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Water quality in the central zone of the Texcoco aquifer, Mexico

Pascual-Ramírez, F.[1]**; Martínez-Ruiz, A.**[2]**; Prado Hernández, Jorge V.**[3*]**; Cristóbal-Acevedo, D.**[3]

[1] Universidad Nacional Autónoma de México, Instituto de Investigaciones en Ecosistemas y Sustentabilidad Campus Morelia, Morelia, Michoacán, México, C. P. 58190.

[2] Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias, Campo Experimental San Martinito, Tlahuapan, Puebla, México, C.P. 74100.

[3] Universidad Autónoma Chapingo, Departamento de Suelos, Chapingo, Texcoco, México, México, C. P. 56230.

* Correspondence: jpradoh@chapingo.mx

ABSTRACT

Objective: To determine water quality in the central zone of the Texcoco aquifer, Mexico, for human use and consumption and agricultural use.

Methodology: The physical, chemical, and biological indicators of the water from 16 wells in urban areas of the central zone of the aquifer were determined. The sampling was carried out, based on the parameters and definition of water quality per use established in the current official Mexican standards.

Results: According to the physical indicators and concentrations of CO_3^{2-}, HCO_3^{-}, Ca^{2+}, Mg^{2+}, Cl^{-}, SO_4^{2-}, PO_4^{3-}, Na^{+}, K^{+}, Fe, Cu, and Zn, the water in the sample was suitable for human use and consumption and agricultural use. Based on the cadmium (Cd) concentration, the water was unsuitable for human use and consumption and agricultural use, in 12 and 6 wells, respectively. According to the lead (Pb) concentration, water was suitable for agricultural use in the 16 wells studied; however, it was unsuitable for human use and consumption in any of the wells. In eight wells analyzed, the presence of fecal coliforms was lower than the permissible limit for agricultural use.

Implications: This study complements researches done in other areas of the aquifer. The causes of water pollution are unknown and researches about the vulnerability of the aquifer and the possible polluting sources should be carried out.

Conclusions: The water from the aquifer in the central zone has limitations for human use and consumption and agricultural use, as a consequence of the high Cd and Pb concentrations and its microbiological quality.

Keywords: Aquifer contamination, groundwater, wells.

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INTRODUCTION

Mexico has 653 aquifers that supply 38.9% of the water for various uses. In 2020, 157 overexploited aquifers were reported (CONAGUA, 2021). Several aquifers present inadequate water quality —in physical, chemical or biological terms, or in all three of them—, as a result of various factors that may involve human activities or of the mineral constitution of their rocks (Foster and Hirata, 1988). In the Mezquital Valley, Hidalgo, Mexico, inadequate biological quality of shallow groundwater was recorded; although it was

Image by S. Hermann & F. Richter at Pixabay used for domestic purposes and irrigation, it had been polluted by wastewater from Mexico City (Downs, Cifuentes-Garcia, and Suffet, 1999). Cardona, Carrillo, and Armienta (1993) found that the high content of heavy elements in the water of the aquifer of the City of San Luis Potosí, Mexico, is largely caused by the composition of its rocks; human activities have a minor effect. A similar situation was recorded in the Meoqui-Delicias aquifer in the state of Chihuahua, Mexico, where there are high arsenic concentrations (Espino-Valdez, Barrera-Prieto, and Herrera-Peraza, 2009). In other aquifers, groundwater may be polluted by landfill leachate (Pérez-López, Vicencio-de La Rosa, Alarcón-Herrera, & Vaca-Mier, 2002) or by the transit of wastewater in unlined canals (Ramírez, Robles, Sainz, Ayala, and Campoy, 2009; Ramírez-Flores, Robles-Valderrama, Ayala-Patiño, and Martínez-Rodríguez, 2012; Robles, Ramírez, Durán, Martínez, and González, 2013).

A study carried out in the metropolitan area of Mexico City by Soto-Galera, Marai-Hiriart, and Bojórquez-Tapia (1990) showed that the Texcoco aquifer had the largest number of wells in the area. However, groundwater pollution was not a risk, because there were few pollution sources —such as landfills or fuel deposits, gas stations, and industries. Nevertheless, that situation drastically changed in recent years. For example, Guzmán-Quintero, Palacios-Vélez, Carrillo-González, Chávez-Morales, and Nikolskii-Gavrilov (2007) observed that biological quality of wastewater from the Texcoco River was unsuitable for agricultural, public, and urban uses.

The Texcoco aquifer covers an area of 934 km^2, and it has a predominantly urban public use. This aquifer is very important, because it supplies a large population: in 2015, 3,105,559 people lived within its limits (DOF, 2019). In addition to water for human consumption, the aquifer supplies different productive activities, through 921 wells distributed in fourteen municipalities (DOF, 2015).

It faces severe overexploitation problems, with a deficit of 111.02 hm^3 (DOF, 2020). Studies about the aquifer's water quality are scarce and isolated, despite the fact that most of the surface runoff —sewage transported through unlined canals from towns, farms, and other activities—could be a source of groundwater pollution. One of the most recent studies was carried out by Martínez-Luna (2014), who focused solely on the wells of the municipality of Texcoco, finding some indications of inadequate water quality.

The continuous fall of the Static Water Level in the Texcoco aquifer (an average of 1.21 m per year) (Carrillo, Gómez, Valle, and Prado, 2016), the rise in water demand, and the increase of sewage discharges and wastewater from other activities in unlined canals pose the imperative need to find out the annual evolution of the water quality in the said aquifer. The information obtained from the central zone of the aquifer will expand the information about the water quality in the Peñón-Texcoco and Lago Nabor Carrillo areas (DOF, 2019). The information could be useful for the authorities in charge of implementing a sustainable management plan for the aquifer, which would guarantee adequate quality water. Water samples from 16 wells of the Texcoco aquifer were analyzed; those wells were located in places with a high population density and close to unlined surface runoffs. Their quality for human use and agricultural consumption was determined according to current official Mexican standards; physical, chemical, biological, and heavy metals indicators of negative impact on human health were taken into account.

MATERIALS AND METHODS

Location of the Texcoco aquifer

The Texcoco aquifer (key 1507) is located in the central-eastern portion of the Estado de México, within the Valley of Mexico hydrological basin (19° 18' and 19° 38' N and 98° 39' and 99° 03' W), with an area of 934 km^2. It comprises the municipalities of Chicoloapan, Chimalhuacán, Chiconcuac, Papalotla, and Texcoco; it covers almost all of Atenco, Chiautla, Ixtapaluca, Nezahualcóyotl, La Paz, and Tepetlaoxtoc, and part of Acolman, Ecatepec de Morelos, and Tezoyuca. There are ten main surface rivers on the aquifer, the vast majority of which are unlined and carry stormwater runoff and wastewater to the federal zone of Ex-Lago de Texcoco. Its final destination is the collector drain of the Valley of Mexico (DOF, 2019).

Water sampling and determinations

Water samples were taken from 16 wells, located in areas of high population density in the municipalities of Atenco, Chicoloapan, Chiautla, Chimalhuacán, Ixtapaluca, La Paz, Tepetlaoxtoc, and Texcoco (Figure 1). Physical, chemical, and heavy metal indicators were determined for the 16 samples. Biological determinations were made in eight of them, whose water comes from wells located near unlined surface runoffs that carry sewage or waste from other activities. The samples were collected according to the guidelines established in the NOM-014-SSA1-1993 standard (DOF, 1994), in the months of June and July 2016.

Three repetitions were used to obtain the potential of hydrogen (pH), electrical conductivity (CE), and total dissolved solids (STD) —which were considered as physical indicators. Chemical determinations were also made with three repetitions and the concentrations of calcium $\left(Ca^{2+}\right)$, magnesium $\left(Mg^{2+}\right)$, sodium $\left(Na^{+}\right)$, potassium $\left(K^{+}\right)$, carbonate $\left(CO_3^{2-}\right)$, bicarbonate $\left(HCO_3^{-}\right)$, chlorides $\left(CL^{-}\right)$, sulfates $\left(SO_4^{2-}\right)$, and phosphates $\left(PO_4^{3-}\right)$ were obtained. Five repetitions were made to obtain the concentrations of the following heavy metals: cadmium (Cd), copper (Cu), iron (Fe), lead (Pb), and zinc (Zn). With regard to the biological characterization, the most likely number of coliform bacteria per 100 mL (NMP 100 mL^{-1}) was determined based on three repetitions.

The determinations were made in specialized laboratories in Mexico, applying the guidelines established in current Mexican regulations, issued by the Secretaría de Comercio y Fomento Industrial and by the Secretaría de Economía in the Diario Oficial de la Federación. Heavy metals were obtained by atomic absorption spectrophotometry, pH and CE by potentiometry, SDT by a CE ratio, Ca^{2+}, Mg^{2+}, CO_3^{2-}, HCO_3^{-}, and Cl^{-} by volumetry, Na^{+} and K^{+} by flame spectrometry, and SO_4^{2-} and PO_4^{3-} by visible spectrometry (standards: NMX-AA-042-SCFI-2015, NMX-AA-072-SCFI-2001, NMX-AA-004-SCFI-2013, NMX-AA-006-SCFI-2010, NMX-AA-008-SCFI-2011, PROY-NMX-AA-029/1-SCFI-2008, PROY-NMX-AA-034/1-SCFI-2008, PROY-NMX-AA-051/1-SCFI-2008, PROY-NMX-AA-051/1-SCFI-2008, PROY-NMX-AA-051/2-SCFI-2008, PROY-NMX-AA-051/4-SCFI-2008, NMX- AA-115-SCFI-2001).

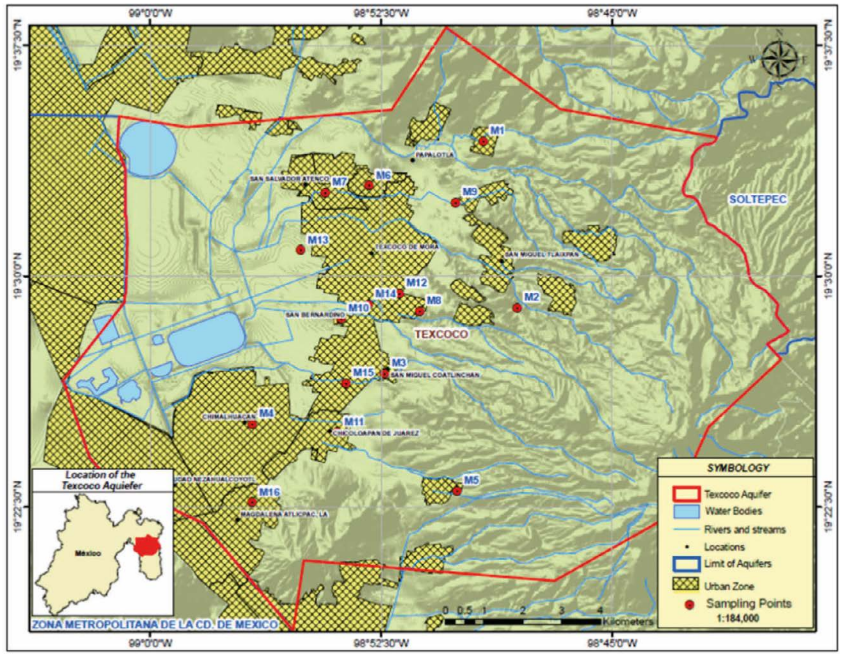

Figure 1. Limit of the Texcoco aquifer and location of the sampling wells.

Water quality analysis

The suitability of the water for human use and consumption was defined based on the permissible limits established in the modifications to the NOM-127-SSA1-1994 standard (DOF, 2000) and, for agricultural irrigation, based on the values established by the Ley Federal de Derechos de Agua 2016 (CONAGUA, 2016) and by the Criterios Ecológicos de Calidad del Agua of the CE-CCA-001/89 standard (DOF, 1989).

RESULTS AND DISCUSSION

According to the pH, CE, and STD results (Table 1), the water from the 16 wells analyzed was suitable for human use and consumption. Only in two of them (Chimalhuacán and La Pastoría), the CE value makes it unsuitable for agricultural irrigation.

In the 16 wells, the Ca^{2+}, Mg^{2+}, CO_3^{2-}, HCO_3^{-}, Cl^{-}, Na^{+}, K^{+}, SO_4^{2-} and PO_4^{3-} concentrations (Table 2) indicated that water was unsuitable for human use and consumption and agricultural use. These results are reliable, because the error of the ionic balance between anions and cations was less than the $\pm$8.0% allowed (Custodio and Llamas, 1976).

The chlorides and sulfates concentrations in the El Cooperativo well increased by 10.0 and 1.9 mg L^{-1}, respectively, with regard to the findings of Martínez (2004); meanwhile, in the San Luis Huexotla well, the said concentrations increased by 7.0 and 2.3 mg L^{-1}, respectively. In the remaining wells of the municipality of Texcoco, the pH, CE, Na^{+}, and coliforms did not present an appreciable difference.

The determinations of heavy elements resulted in minimum and maximum standard deviations of 0.0009 and 0.00128 (Zn), 0.00025 and 0.00096 (Fe), 0.00019 and 0.00043 (Cu), 0.00042 and 0.00103 (Cd), 0.0009 and 0.0021 (Pb) mg L^{-1}; therefore, the reliability of the results has been established.

Table 1. Results of the physical indicators.

Sample	Location	Municipality	pH	CE (μS cm^{-1})	STD (mg L^{-1})
M1	Tepetlaoxtoc	Tepetlaoxtoc	7.6	207.0	84.6
M2	San Miguel Tlaixpan	Texcoco	7.6	171.0	71.1
M3	San Miguel Coatlinchán	Texcoco	7.2	182.0	75.7
M4	Chimalhuacán	Chimalhuacán	7.6	503.0	210.0
M5	Coatepec	Ixtapaluca	7.1	102.0	42.6
M6	San Andrés	Chiautla	7.6	267.0	103.0
M7	La Pastoría	Atenco	7.1	644.0	267.0
M8	San Luis Huexotla	Texcoco	6.9	774.0	32.3
M9	San Joaquín Coapango	Texcoco	7.1	412.0	171.0
M10	San Bernardino	Texcoco	7.0	456.0	193.0
M11	Santiago Cuautlalpan	Texcoco	7.2	319.0	133.0
M12	Tecamachalco	La Paz	7.5	297.0	125.0
M13	San Vicente	Chicoloapan	7.0	329.0	135.0
M14	U. H. Emiliano Zapata ISSSTE	Texcoco	7.1	182.0	75.5
M15	Colonia Lázaro Cárdenas	Texcoco	7.5	306.0	125.0
M16	El Cooperativo	Texcoco	7.2	152.0	63.5

Table 2. Results of the chemical indicators.

Sample	Concentration (mg L^{-1})							
	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	HCO_3^-	Cl^-	SO_4^{2-}	PO_4^{3-}
M1	39.01	17.01	24.2	9.10	103.70	11.09	0.012	0.002
M2	13.93	4.88	25.8	8.40	70.15	11.09	0.007	0.012
M3	20.23	8.11	26.6	7.80	84.18	11.09	0.014	0.006
M4	53.62	89.63	37.7	11.50	210.45	28.84	0.073	0.018
M5	21.89	7.34	15.4	5.40	32.33	19.97	0.031	0.009
M6	43.17	28.79	27.8	11.60	134.20	15.53	0.011	0.020
M7	63.49	164.61	35.6	14.90	289.75	28.84	0.103	0.000
M8	21.39	7.49	14.9	5.90	45.75	11.09	0.007	N/D
M9	72.14	60.41	31.1	11.10	227.53	11.09	0.014	0.029
M10	66.69	67.98	31.4	9.20	195.20	24.41	0.050	0.013
M11	48.38	31.07	30.6	9.70	127.49	19.97	0.010	0.023
M12	20.61	30.29	30.4	8.40	106.75	24.41	0.012	0.005
M13	33.94	29.77	30.6	9.70	127.49	15.53	0.016	0.014
M14	20.66	5.56	26.9	8.30	62.83	15.53	0.018	0.015
M15	50.98	33.95	27.4	9.60	137.25	11.09	0.016	0.018
M16	16.14	6.46	23.5	6.50	68.32	11.09	0.011	0.004

The water from the 16 wells was suitable for human use and consumption and agricultural use, since their Zn, Fe and Cu concentrations were lower than the 2.0, 0.3 and 0.2 mg L^{-1} limits established for human use and consumption (Figure 2). In 12 of the

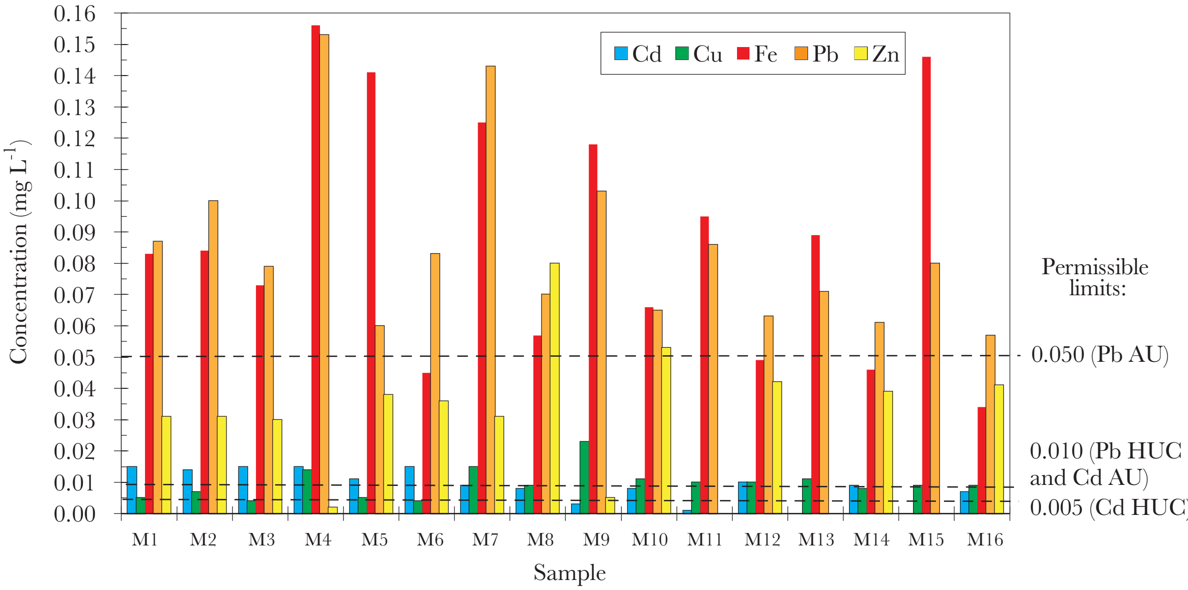

Figure 2. Cadmium (Cd) and lead (Pb) maximum concentrations and permissible limits for human use and consumption (HUC) and agricultural use (AU).

wells (1, 2, 3, 4, 5, 6, 7, 8, 10, 12, 14, and 16), water was unsuitable for human use and consumption, because Cd exceeded the maximum permissible value of 0.005 mg L^{-1}. Likewise, it was unsuitable for agricultural use in six of them (1, 2, 3, 4, 5, and 6), because it exceeded the permitted Cd concentration of 0.01 mg L^{-1}. The water from three of the wells was acceptable by a narrow margin (7, 12, and 14). With regard to maximum permissible Pb levels, water was unsuitable for human use and consumption (0.01 mg L^{-1}), but it was suitable for agricultural use (0.50 mg L^{-1}) in all the wells.

The predominant subsoil material of the first 40 m of the Texcoco aquifer is made up of clays with high porosity and low permeability (DOF, 2019) that can protect it from surface pollution (Ramos-Leal, Medrano-Noyola, Tapia-Silva, Silva-Garcia, and Reyes-Garcia, 2012). These characteristics of the aquifer should protect it from pollution by Cd and Pb, and other pollutants. However, other characteristics of the aquifer —such as a poor design and installation of the sanitary seal in extraction wells and the fractures generated by the differential subsidence, as a result of the overexploitation of the aquifer (Vargas and Ortega-Guerrero, 2004)— must be taken into consideration, because they can increase the probability of pollution by surface sources (Hernández-Espriú *et al.*, 2014; Hizar-Álvarez, Carrillo-Rivera, Ángeles-Serrano, Hergt and Cardona, 2004). In some aquifers where subsidence has not been considered, a contradiction between the vulnerability and quality of groundwater has been reported (Hernández-Espriú *et al.*, 2014; Ramos-Leal *et al.*, 2014).

The water from the eight wells that were subject to a biological analysis is unsuitable for human use and consumption, as a result of the presence of total coliforms; however, it can be used for agricultural irrigation —whose maximum permissible limit is 1,000 NMP 100 mL^{-1} (Table 3). The presence of coliforms is caused by anthropogenic pollution; they have also been detected in other aquifers in Mexico (Pérez *et al.*, 2002; Ramírez *et al.*,

Table 3. Result of the microbiological indicator.

Sample	M1	M2	M3	M4	M5	M6	M7	M8
Total coliforms (NMP 100 mL^{-1})	2.0	<2.0	9.0	<2.0	5.0	<2.0	49.0	8.0

2009; Ramírez *et al.*, 2012; Robles *et al.*, 2013), where sewage is discharged into the surface runoff without lining. Indeed, in the unlined stream of the Texcoco River, the presence of fecal coliforms far exceeds the permissible limits for irrigation and for public and urban use (Guzmán *et al.*, 2007).

The results of this research —along with the report about the poor water quality for human use and consumption in the Peñón-Texcoco and Lago Nabor Carrillo areas, as a consequence of its chlorides, STD, Fe, and Mn contents (DOF, 2019)— suggest an inadequate groundwater quality in a large extent of the Texcoco aquifer.

CONCLUSIONS

The water quality from the 16 wells analyzed was suitable for human use and consumption and agricultural use, based on the physical-chemical parameters analyzed and certain heavy metals (Zn, Fe, and Cu) it contains. Regarding the Cd content, it was unsuitable for human use and consumption in 75% of the wells studied and unsuitable for agricultural use in 38% of them. In all the wells studied, water was unsuitable for human use and consumption, but it was suitable for agricultural use, when its Pb content and presence of total coliforms were taken into account. The sustained depletion and poor water quality of the aquifer suggest the urgent implementation of responsible water extraction policies and proper wastewater management.

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