NIGERIA: A REVIEW. Arid Zone Journal of Engineering, Technology and Environment, October, 2017; Vol. 13(5): 593-603 Copyright © Faculty of Engineering, University of Maiduguri, Maiduguri, Nigeria. Print ISSN: 1596-2490, Electronic ISSN: 2545-5818, www.azojete.com.ng.

[6] Rajesh, KS., Madhoolika, A., and Fiona, M., 2007. Heavy metal contamination of soil and vegetables in suburban areas of Varanasi, India. Ecotoxicology and Environmental Safety 66 (2007) 258-266.

[7] Kao Tomgouani, Khalid EL MEJAHED &Abderrahim BOUZIDI, “Evaluation de la pollution métallique dans les sols agricoles irrigués par les eaux usées de la ville de Settat (Maroc) ”, Bulletin de l’Institut Scientifique, Rabat, section Sciences de la Vie, n°29, pp.89-92, 2007.

[8] Aydinalp C., S. Marinova, 2003. Distribution and Forms of Heavy Metals in Some Agricultural Soils. Polish Journal of Environmental Studies Vol. 12, No. 5 (2003), 629-633.

[9] Neilson Sarah and Nishanta Rajakaruna, 2015. Phytoremediation of Agricultural Soils: Using Plants to Clean Metal- Contaminated Arable Land. A.A. Ansari et al. (eds.), Phytoremediation: Management of Environmental Contaminants, Volume 1, © Springer International Publishing Switzerland 2015, pp 159-168.

[10] Cui YL., Zhu, YG., Zhai, RH., Chen, DY., Huang, YZ., and Qiu, Y. 2004.Transfer of metals from soil to vegetables in an area near a smelter in Nanning, China. Environ. Int. 30:785-791.

[11] Kedowide Mevo Guezo Conchita G., 2011. “SIG et analyse multicritère pour l’aide à la décision en agriculture urbaine dans les pays en développement, cas de Ouagadougou au Burkina Faso”. Thèse Soutenue publiquement le 24 novembre 2011pour le grade de docteur de l’Université de Paris 8 p301.

[12] Doumtoudjinodji Prosper, 2007. “Renforcement des capacités des exploitants maraîchers: cas du village de Noungou dans le département de Loumbila”, mémoire présente a Institut International d’ingénierie en Eau et Environnement, p.124, 2007.

[13] Bonnard R. 2003. Evaluation de l'impact sur la santé des rejets atmosphériques des tranches charbon d'une grande installation de combustion. Partie 2: Exposition par voies indirectes: Ineris; 2003. Report No.: DRC-03-45956/ERSA-n°92-RBn-/GT-GICversion4.

[14] InVS (Institut de Veille Sanitaire), 2005. “Stockage des déchets et santé publique”. ISBN: 2-11-095110-9, Imprimé par : CARACTERE SAS - Aurillac, Dépôt légal : Mars 2005, p348.

[15] FAO, 1985.Water Quality for Agriculture. Food and Agriculture Organization, Rome, Italy http://www.fao.org/3/T0234E/T0234E00.htm.

[16] Ngweme Georgette N., Emmanuel K. Atibu, Dhafer Mohammed M. Al Salah, Paola M. Muanamoki, Guillaume M. Kiyombo, Crispin K. Mulaji, Jean-Paul Otamonga, JohnW. Poté, 2020. Heavy metal concentration in irrigation water, soil and dietary risk assessment of Amaranthus viridis grown in peri-urban areas in Kinshasa, Democratic Republic of the Congo. Watershed Ecology and the Environment 2 (2020) 16-24; journal homepage: www.elsevier.com/ locate/wsee

[17] Matech F., F. Zaakour, K. Moustarhfer, Z. Chemsi, “Concentrations en éléments traces métalliques dans les sols irrigués par les eaux usées versées dans L’OUED MERZEG (CASABLANCA -MAROC) ”, European Scientific Journal October 2014 edition vol.10, No.29 ISSN: 1857- 7881 (Print) e - ISSN 1857- 7431, 2014.

[18] Kebir Tahar, 2012. “Étude De Contamination, D’accumulation Et De Mobilite De Quelques Metaux Lourds Dans Des Legumes, Des Fruits Et Des Sols Agricoles Situes Pres D’une Decharge Industrielle De L’usine Alzinc De La Ville De Ghazaouet.”. These soutenue pour le grade de docteur de l’UNIVERSITÉ ABOU BEKR BELKAID -TLEMCEN p282.

[19] Ayers R.S. and Westcot D.W. - Water Quality for Agriculture. FAO irrigation and Drainage paper 29 (Revised). FAO, Rome, Italy, 1989. http://www.fao.org/docrep/003/t0234e/t0234e00.HTM.