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SPATIAL ANALYSIS OF HEAVY METALS IN AGRICULTURAL SOILS OF THE ATOYAC-ZAHUAPAN SUB-BASIN AND RISKS TO PUBLIC HEALTH

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ABSTRACT

In the Alto Balsas sub-basin in the states of Puebla and Tlaxcala, agricultural soils are irrigated with wastewater that has accumulated heavy metals. These compounds represent a health risk because they can be ingested, inhaled or absorbed and cause cancerous and non-cancerous diseases. The aim of this research was to determine the content of Cd, Pb, Cr and As in the agricultural soils of four irrigated areas: Tepetitla de Lardizabal, Nativitas, Santa Isabel Tetlatlahuca and Tecamachalco; asessments were made using an Inductively Coupled Plasma Optical Emission spectroscop (ICP-OES). The health risk for men, women and children was calculated using equations from the Unites Estates Environmental Protection Agency (USEPA) and the extent of impact of soil contamination with heavy metals was calculated in terms of percentage by spatial analysis. Apparently, adults are at greatest risk and Cd and Cr are the most dangerous metals for the population. The method of exposure that represents the greatest risk for children was oral but among adults it was dermal. Cancer risk was greatest among adults, in descending order Cd>As>Cr>Pb. Regarding the aspect of affectation, 51 municipalities of the Alto Balsas and Valsequillo canal sub-basin are affected, where Cd, Pb and Cr were found in 100% and As in 99%, of the total surface.

Keywords: wastewater, pollution, cancer risk

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INTRODUCTION

Agricultural soils, irrigated with untreated wastewater represent a risk to public health, both for farmers and for the surrounding population (Mitra *et al.*, 2022). In the Alto Balsas sub-basin formed by the Atoyac and Zahuapan rivers in the states of Puebla and Tlaxcala, irrigation district No. 056 Atoyac-Zahuapan comprises the south-central region of Tlaxcala and No. 030 exists due to the "Valsequillo" dam in the state of Puebla. In this area, soils are irrigated with a mixture of wastewater from different sources. Those that present greatest risk come from the industrial complexes of the region (Estrada-Rivera *et al.*, 2022), but also from urban sources and the return of water from agricultural fields, where agrochemicals are used (Castro-González *et al.*, 2019).

Among other contaminants brought by wastewater are heavy metals, which may be retained in the soil (Ríos-Reyes *et al.*, 2020; Yan *et al.*, 2022), affect the food chain, and consequently, the public health of consumers (de Moya - Sánchez *et al.*, 2021). In the study region, the main crops are alfalfa, maize and vegetables, whose production process requires peasant families to be in direct contact with contaminants when carrying out various agricultural tasks; however, the majority of the population who reside in this region, comprising 1,451,013 inhabitants, according to the National Institute of Statistics and Geography (INEGI, 2023), may be exposed to these contaminants by ingesting food produced here, inhalation of that suspended in the air or by direct contact with contaminated soil.

Briffa *et al*. (2020), Mitra *et a*l. (2022), Ohiagu *et al*. (2022) and other authors mention neurotoxic, cardiovascular, carcinogenic and genotoxic effects of heavy metals; besides damage to specific organs such as the liver, kidney, skin and weakening of the immune system, among other factors. In the study region, the effects are visible; Ortega *et al*., (2023) report serious problems affecting the renal system of children, which they associate with environmental pollution; moreover, due to neurotoxic effects, these infants may be affected and suffer poor development in terms of their brain and other organs; similarly, among the population they can be the cause of cardiovascular and cancer diseases (Mitra *et al* 2022; Agency for Toxic Substances and Disease Registry: ATSDR, 2012; Centers for Disease Control and Prevention: CDC, 2023). This last disease, due to alterations in the proteins and expression patterns of various genes, which then present a high risk for triggering various health disorders (Haidar *et al*., 2023).

Studies carried out on soils in industrial areas of India (Kumar *et al*., 2019) and China (Yan *et al*., 2022; Han and Gu, 2022), report values for at least seven heavy metals, but conclude that Cd, As and Pb, exceed the permitted limits and are the most dangerous for the environment and for population health; likewise women and children are the most susceptible. Kumar *et al*. (2019) find values of 14.60, 148.70, 61.87 and 161.42 mg/kg, respectively, for Cd, As, Pb and Cr in India and Han and Gu (2022) of 0.30, 26.7 and 79.97 mg/kg for Cd, Pb and Cr respectively, in China. To assess the risk that the presence of metals in soil represents for the health of the population, the USEPA proposes methodologies based on the concentration of these contaminants and on a series of characteristics among the exposed population, to define carcinogenic and non-carcinogenic disease risk indices, by inhalation, skin contact and ingestion of these contaminants. Besides this, there are geographic information system (GIS) tools that allow spatial definition of the magnitude of the contamination problem for a given area, based on specific sampling points. These two proposals enable the population of the study region to be alerted about the risk level represented by the presence of heavy metals in the soil of a certain area, the most dangerous metal, the most important route of entry into the body and the presence or not of cancerous and non-cancerous diseases.

The objective of this work, was to determine the risk of cancerous and non-cancerous diseases due to ingestion, inhalation and skin contact with Cd, Pb, Cr and As, present in agricultural soils and use spatial analysis, to define the areas of influence of the contamination of four areas, irrigated by the Atoyac and Zahuapan rivers in the states of Tlaxcala and Puebla in Mexico.

THEORETICAL FRAMEWORK

Wastewater in agriculture

As time passes, worldwide demand for water continuously increases. Population growth, greater urbanization and the intensification of industrial and agricultural activities, among other factors (Narsimha *et al.*, 2018), have triggered the need to make more efficient use of this resource. Being a universal solvent, water is used in multiple processes that unfortunately lead to its easy contamination, resulting in a series of environmental, public health and economic problems (Mishra *et al.*, 2023). In his review, Singh (2021) mentions that more than 50% of the world's water sources become contaminated by untreated wastewater of industrial, domestic and agricultural origin, due to the fact that more than 80% of wastewater is consequently released without any treatment, reaching figures of 95% in underdeveloped countries, so the United Nations recommendation (2023) is to treat wastewater and reuse it.

Agriculture uses 70% of available water and the use of treated wastewater for irrigation generates controversy among authors, concerning beneficial and negative effects for soil and plants. Benefits for crops are reported in terms of increasing the content of organic matter in the soil, essential nutrients such as N, P, K, improvement of microbial activity and conditioning of its physical structure; however, it has negative effects in terms of increasing soil and food contamination, raising the content of pathogenic microorganisms, antibiotics, and heavy metals in the soil (Singh, 2021). The negative effects are compounded when untreated wastewater is used. Studies carried out in the Atoyac River area have shown that there is a significant bacterial load (fecal coliforms), which generates gastrointestinal diseases among the population, representing an economic expense in terms of treatment (Aquino *et al.*, 2015).

Heavy metals as pollutants

Nayak and Pathan (2023) mention that, according to the World Health Organization, 25% of diseases are caused by contaminated water, soil and air, especially wastewater that contains significant amounts of organic dyes, agrochemicals and heavy metals. It is known that the latter are natural components of the earth's crust and through natural erosion caused by water and wind, these are naturally distributed into the environment in the form of dust or are filtered into rivers; however, these natural processes emit a smaller amount of metals into the socio-productive environment than the various anthropogenic activities implemented by man.

Frequent watering, coupled with specific soil conditions, such as high organic matter content from manure application, low pH, and other factors, can encourage heavy metals to accumulate in the soil. These chemical elements, which can become highly toxic, have low density, an atomic weight between 63.5 and 200.6 g/mol, and a specific gravity that exceeds 5 g/cm^3. They become increasingly dangerous as they cannot be degraded, so over time they bioaccumulate and biomagnify.

Among the elements considered to be most toxic are Cd, Pb, As, Hg and Cr; however, there are others that although they perform metabolic functions within the organism, when ingested in amounts exceeding those established in various regulations, cause toxicity, for example Zn, Co, Ni, Cu and Se (Turdean , 2011). For these reasons, numerous studies have been carried out worldwide related to the effect that these metals have on public health and food safety. In the specific case of the Alto Balsas sub-basin (Atoyac and Zahuapan), authors such as García-Nieto *et al*. (2011) and Castro-González *et al*. (2019), have reported significant concentrations of heavy metals, including Pb and Cd in irrigation water and agricultural soils.

The dispersion of large amounts of these elements in the environment causes them to be passed into the food chain. Heavy metals, being elements that have high density compared to water, are present in various matrices in the form of traces. Their heaviness and toxicity are interrelated, as heavy metals can induce toxicity even at low doses (Bhargava *et al*., 2012; Govind and Madhuri, 2014; Dai *et al*., 2016; Giromini *et al*., 2016). Besides this, it is apparent that metals can cause health disorders individually or potentiate their effect by acting in combination with other metals; however, the relationships between these compounds are complex and to date there is not much clarity in this context (Haidar *et al*., 2023). In a study on liver damage, Huang *et al*. (2022) found a strong concentration of As, Pb, and Cd associated with the functional weakening of this organ; similarly, in another study Chang *et al*. (2023) conclude that the rural population of China is co-exposed to high concentrations of Cr, Co, Cd and Pb, causing serious outcomes.

METHODOLOGY

Study area

The study area is located in the south-central region of the state of Tlaxcala and the south-east of the state of Puebla. It is part of hydrological region No. 18 and is situated between the parallels 18 ° 50 ‘and 19 ° 20’ north latitude and the meridians 97 ° 40 ‘and 98 ° 20’ west longitude. Various field trips were undertaken to define sampling areas, and locate representative sites that are irrigated with water flowing in the Atoyac and Zahuapan rivers, either directly or conducted along canals.

The location of waste water basins related to different sources of contamination was taken into account; those where water of industrial origin converges, or water reemerges after irrigating the land, as well as water from urban areas. Four sampling areas were defined, as follows: Zone 1 Tepetitla de Lardizabal, Zone 2 Nativitas, both in the state of Tlaxcala and corresponding to the Atoyac river; Zone 3 Santa Isabel Tetlatlahuaca, Tlaxcala, which receives water from the Zahuapan River and Zone 4 corresponded to Tecamachalco, Puebla, irrigated with water from the Valsequillo canal. An area of influence was defined to comply with the radius of the area covered by data obtained from soil sampling in the field, with a total of 51 municipalities included in the study area.

Soil samples

For each zone, four sites were sampled, in each of these, 10 subsamples were taken to form a composite sample. Starting from the river, the canals that distribute irrigation water were monitored in an area of approximately one km radius, where the sampling sites were located. These corresponded to alfalfa plots in an area ranging between half and one hectare, belonging to cooperating producers who agreed to participate in the study. The soil sample was taken from the surface layer at a depth of 0 to 30 cm, because metals in cultivated soils are generally more homogeneously distributed at this level (Esmaeili *et al.*, 2014). Handling and preparation of the soil samples was carried out in compliance with NOM-021-SEMARNAT-2000.

Identification of heavy metals

Samples were digested in the laboratory following protocol 3051 of the Unites Estates Environmental Protection Agency (EPA), using a microwave oven (CEM-MarsX, CEM corporation Mathews, North Carolina); subsequently, they were filtered through Wathman 42 paper, submerged in 50 ml of deionized water and refrigerated until analysis. Identification of heavy metals Cd, Pb, Cr and As was carried out by means of inductively coupled plasma optical emission spectroscopy (ICP-OES) (Varian 730 – ES). All chemicals used were of analytical reagent grade.

Risk analysis

Health risk was evaluated considering concentrations of heavy metals (Cd, As, Cr and Pb) detected in the soil, taking into account that inhabitants are exposed to these elements. According to the International Agency for Research of Cancer (IARC, 2023), these are classified as carcinogenic and according to Chen *et al.* (2015), can enter the body by ingestion, skin contact and inhalation. For this, the following equations were used to evaluate exposure to toxic substances, as proposed by USEPA (2001; 2011):

$$ADI_{dermal} = C_{soil} \times \frac{SA \times AF \times ABS \times ED}{BW \times AT} \times 100^{-6} \quad (1)$$

$$ADI_{ing} = C_{soil} \times \frac{IngR \times EF \times ED}{BW \times AT} \times 100^{-6} \quad (2)$$

$$ADI_{inh} = C_{soil} \times \frac{InhR \times EF \times ED}{PFT \times BW \times AT} \quad (3)$$

where *ADIdermal*, *ADIing* and *ADIinh* correspond to average daily soil consumption, either through dermal contact, ingestion or inhalation (mg kg day^{-1}), respectively; C_{soil} is the concentration of metals in the analyzed soil (mg kg^{-1}); *SA* is the exposed skin surface area (cm^2); *AF* is the adherence factor (kg cm^2 day^{-1}); *ABS* is the dermal absorption factor (without units); *ED* exposure time (years); *IngR* and *InhR* represent the rate of soil ingestion and inhalation (mg day^{-1} and m^3 day^{-1}, respectively); *EF* is the frequency of exposure (day year^{-1}); *PFT* is the emission factor (m^3 day^{-1}); *BW* is the body weight (kg) of the exposed person; *AT* is the period of time (day) for which, the dose is averaged (for non-carcinogens: $AT=ED\times365$ days, for carcinogens: AT=life expectancy×365 days) in this case, an age of 78 years was taken for men and women and 16 years for children.

For women, men, and children, the hazard quotient (HQ) and hazard index (HI) were calculated for individual and multiple metals respectively, and in terms of routes of exposure, using the equations proposed by Khan *et al*. (2008); Bermudez *et al*. (2011) and Khan *et al*. (2013). Cancer risk was calculated using the result obtained from the equation presented by Castro-González *et al*. (2017).

$$HQ=\frac{ADI_i}{RfD_i} \tag{4}$$

$$HI\sum HQ_I=\sum\frac{ADI_i}{RfD_i} \tag{5}$$

$$HI\sum HQ_{\exp}=HQ_{dermal}+HQ_{ingestion}+HQ_{inhalation} \tag{6}$$

where *RfD* is the reference dose for the hazardous substance (mg kg $^{-1}$ day $^{-1}$) for each route of exposure. Dermal *RfD*: 1.00E-05, 6.00E-05, 1.23E-04, 5.25E-04, for Cd, Cr, As, Pb, respectively; *RfD* ingestion: 3.00E-04, 1.00E-03, 3.00E-03, 3.50E-03, for As, Cd, Cr and Pb; *RfD* for inhalation: 2.86E-05, 5.71E-05 for Cr and Cd (Ferreira-Baptista, 2005; Integrated Risk Information System IRIS, 2015).

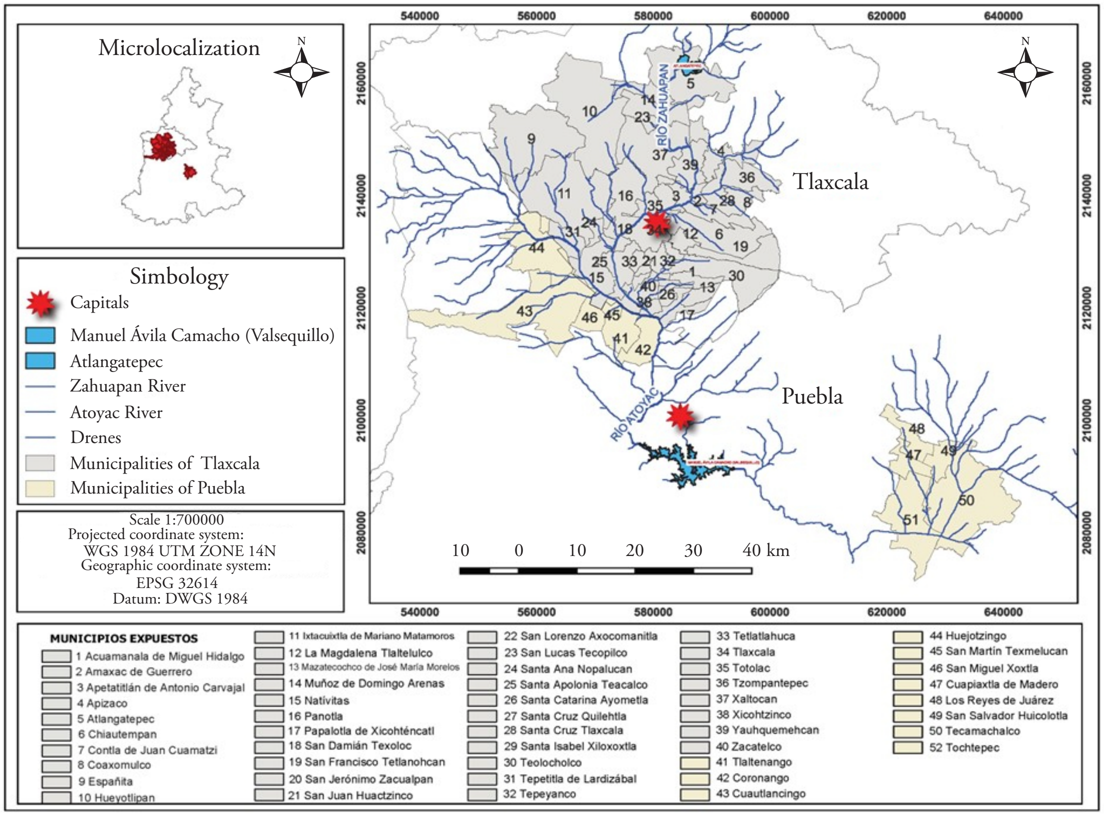
From the result obtained, the cancer risk index (CRI) was calculated, applying the following equation:

$$Risk\sum ADI_i\times SF_i \tag{7}$$

where *SFi* is the dependent factor (mg kg-1) of Cd, Cr and As, which are considered to be carcinogenic (Chen *et al*., 2015) and Pb probably carcinogenic (IARC, 2015). The *SFi* values for the oral route were: 15.0, 1.5, 0.5 and 0.0085 for Cd, As, Cr and Pb, respectively (IARC, 2015); for the inhalation route: 42.0, 15.1, 6.3 and 0.042 for Cr, As, Cd, and Pb; and for the dermal route, only As is considered, with a value of 3.66 (Ferreira-Baptista, 2005; Office of Environmental Health Hazard Assessment: OEHHA, 2009).

Spatial analysis

Area of influence was selected according to the radius for the data obtained in the soil sampling in the field, totaling 51 municipalities within the study area (Figure 1), 40 from the state of Tlaxcala and 11 from Puebla that use water from the Atoyac and Zahuapan rivers. Municipalities 47 to 51 are irrigated by water from the Valsequillo canal, which transports water from the Manuel Ávila Camacho dam.



Source: self elaborated (Val y Rich) with data from INEGI.

Figure 1. Municipalities pertaining to the Alto Balsas sub-basin, where agricultural soils in the states of Puebla and Tlaxcala are irrigated with wastewater.

Spatial analysis was carried out using the QGIS 3.22 Białο-wieża software, which is a GIS (Geographic Information System). This spatial analysis tool was developed with interpolation methods and procedures to predict a value where sampling has not taken place, converting specific observations into continuous surface areas (Journel and Huijbregts, 1978; Goovaerts, 1997; Wallo and Cuestas, 2006).

Statistical analysis

For the statistical analysis, the SAS package version 9.0 (2002) was used, creating a General Lineal Model (GLM) to determine the differences in HQ, HI and cancer risk between men, women and children. For the comparison of means, the Tukey test was performed at a confidence level of 95% (p≤0.05).

RESULTS

Metals in soils irrigated with wastewater

The results obtained from the analysis of soils irrigated with water from the Atoyac, Zahuapan rivers and the Valsequillo canal showed similar levels of heavy metals in the four areas sampled. A significant difference ($p<0.05$) was only perceived in the case of Cr in zone three, which presented a higher value when compared to zone four, (Table 1). In general terms, there is a tendency towards higher concentrations of Cd, Pb and Cr in zone three, which corresponds to the Zahuapan River, into which waste from the state of Tlaxcala is discharged. The least affected by Pb, Cr and As is the Tecamachalco area, possibly due to the fact that the Valsequillo dam serves as a natural filter for these contaminants. The Mexican norm NOM-147-SEMARNAT/SSA1-2004 establishes references for total concentrations in soil for Cd, Pb, Cr and As, with respective concentrations of 37, 400, 280 and 22 mg kg-1, in agricultural soils consisting of a surface area of less than 1000 m^2, determined by flame spectrophotometry. According to the standard, for surfaces larger than this, a conceptual model must be developed to select methodologies for sampling and analysis of samples. The values for this study are reported in mg/gr, obtained by inductively coupled plasma optical emission spectroscopy, and these are not referred to in the norms. Regarding the values reported in studies carried out by Han *et al*. (2022) in China, those found in this research are very low, and are even further removed from those reported by Kumar *et al*. (2019) in India; however, the concentrations of heavy metals found in this basin are similar to those reported by Núñez-Gastélum *et al*. (2019) for Pb and Cd in agricultural soils of the Juárez Valley, in the border area between Mexico and the USA.

Routes of entry of heavy metals into the body

The oral route showed significant differences (p≤0,001), representing a greater risk in the case of children, where the following values were detected; As (2,09E-01 ± 2,09E-01), Cr (7,02E-02± 1,68E-02), Pb (4,99E-02±1,32E-02) and Cd (1,46E-02±3,29E-03), followed by the dermal pathway. Up to the age of 16, metals are more likely to enter through food than through environmental exposure.

Contrarily, the dermal route is the one presenting greatest risk among adults, showing p≤0.001 over the other routes, with values of: Cd (2.11E+01±4.73E + 00), Cr (7.76E

Table 1. Metal and As content (mg kg^{-1}) in agricultural soils of the Alto Balsas sub-basin irrigated with wastewater, in the states of Puebla and Tlaxcala, Mexico.

Metals and Arsenic / Zone	Cd	Pb	Cr	As
1	1.16±0.2^a	14.79±1.2^a	19.04±3.3^{ab}	5.16±1.1^a
2	1.15±0.3^a	13.03±4.8^a	17.35±3.2^{ab}	5.91±2.2^a
3	1.42±0.5^a	17.67±7.1^a	20.25±5.8^a	5.70±1.2^a
4	1.22±0.2^a	13.60±2.6^a	14.37±2.2^b	4.51±2.6^a

Different literals (a b) represent significant differences (p≤0.05) between Zones. Zones: (1) Atoyac. (2) Atoyac. (3) Zahuapan. (4) Valsequillo canal. (±): Standard deviation.
Source: own data.

+ 00±7.14E + 00) and As (1.58E + 00± 6.68E-01). This result may be associated with permanent exposure on the part of inhabitants to earth, particularly the rural population, who work in direct contact with the soil throughout their lives. These data differ from that reported by Qing *et al*. (2015) and Wei *et al*. (2015), who identified the oral route as the main route of entry of metals, followed by the dermal route.

Hazard Quotient (HQ)

Regarding HQ, it was found that for Cd there were values of QH>1, with significant differences (p≤0,05), and adults obtaining higher values than those among children (Table 2), who showed HQ<1, which indicates that at the age when they are being evaluated (16 years) there is less probability that they will present effects or conditions affecting their health (USEPA, 2001).

HI, is the sum of HQ values; in this work there were no significant differences (p≥0,05) related to area; however, the average value obtained in the four zones was (HI>1), indicating a high risk for the population for developing non-cancerous diseases (central nervous system disorders, renal failure, cardiovascular disorders, poor brain development in infants, osteoporosis among others) (ATSDR, 2012). The effect calculated by the sum of metals presents a higher risk for men (p≤0,05) compared to women (Table 2) and is even lower (p≤0,05) for children. However, the route of greatest exposure to metals in adults was through dermal contact, which showed (p≤0,05) differences compared to oral and inhalation exposure.

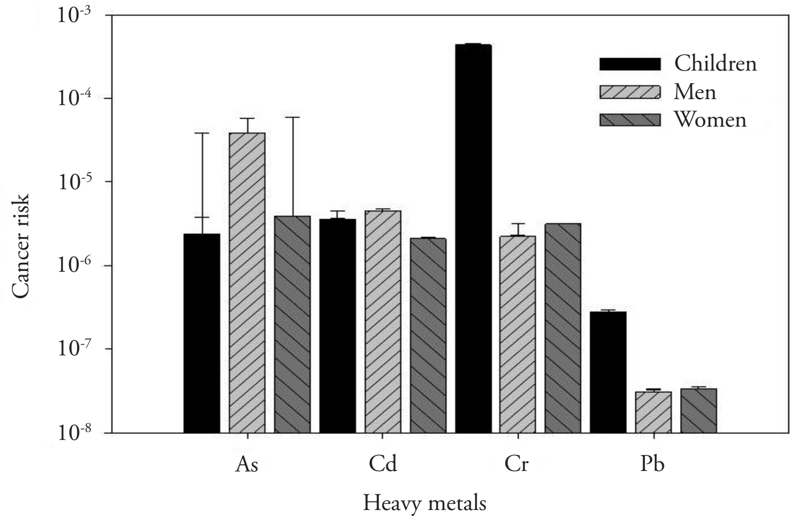
Cancer risk

Regarding the cancer risk analysis on an individual basis, it was apparent that Cd is the metal presenting highest risk for both men and women, followed in descending order by: As>Cr>Pb (Figure 2). Adults (men and women) presented higher values than children, with a significant difference (p≤ 0,05). The values for this variable were higher than the

Table 2. Hazard quotient (HQ) among children, men and women due to exposure to heavy metals found in agricultural soils in the Alto Balsas sub-basin in the states of Puebla and Tlaxcala, Mexico.

Metals heavy	Children		Men		Women	
	Medium	DS	Medium	SD	Medium	SD
As	8.35E-02	1.10E-01	6.36E-01 [a]	8.70E-01	6.45E-01 [a]	8.80E-01
Cd	6.00E-03 [b]	7.00E-03	8.38E+00 [a]	1.00E+01	8.47E+00 [a]	1.00E+01
Cr	5.10E-01 [b]	1.00E+00	6.26E+00 [a]	7.10E+00	9.23E-01 [b]	1.00E+00
Pb	1.90E-02 [b]	2.00E-02	8.40E-02 [a]	1.00E-01	8.52E-02 [a]	1.00E-01
HI∑ HQ Cd+Pb+Cr+…	1.20E-01 [c]	1.77E-01	1.27E+01 [a]	1.88E+01	8.54E+00 [b]	1.25E+01

(a, b, c) literals represent significant difference p≤0.05, SD standard deviation.
Source: own data.



Source: own data.
Figure 2.- Risk of cancer among children, men and women due to the content of heavy metals in contaminated soils in the Alto Balsas sub-basin in the states of Puebla and Tlaxcala, Mexico.

range established as the maximum for cancer risk (10^{-6} a 10^{-4}) by the USEPA (2001) and reported by Hu *et al*. (2012) (Figure 2). It is thus apparent that the risk of cancer among men, women and children in the four study areas is high.

In the case of men, the risk of cancer identified in this work may be due to the tilling of agricultural soils, as they come into direct contact and do not use any protective clothing, so the skin of their hands, feet and faces are openly exposed.

The high values found among women may be due to the fact that they often help with the work of men in the fields, as well as hand washing the clothes and utensils that men use in the field (ATSDR, 2012). We should stress that children will be at risk in the long term, because heavy metals have a tendency to be cumulative and do not biodegrade within the organism, being able to remain there for a period of up to 30 years. (USEPA, 1986; Chen *et al*., 2015).

Heavy metals can accumulate in the bones, kidneys and other organs, taking advantage of the metabolic disorders suffered by children in the growth stage, where Ca and Fe are replaced by metals and during the adult stage in the case of women, affecting their bones and possibly developing into osteoporosis (WHO, 2010; Lim *et al*., 2016; Feng *et al*., 2023).

Cd manifested the highest values for cancer risk when compared individually, followed by As, Cr, and finally Pb. When determining the total risk of cancer in the four zones by the sum of the effect that each of them exerts on the body, a value of 8.56E+00 (±1.96E-01) was calculated, revealing a high risk for all the inhabitants in these areas, and especially for the farmers and their families. This is considered a serious problem because farmers are in contact with agricultural land and the products resulting from their work, throughout the year.

Spatial analysis

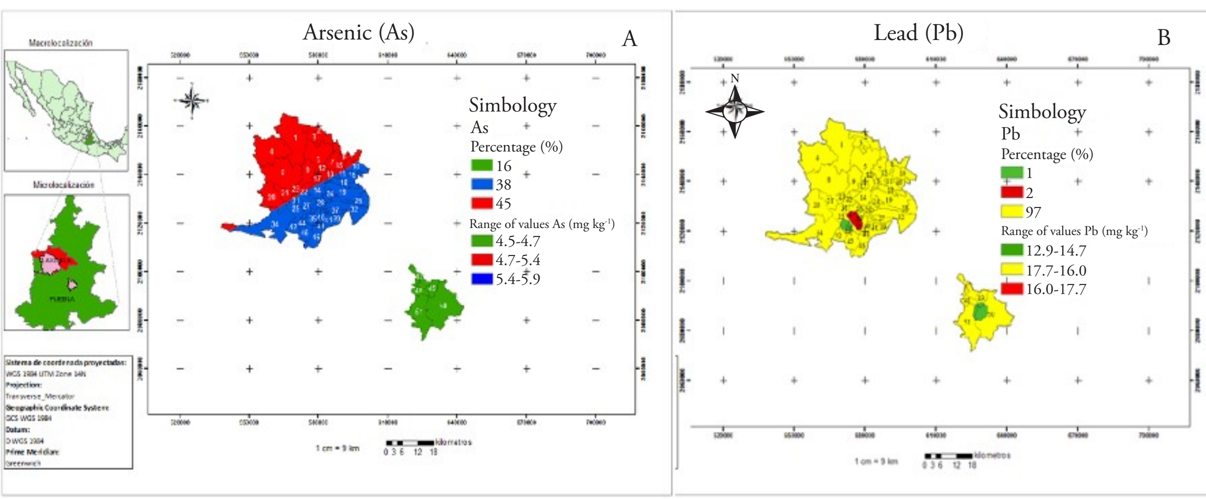
The results obtained from the spatial analysis concerning the assessment of the content and distribution of heavy metals in the soil were divided into high, medium and low concentration; in order to present the percentage concentration value.

It was concluded that the detected metals represent a risk to the health of a population of approximately 1,451,013 inhabitants in the 51 municipalities that surround the sample areas, thus indicating the extent of contamination from these toxic elements.

In the case of Arsenic, evidently 38% of the surface has levels ranging from 5.4 to 5.9 mg kg^{-1}, 45% ranges from 4.7 to 5.4 mg kg^{-1} and 16% has values from 4.5 to 4.7 mg kg^{-1}, which means that this metalloid is present in 99% of the total area of the 51 municipalities (Figure 3).

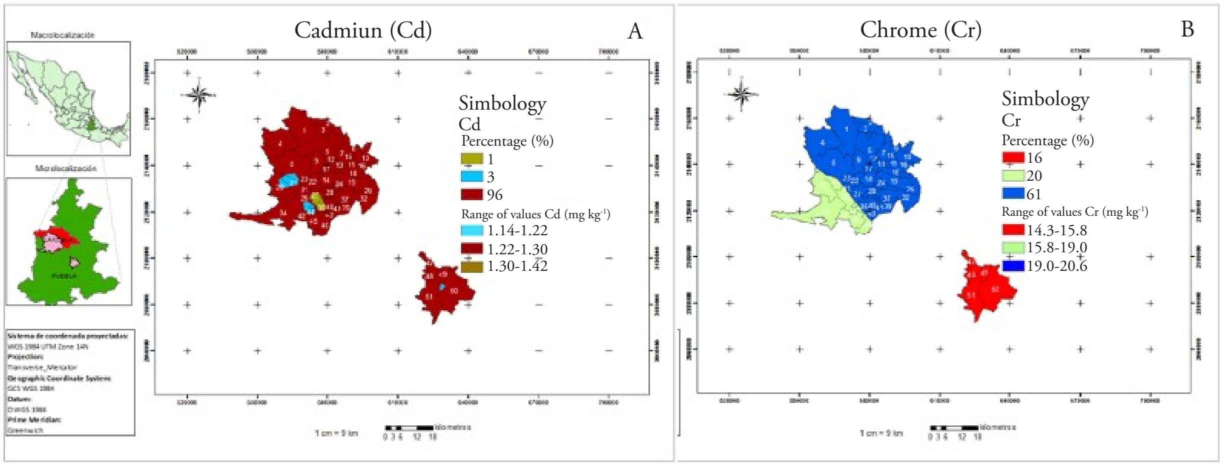
Lead shows values ranging from 12.9 to 14.7 mg kg^{-1} and from 14.7 to 16.0 mg kg^{-1} corresponding to 1 and 2% of the surface respectively, the remaining 97% presents values ranging from 16.0 to 17.7 mg kg^{-1}, which indicates that 100% of the territory of the municipalities surrounding the sub-basin are contaminated with lead (Figure 3).

Cadmium, considered one of the most toxic elements, was detected at levels of 1.30 to 1.42 mg kg^{-1}, corresponding to only 1% of the study area with a range of values from 1.22 to 1.30 mg kg^{-1}, with 3% of the surface showing values from 1.14 to 1.22 mg kg^{-1}, which corresponds to 96% percent of the surface of the 51 municipalities, a fact that is of great concern, because this implies that Cd is in 100% of the total surface of the soils that correspond to the 51 municipalities bordering the Alto Balsas sub-basin (Figure 4).



Source: self elaborated.

Figure 3. Level of contamination with As (a) and Pb (b) in the 51 municipalities near the Alto Balsas sub-basin and Valsequillo canal.



Source: self elaborated.

Figure 4.- Level of contamination from Cd (a) and Cr (b) in the 51 municipalities adjoining the Alto Balsas sub-basin and Valsequillo canal.

As apparent, Pb, Cd and Cr contaminate 100% and As 99% of the 51 municipalities bordering the Alto Balsas sub-basin, if we consider the risk represented by these toxic elements as demonstrated in the As part of the risk analysis of cancerous and non-cancer diseases and cancer risk, evidently the region consisting of the 51 municipalities analyzed here is at serious risk of suffering from a disease related to one or several of the heavy metals present in the agricultural soils.

CONCLUSIONS

According to the results found, we conclude that the four areas studied were similar in terms of risk in terms of the contamination of agricultural soil for the families of farmers and the inhabitants of those areas, with routes of entry of contaminants into the body among children being mainly by ingestion, whereas among adults this occurs through skin contact.

It turned out that the risk of non-cancer diseases was higher among adults than children, due to duration of exposure, and Cd represented greatest risk. The risk of suffering from cancerous diseases is high both for children and adults, although it is more accentuated in this last stratum of the population, caused mainly by Cd, followed by As, Cr and Pb.

Regarding level of affectation, 51 municipalities in the Alto Balsas sub-basin and Valsequillo canal area are affected, with Cd, Pb and Cr found in 100% of the overall surface and As in 99% of the total area. The accumulation of all these metals in the soil places the population at high risk from cancer.

It is paramount to impose constant monitoring of water and soil in order to establish remediation programs to limit the presence of diseases. As we know that soils are contaminated, and that they represent an ongoing threat to the health of the population, it is appropriate that institutions coordinate to implement effective treatment of the water used for irrigation and that procedures to remedy soils are implemented.

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