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Full Length Research Paper

Irrigation wastewater and heavy metals in agricultural soils of Mixquiahuala, Hidalgo, Mexico

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Agricultural soils irrigated with wastewater pose a significant risk in the accumulation of heavy metals, a problem that affects agriculture and human health. An investigation was conducted on the concentration of heavy metals in agricultural soils and wastewater used for irrigation in plots of Mixquiahuala, Hidalgo. It analyzed the potential of hydrogen (pH), electrical conductivity (EC) and total extractable heavy metals in water and soil: As, Cd, Cr, Hg, Ni, Pb and Zn. Heavy metals were determined by using an Inductively Coupled Plasma (ICP) Perkin Elmer Optima 5300 (Inductively Coupled Plasma), using the methods recommended by the EPA (Environmental Protection Agency) and APHA (American Public Health Association). The study was conducted in November 2009. The sampling was conducted in two replications for both soils and wastewater. It compared the concentration of heavy metals with the criterion of Norma Oficial Mexicana-001-ECOL-1996. Based on these results, the concentration of extractable metals in agricultural soils of Mixquiahuala, Hidalgo, was presented in the following order: Pb > Ni > Cd > As > Cr > Hg. Water for agricultural irrigation did not present problems for use based on the concentration of As, Cd, Hg, Ni, Cr and Zn. However, lead concentration exceeded the maximum permissible limits in 40% of water samples analyzed. Considering the limits established in Spain, the concentrations of As, Ni and Cd exceeded permissible levels in 20, 60 and 60% respectively, of the samples analyzed.

Key words: Heavy metals, agricultural soil, maximum permissible limits.

INTRODUCTION

In the state of Hidalgo, Mexico, it is located the irrigation district 112 Ajacuba, where the main source of irrigation water is wastewater from Mexico City. This water has been used for irrigation for over 80 years (Vazquez et al., 2001; Prieto et al.,2007). According to some studies, this water has high concentration of detergents, fats, oils and trace metals that affect the soils (Siebe, 1994; Sanchez, 2006). The problem of high levels of heavy metals such as lead, nickel and cadmium in soils (Corinne et al., 2006), and in wastewater used for irrigation, mainly lies in the fact that they can be accumulated in these systems that are critical to agriculture. Heavy metals are dangerous because they are non-biodegradable, bio-available and toxic for different crops (Mahler, 2003; Garcia and Dorronsoro, 2005). Some of these heavy metals are mercury, arsenic and chromium (Lucho et al., 2005).

These elements are usually found as natural components of earth's crust, as minerals, salts and other compounds that can be absorbed by plants and incorporated into the food chain (Rooney et al., 2006; Zhao et al., 2006). They can pass into the atmosphere by volatilization and can be mobilized into surface water or groundwater. They cannot be easily degraded, destroyed naturally or organically since living beings do not have specific metabolic functions for them (Abollino et al., 2002).

An increasing trend in soil metal concentrations is reported in places where wastewater has been used for irrigation (Garcia et al., 2000; Hettiarchchi and Pierzynski,

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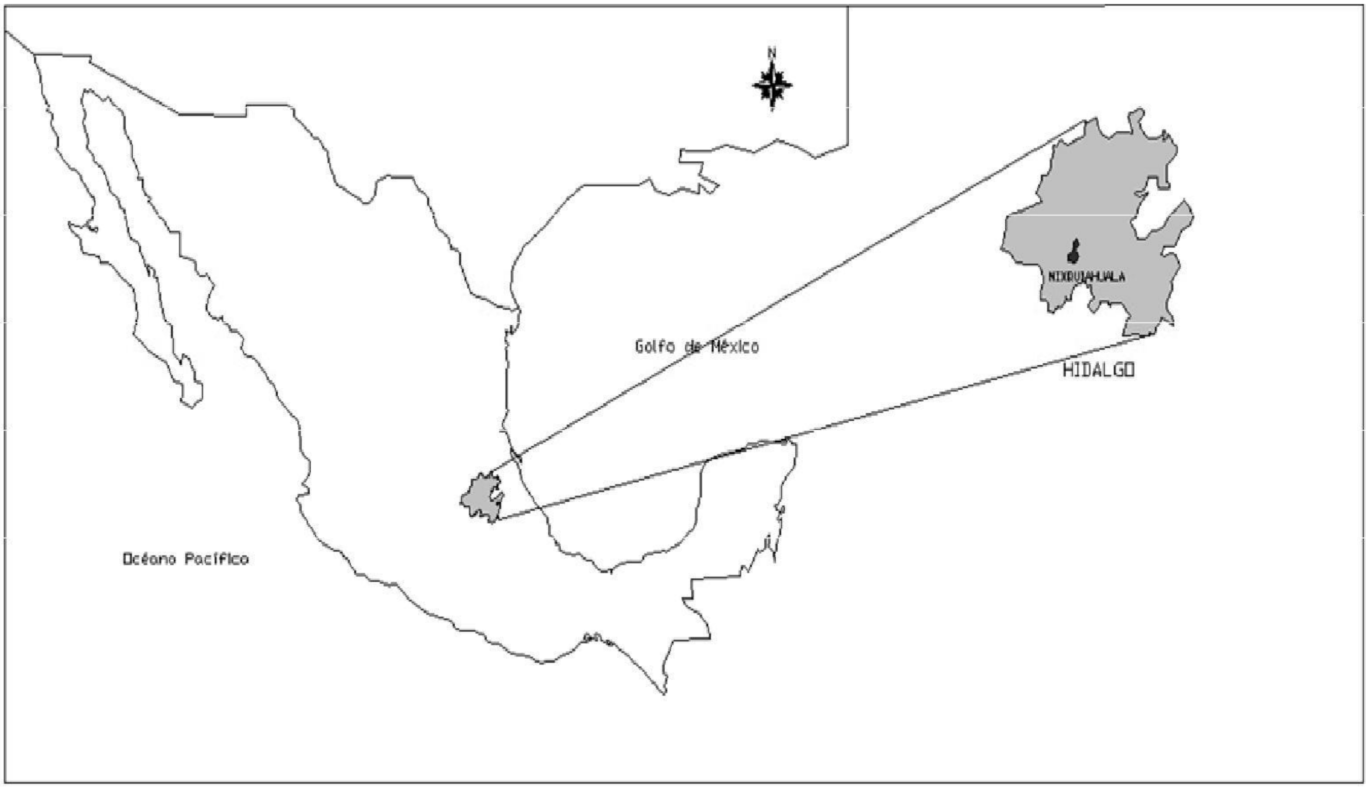

Figure 1. Location of the study area.

2002). There was ample research on the risk of heavy metals on health and the environment (Spain et al., 2003). Several authors have shown the risk of contamination by heavy metals in water (Yang et al., 1996; Ramos et al., 1999; Topalian et al., 1999; Santos et al., 2002; Taboada-Castro et al., 2002; Lee and Moon, 2003; Montes-Botella and Tenorio, 2003; Smolders et al., 2003; Lucho et al., 2005; Mapanda et al., 2005; Tahri et al., 2005; Prieto et al., 2007), in the accumulation of heavy metals in soils and sediments (Fytianos et al., 2001; Ho and Egashira, 2001; Moor et al., 2001; Ramos-Bello et al., 2001; Lin, 2002; Moral et al., 2002; Davor, 2003), and the potential risk to human health due to the accumulation of heavy metals in plants (Zhou et al., 2000; Fytianos et al., 2001; Long et al., 2003; Wang et al., 2003; Qi-Tang et al., 2004; Ismail et al., 2005; Mapanda et al., 2005; Prieto et al., 2009).

The objective of this study was to determine the concentration of heavy metals such as: As, Cd, Pb, Hg, Cr and Ni, in soil and wastewater used for irrigation in plots of the district 112-Ajacuba, Hidalgo. The concentration of these elements was compared to the maximum permissible limits established in the NOM-001-ECOL-1996.

METHODOLOGY

The study was conducted in the irrigation district 112-Ajacuba, it is located Mixquiahuala, Hidalgo, Mexico (Figure 1). This region is placed in the southwestern part of the state, in a region called "Valle del Mezquital". It is it is located the following geographical coordinates: 20°11'51" N latitude, 90°11'51" W longitude, and an altitude of 1996 m.

Samples of soil and water were taken in different plots, irrigated for over 80 years with wastewater. Samples were taken in November 2009, after irrigation. Water samples were acidified with nitric acid, adding 2 ml/L, according to NOM-014-SSA1.1993. Heavy metals of soil samples were extracted using DTPA solution as described by Araujo do Nacimiento et al. (2006).

Parameters analyzed in the samples were pH, EC (both in relation 1:2) with an EXCEL 20/pHmeter-mV-conductivity meter, heavy metals (As, Ni, Cr, Pb, Hg and Cd), using an ICP Perkin Elmer 5300 Optima model. Analyses were performed in the Environmental Sciences Laboratory located at Colegio de Postgraduados. In this study, As, Ni, Cr, Zn, Pb, Hg and Cd were considered for their toxicological relevance for plants, the differences of these metals in their behavior in soils and their availability for crops (Cd > Pb > Cr) (Scheffer and Schachtschabel, 1984). It is important to mention that sampling and analysis were performed according to procedures of APHA (1995) and EPA (1983).

The recovery values obtained infortified samples for metal analysis were as follows: As 109.1, Al 99.7, Cr 99.46, Cu 99.25, Hg 106.15, Zn 98.21, Cd 100.35, Pb 96.93 and Ni 98.24%, which are within the recommended range and near to 100% (EPA, 1996), so there was no interference in the samples analyzed.

The concentrations of heavy metals in wastewater were compared to the maximum permissible limits of NOM-001-ECOL-1996 (Table 1). The maximum permissible limits, in terms of concentration of heavy metals in irrigation water, was set considering that the accumulation of these elements in the

Table 1. Maximum permissible limits for heavy metals, NOM-001-ECOL-1996.

Parameter	Rivers used in agricultural irrigation		Natural and artificial reservoirs used in agricultural irrigation	
mg L^{-1}	M.A.	D.A.	M.A.	D.A.
Arsenic	0.2	0.4	0.2	0.4
Cadmium	0.2	0.4	0.2	0.4
Copper	4.0	6.0	4.0	6.0
Chromium	1.0	1.5	1.0	1.5
Mercury	0.01	0.02	0.01	0.02
Nickel	2.0	4.0	2.0	4.0
Lead	0.5	1.0	0.5	1.0
Zinc	10.0	20.0	10.0	20.0

D.A. = Daily average; M.A. = monthly average.

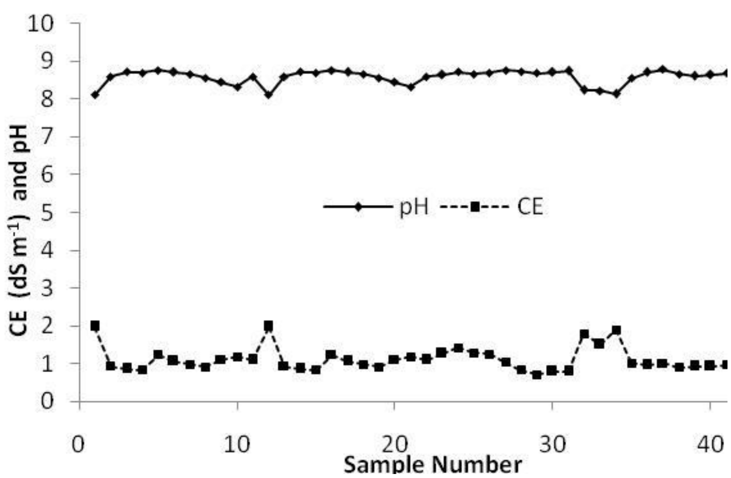

Figure 2. Electrical conductivity and pH measured in the saturation extract of soil samples.

arable layer does not pose a risk for human health

RESULTS AND DISCUSSION

Figure 2 shows the electrical conductivity and the potential of hydrogen measured in the soil extract. The soil pH is slightly alkaline, 99% of the samples showed values above eight, electrical conductivity in the soil showed values below 2 dS m^{-1}, indicating that there is no problem for the growth of crops in the plots, according to Jalali et al. (2008).

Figure 3 shows that the sampled soil presented levels of concentration of extractable heavy metals is in the following order: Pb > Ni > Cd > As > Cr > Hg; for this reason, the elements of greater availability for organisms living in the soils were: Pb, Ni and Cd. Results found in this study are similar to results showed in other studies developed in the region, these results found that Pb, Ni and Cd tend to accumulate in agricultural soils irrigated with wastewater in the region of study. However, the concentrations found of these metals do not represent a risk according to the limits established by the Mexican official norm, NOM-021-SEMARNAT-200 (SEMARNAT, 1996).

In a study made by Chapela (2010) in the region of this study, soils irrigated with wastewater were analyzed to determine the concentrations of heavy metals. It was found that the concentration trend was Zn < Cu < Pb < Cd, while in this study the concentration trend found was Hg < Cr < Cd < As < Ni < Pb. This Show that the Pb concentrations were higher than the Cd concentrations in this study. Agricultural soils of this Mezquita Valley have been studied by several researchers; these soils have been irrigated with wastewater since more than one hundred years ago (Vazquez et al., 2005).

Heavy metal accumulation in agricultural soils can be a problem when using wastewater to irrigate the soil for

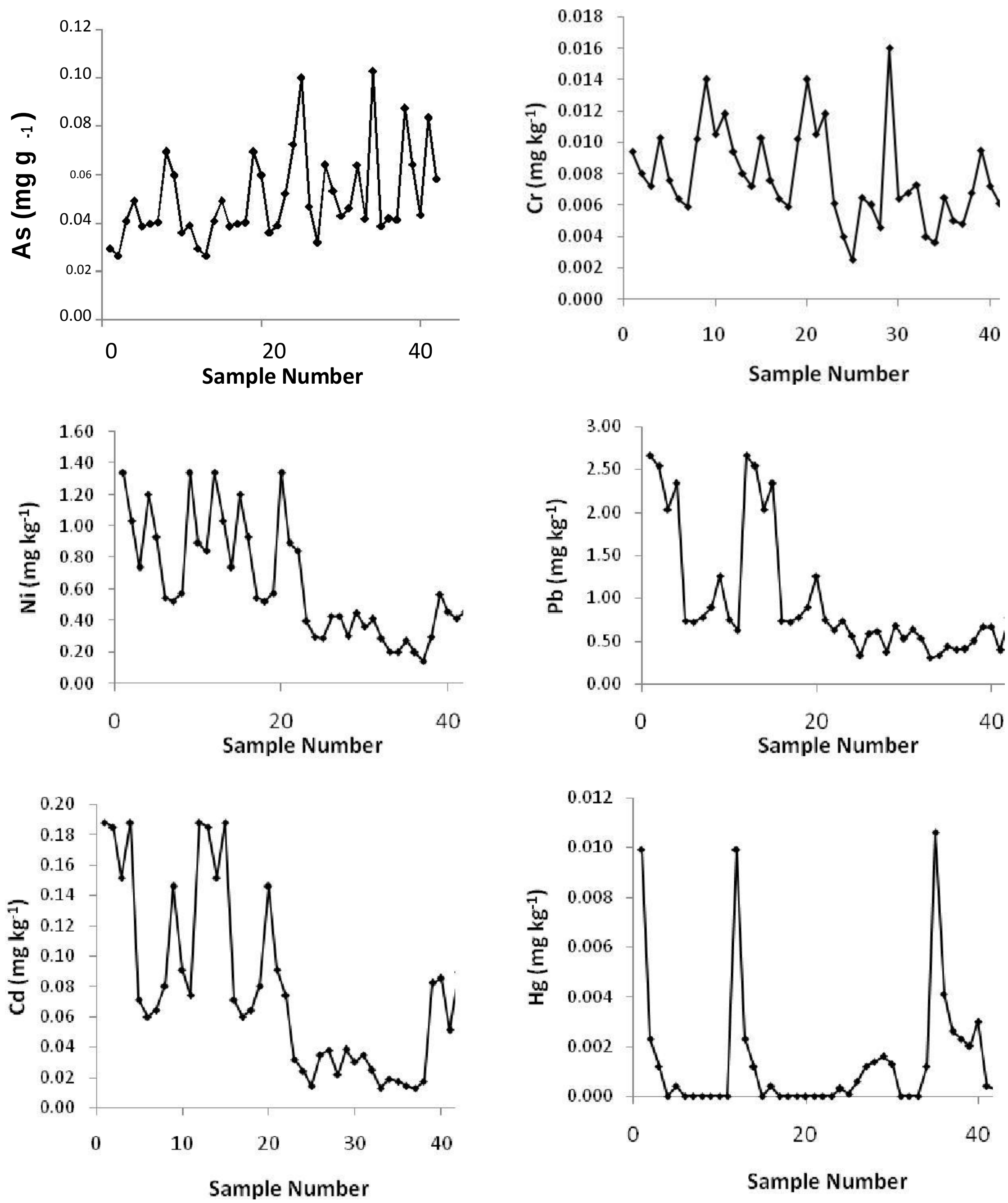

Figure 3. Concentration of heavy metals in agricultural soils.

more than a century. Cajuste et al. (2001) mentioned that in the Mezquital Valley the annual accumulation rate of heavy metals is between 384 and 640 g ha^{-1}. Figure 4 shows the electrical conductivity and the potential of hydrogen measured in wastewater used for irrigation in the plots of Mixquiahuala, Hidalgo. The pH presented values above eight, which means that water is slightly alkaline. The electrical conductivity presented values below 2 dS m^{-1}, which means that water is recommended for use in agricultural irrigation without restrictions, considering the salinity factor according to Al-Nabulsi, (2001) and Perdomo (2005).

Figure 5 shows the concentration of heavy metals found in wastewater used for irrigation in Mixquiahuala, Hidalgo. According to NOM-001-ECOL-1996, the total concentration of heavy metals such as As, Cd, Ni, Cr, Zn, Hg and Mn present in wastewater analyzed, did not exceed the maximum permissible limits. However, the concentration of Pb exceeded the maximum permissible limit in 40% of the samples analyzed. In a similar way,

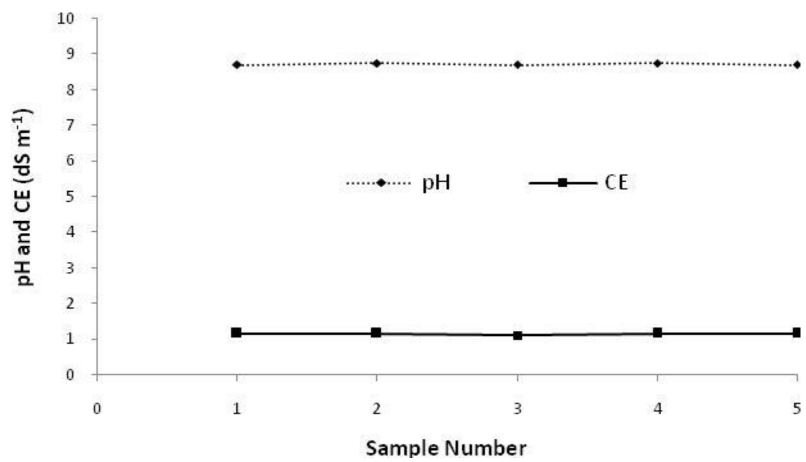

Figure 4. Electrical conductivity and pH measured in wastewater used for irrigation.

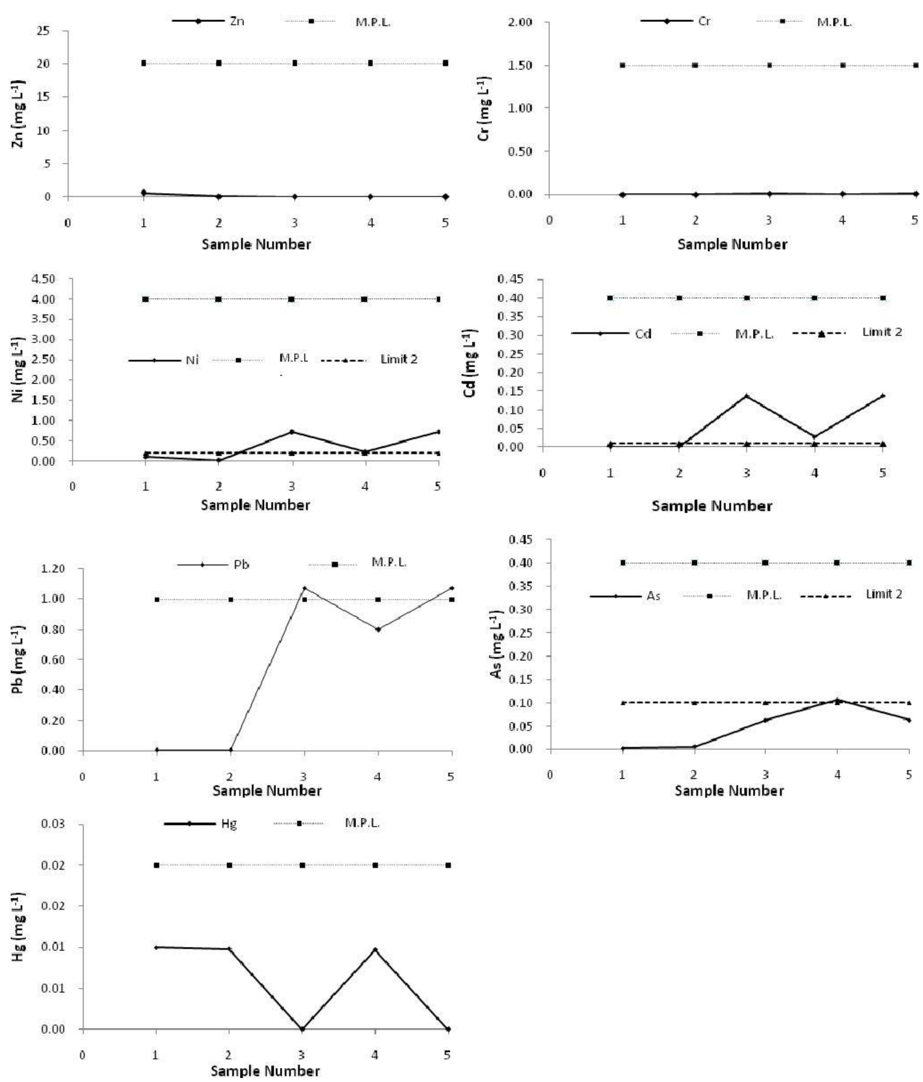

Figure 5. Concentrations and maximum permissible limits of heavy metals in water for irrigation. M.P.L. = Maximum permissible limit (NOM-001-ECOL-1996), limit 2 = maximum permissible concentration in Spain (Urbano, 2001).

Cajuste et al. (1991) and Carrillo et al. (1992) found concentrations of heavy metals such as Ni, Pb and Cr in irrigation water that exceeded the maximum permissible limits. Siebe (1994) concluded that a heavy metal accumulation process is occurring in the Mezquital Valley, were the present study was made. Siebe (1994) showed that heavy metal concentrations of soils irrigated with wastewater were 3 to 6 times higher than heavy metal concentrations of soils under rainfed agriculture.

Considering the limit 2, established by Urbano (2001), the concentration of As, Ni and Cd exceeded the permissible level in 20, 60 and 60%, respectively, of the samples analyzed. Accumulation of heavy metals in the soil, due to the use of wastewater for irrigation, did not represent a risk for the soil productive potential nor increased to preoccupant levels the incorporation of metals into the food chain. However, the results of this investigation put in evidence that irrigation with wastewater should not be done during unlimited periods, since heavy metals (such as As, Ni, and Cd) tend to concentrate in the arable stratum of soils and can be absorbed by crops. Consequently, it is important to establish tolerance limits of heavy metal concentration according to the number of years that wastewater will be used for irrigation. To correlate tolerance limits with the number of years that the wastewater can be used, it is necessary to take into account the differences in filter and buffer capacity of agricultural soils, since these will be extinguished faster in sandy soils and slightly acid reaction, than in silty soils and neutral to alkaline reaction, according to Siebe (1994).

Conclusion

The concentration of extractable heavy metals in agricultural soils of Mixquiahuala, Hidalgo, presented levels in the following order: Pb > Ni > Cd > As > Cr > Hg. Heavy metals of greater bioavailability in the soils sampled were Pb, Ni and Cd. Wastewater used for irrigation did not showed restrictions for its use considering the concentration of heavy metals such as: As, Cd, Ni, Hg, Cr and Zn. However, the Pb concentrations exceeded the maximum permissible limits in 40% of the water samples analyzed.

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