DOI: 10.24850/j-tyca-2019-01-02
Articles

Diagnosis of indicators of physical-chemical quality of water in affluents of the Atoyac River

Diagnóstico de indicadores de calidad físico-química del agua en afluentes del río Atoyac

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Abstract

In the area of Texmelucan, Puebla, the main source of irrigation water come from the melting of ice on the volcanoes and from deep wells; these sources satisfy the water needs of the agricultural area of Texmelucan and its surroundings. However, around 350 farmers also use wastewater to irrigate their crops. We evaluated some parameters that incide on the physical and chemical quality of the water when it is

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used for irrigation (pH, CE, Ca^{2+}, Mg^{2+}, K^{+}, PO_4^{2-}, SO_4^{2-}, CO_3^{2-}, HCO_3^{-}, Na^{+}, B and Cl^{-}). Random sampling was performed in 28 points, in tributaries of the Atoyac River, where water samples were taken to perform the corresponding physical and chemical analysis. Results show that the EC fluctuated between 0 and 0.875 dS m^{-1}; 64.28% were waters with a low salinity and sodium contents (class C1S1), 28.57% were waters with a medium salinity and low sodium content (clase C2S1) and 7.15% were waters with a high salinity and a low sodium content (class C3S1). On average, Ca (0.98 meq L^{-1}) and Mg (1.11 meq L^{-1}) were present in higher concentrations, which favorably modified the sodium adosrption ratio (SAR). The ion bicabronate (HCO_3^{-}) in the water presented an average of 1.83 meq L^{-1}. The concentration of Cl^{-}, HCO_3^{-}, CO_3^{-2}, B and SO_4^{-2} has not affected the established crops and the concentration of PO_4^{2-} is a significant contribution to the crops. These results indicate that the area of Texmelucan, Pue. Has adequate water for irrigation from the physical and chemical standpoint, disregarding its content of heavy metals or biological analyses.

Keywords: Municipal and industrial wastewater, salinity, sodicity, vegetables, ornamental flowers, nutrients.

Resumen

El agua para riego que se utiliza en la región de Texmelucan, Puebla, y zonas colindantes proviene, principalmente, del deshielo de los volcanes y de los pozos profundos, aunque alrededor de 350 productores emplean aguas residuales. Se evaluaron algunos parámetros que inciden en la calidad físico-química del agua cuando se utiliza con fines de riego (pH, CE, Ca^{2+}, Mg^{2+}, K^{+}, PO_4^{2-}, SO_4^{2-}, CO_3^{2-}, HCO_3^{-}, Na^{+}, B y Cl^{-}) mediante un muestreo aleatorio realizado en 28 puntos de diversos afluentes del río Atoyac. Los resultados muestran que la CE osciló entre 0 y 0.875 dS m^{-1}; el 64.28% correspondió a aguas de baja salinidad y bajo contenido de sodio (clase C1S1), el 28.57% a aguas con salinidad media y bajo contenido de sodio (clase C2S1) y el 7.15% a aguas de salinidad alta y bajo contenido de sodio (clase C3S1). En promedio, el Ca (0.98 meq L^{-1}) y Mg (1.11 meq L^{-1}) estuvieron presentes en mayor concentración, lo que modificó favorablemente los valores de la relación de adsorción de sodio (RAS). Los iones bicarbonato (HCO_3^{-}) en el agua presentaron una media de 1.83 meq L^{-1}. La concentración de Cl^{-}, HCO_3^{-}, CO_3^{-2}, B y SO_4^{-2} no ha afectado a los cultivos establecidos y la concentración de PO_{42-} es un aporte significativo a los cultivos. Estos resultados indican que la región de Texmelucan tiene agua apta para el riego desde el punto de vista físico-químico; sin considerar el contenido de metales pesados ni el resultado de los análisis biológicos de la misma.

Palabras clave: aguas residuales municipales e industriales, salinidad, sodicidad, hortalizas, flores de corte, nutrimentos.

Recived: 07/10/2015

Accepted: 02/07/2018

Introduction

Worldwide, irrigation crops account for 16% of the total of areas dedicated to agriculture (FAO, 2013). The use of surface waters and of deep wells are the two main ways in which water is obtained for its use on crops. However, the extraction of underground water has caused considerable lossses in the level of surface waters due to the overuse in agricultural areas, and this has led to a reduction in the quality of the water due to its contamination. The discharge of untreated wastewater into river tributaries have a negative impact on their use and reduce their potential for use by affecting their quality (physical, chemical and biological), which may very possibly lead to critical deficits in some regions of Mexico (Can *et al.,* 2008).

The concept of water quality has been defined by diverse authors as "the chemical, physical and biological properties of water that affect its use." Form an agricultural viewpoint, water quality refers to the type and amount of salts it contains, its effect on the soil, and crop development and growth (Letey *et al.,* 2003). The main variables that determine the quality of irrigation water, from an agricultural perspective, are the total concentration of solids dissolved or soluble salts, the relative presence of sodium, the content of carbonates and bicarbonates and the concentration of other specific ions that may be toxic, such as chlorine and boron (De Pascale & Barbieri, 1995; Castellanos, 2015). These elements, which affect the quality of water, originate in the dissolution or weathering of rocs and other edaphic components; they are transported via surface or underground currents and deposited onto the soil naturally or by irrigation (Römheld, 2002). Several parameters help determine the quality of water, including acidity and alkalinity, pH, electric conductivity (EC), the sodium adosprtion ratio (SAR) (Richards, 1982, Ayers & Westcot, 1989 effective salinity, potential salinity, and the permeability index (Cortés-Jiménez *et al*., 2008). In this sense, Cortés-Jiménez *et al*., (2009) carried out a correlation between quality indices for water with agricultural use, in which they estalished that most of the water quality indices evaluated (Na^+, Ca^{2+}, Mg^{2+}, Cl^-, SO_4^{2-} and HCO_3^-), except for SAR, were correlated with EC, wheereas the SAR values were only correlated with each other. Due to this, they concluded that both indicators are the most important ones in the diagnosis of water quality, and that the value of EC interpreted by the FAO and the calculation and interpretation of the EC according to Richards (1982) o Ayers y Wescot (1989 are the most adequate, sufficient and simplest criteria.

In the area of San Martín Texmelucan, Puebla, the production of vegetables and ornamental flowers is one of the most important activities (González-Pérez, Carrillo-Salazar, García de los Santos, Yáñez-Morales & Juárez-Muñoz, 2011). In this region, approximately 65% of the surface dedicated to agricultural production is irrigated, and the main sources of water supplies come from surface currents, springs, and the melting of ice on the Iztaccíhuatl and Popocatépetl volcanoes, which is one of the reasons for the low concentration of ions in these waters, along with the use of urban and industrial wastewater, which have different ionic concentrations and compositions, and which are easily altered due to their origin. Wastewaters contain considerable amounts of toxic ions such as bicarbonates, boron, chlorine, cadmium and fluorine, amongst others that affect some corps (Ayers & Westcot, 1989). These ions cause burns in the apex of the leaves of some cultivated plants, and the repercussion of this is a reduction of the aspect and flavor of the plant, thus affecting its price in the market.

This investigation analyzed different water samples collected in the tributaries of the Atoyac River; the area studied was the farming area of the Texmelucan Valley, which is a mountainous area which covers the municipal areas of San Felipe Teotlalcingo, San Martín Texmelucan, San Matías Tlalancaleca, Santa Rita Tlahuapan and San Salvador el Verde. With this background, and due to the absence of studies of this area on the quality of water used for irrigation, the goals of this investigation were to carry out a diagnosis of the main indicators of the quality of the water in the main tributaries of the Atoyac River, which is used for irrigation in the area of Texmelucan, Pue., and to determine the concentration of ions that affect the soil and the development of the crops irrigated with this water.

Materials and methods

Area of study

The vegetable and ornamental flower producing region of the Texmelucan Valley, Pue., is located at 19°17' N and 98°26' O at an altitude of 2,278 meters above sea level (masl). Its climate is warm and humid with a dry winter season (Cw), and an average yearly temperature of 17 °C. The rainy season begins in May and ends in October, with an average yearly rainfall of 801.6 mm and frequent rains in the afternoon. Between November and February, frosts are common (below 0 °C) and the weather is cold (5 °C) (García, 2004).

Sampling

In 2011, samples were taken from the tributaries of Achichipilco, Santa María and San Felipe del Atoyac River, and points located in the municipal areas of San Felipe Teotlalcingo, San Matías Tlalancaleca, San Martín Texmelucan, San Salvador el Verde, and Santa Rita Tlahuapan. The sampling stations were established in different points of these municipal areas with the purpose of covering the largest possible areas in which irrigation is carried out with this water (Table 1). The sampling points were chosen using the criteria of accessibility to the sampling point, that water was used for irrigating crops, and that the sampled surface covered most of the area of study. Each sample was taken from the river in intervals of 2 to 5 km apart, and in deep wells, it was taken from the discharge pool (Fig. 1).

Table 1. Identification of the sampling points located in the production area of the Texmelucan Valley, Puebla.

No	Sitio de muestreo	No	Sitio de muestreo	No	Sitio de muestreo
1	Santa María (desagüe).	11	Ejido El Banco.	21	Pozo Tlanalapan.
2	Río Santa María.	12	San Antonio A. (río).	22	San Simón Atzizintla.
3	Ameyal Santa María.	13	Atoyac (Texmelucan).	23	San Rafael Tlanalapan.
4	San Felipe (desagüe).	14	San Martín Texmelucan.	24	El Moral.
5	San Felipe Teotlacingo.	15	San Antonio A. (desagüe).	25	San Cristóbal (desagüe).
6	Ejido El Bentudero.	16	San Matías Atzala.	26	San Cristóbal Tepatlaxco.
7	San Miguel Teanguistenco.	17	Pozo Tlalancaleca.	27	Puebla de Zaragoza.
8	San Salvador El Verde.	18	Presa de Chautla.	28	Presa Manuel Ávila Camacho.
9	Ejido La Virgen.	19	Ex-hacienda de Chautla.		
10	Hagüey La Virgen.	20	Teotlalzingo.		

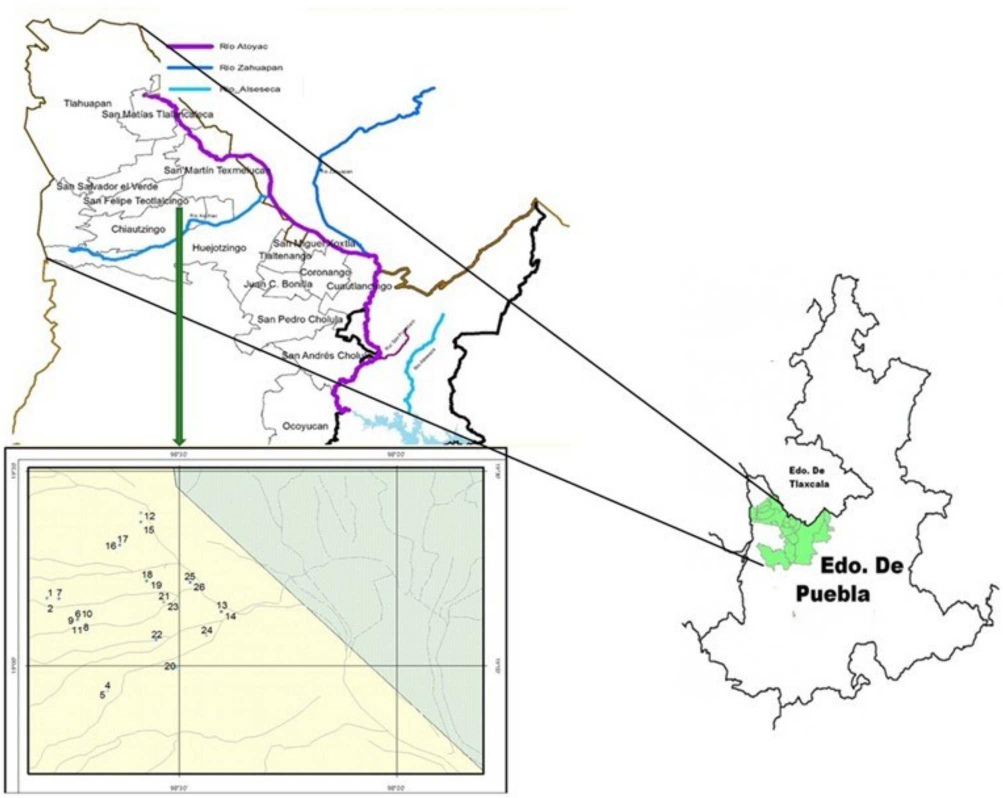

Figure 1. Geographic location of the sampling points (see Table 1 for the corresponding identification).

Collection of samples

Twenty six sampling points were chosen in the Atoyac River tributaries, and only two points out of the deep wells, which were located using a Garmin MAP60 GPS. The points were chosen strategically to know the dominant physical and chemical characteristics of the area’s water. In each point, three samples (repetitions) were taken in plastic bottles (HPDE) which were filled with 500 mL of water. The well samples were taken after the pumping equipment had been working for three hours, and in rivers, water in movement was taken directly, at an average depth of 1.0 m. Each sample was labeled with the description of the place and date of collection, general data and identification code.

In order to know the quantitative composition of the water, the samples were taken to a laboratory to perform the physical and chemical determinations (Table 2-3). The verification of the accuracy of analytical values was carried out using the methods recommended by Eaton, Clesceri, Rice, Greenberg, & Franson, 2005).

Table 2. Physical and chemical parameters evaluated in Atoyac River water samples, method used and corresponding reference.

Determination	**Method**	**Reference**
a. pH	Potentiometer	Eaton *et al.* (2005)
b. Electrical conductivity (EC)	Conductometer	Richards (1982)
c. Dry evaporated residue (DER)	Based on dry weight	APHA (1998)
d. Calcium and Magnesium	Titration	Richards (1982)
e. Sodium and Potassium	Flamometry	Greenberg (1992)
f. Boron	Titration	Page *et al*. (1982)
g. Carbonates and Bicarbonates	Titration	Richards (1982)
h. Chlorines	Titration	Richards (1982)
i. Sulfates	Turbidimetry	APHA (1998)
j. Orthophosphates	Titration	Rodier (1978)

Table 3. Permissible concentration of pH, TSD, of the main cations and anions and B (meq L^{-1}) in water for irrigation, according to Richards (1982).

Parámetro	pH	TSD	$Ca^{†}$	Mg	Na^{+}	K^{*}	CO_3^{-2}	HCO_3^{-}	Cl^{-}	$S0_4^{-2}$	B^{*}
Limite permisibl	6.5 -	<2000	0-20	0-5	0-40	0 -	0-0.1	0-10	0-3	0-20	0.7-3

e	8.4	2	0

TDS = Total dissolved solids

†mg L^{-1}.

Sodium Adsorption Ratio (SAR)

The values of the Sodium Adosrption Ratio (SAR) were studied to determine the variations under different perspectives: observed SAR (SAR), (Gapón, quoted by Ayers and Westcot, 1989; equation 1), adjusted SAR (SARaj), which considers the formation of $CaCO_3$ precipitates, although the $CaSO_4$ precpipitates continue to be ignored, as well as to compare Ca and Mg (Bower & Wilcox, 1965; equation2) and corrected SAR (SAR^o) which considers the effect of the concentrations of carbonates (CO_3^{2-}) and of bicarbonate (HCO_3^-) and the salinity (ECa) on the processes of dilution and precipitation of calcium (Suárez, 1981; equation 3).

$$SARc = 0.08 + 1.115\,RAS \quad (1)$$

$$SARaj = RAS\,[1 + (8.4 - pHc)] \quad (2)$$

$$SAR\,^\circ = \frac{C_{Na^+}}{\sqrt{\frac{C_{CA^\circ} + C_{Mg^{2+}}}{2}}} \quad (3)$$

Where Na = content of sodium in irrigation water in meq L^{-1}; Ca = content of calcium in irrigation water in meq L^{-1}; Mg = content of magnesium in irrigation water in meq L^{-1}; pHc = theoretical pH in which water would reach a balance with $CaCO_3$; and Ca^o = corrected content of calcium in irrigation water in meq L^{-1}.

The pHc was calculated using the equation $pHc = (pK2 - pKc) + p(Ca) + p(Alk)$.

Where pK_2 = the negative logarith of the second constant of dissociation of carbonic acid (H_2CO_3), corrected by the ionic strength of the solution; pKc = the product of solubility of $CaCO_3$, corrected by the ionic strength of the solution; pCa = the negative logarithm of the molar concentration of Ca^{2+}; p(Alk) = the negative logarithm of the equivalent titratable concentration of CO_3^{2-} and HCO_3-.

The value of Ca^o is the content of calcium in irrigation water, corrected by the salinity of the water (CEa), by the content of bicarbonate ions in realtion to their own calcium content (HCO_3^-/Ca^{2+}) and by the partial pressure of the carbon dioxide (CO_2) exerted on the first millimeters of soil (pressure equal to 0.0007 atm).

Results and discussion

Surface flows and springs are the main sources of irrigation water in the Texmelucan valley. However, approximately 800 farmers use urban and industrial wastewaters to irrigate their crops. With this study, we intend to get a wider and clearer view of the quality of the water from the Atoyac river tributaries in the farming area of the Texmelucan Valley. Results indicate low concentrations of ions Ca^{2+}, Mg^{2+}, Na^+, K^+, HCO_3^-, Cl^-, SO_4^{-2}, which is due to soils having low concentrations of soluble minerals (Table 4).

Table 4. Concentration of the main cations and anions and their addition, as well as pH, EC and DER* value fo wastewaters in the tributaries of the Atoyac River, Pue.

		CE				meq L^{-1}							DER
No.	**pH**	**(dS m^{-1})**	**Ca^{2+}**	**Mg^{2+}**	**Na^+**	**K^+**	**Σ**	**B**	**HCO_3^{-1}**	**Cl^-**	**$S0_4^{-2}$**	**Σ**	**mg L^{-1}**
1	6.6	0.114	0.65	0.39	0.03	0.02	1.09	0.19	0.86	0.18	0.08	1.12	82
2	6.	0.109	0.46	0.4	0.	0.	0.	0.1	0.83	0.	0.0	1.	76

	9			5	04	02	97	3		11	6	00	
3	7.0	0.109	0.46	0.53	0.05	0.02	1.06	0.15	0.84	0.10	0.05	0.99	78
4	6.5	0.289	1.07	1.55	0.04	0.02	2.68	0.33	2.31	0.25	0.16	2.72	203
5	6.8	0.164	0.6	0.64	0.20	0.12	1.56	0.26	1.03	0.45	0.10	1.58	115
6	6.9	0.138	0.5	0.67	0.07	0.06	1.30	0.19	0.85	0.39	0.09	1.33	95
7	7.1	0.128	0.50	0.63	0.04	0.02	1.19	0.11	1.03	0.13	0.05	1.21	91
8	6.8	0.126	0.50	0.63	0.05	0.02	1.20	0.12	0.86	0.25	0.07	1.18	86
9	6.9	0.138	0.50	0.65	0.08	0.05	1.28	0.23	0.85	0.33	0.12	1.30	95
10	7.0	0.132	0.50	0.62	0.11	0.03	1.26	0.26	0.79	0.31	0.13	1.23	89
11	6.8	0.126	0.60	0.44	0.08	0.07	1.19	0.17	0.86	0.18	0.18	1.22	91
12	6.9	0.283	1.3	1.18	0.12	0.02	2.62	0.19	1.68	0.75	0.17	2.60	187
13	6.6	0.875	2.56	3.15	2.15	0.38	8.24	0.63	6.92	0.85	0.77	8.54	660
14	7.1	0.358	1.40	1.66	0.14	0.08	3.28	0.21	2.32	0.85	0.16	3.33	238
15	6.7	0.378	1.05	2.13	0.33	0.05	3.56	0.28	2.08	1.25	0.18	3.51	242
16	6.9	0.164	0.80	0.58	0.15	0.02	1.55	0.31	1.20	0.30	0.07	1.57	116
17	6.9	0.214	0.80	0.95	0.13	0.08	1.96	0.19	1.55	0.27	0.16	1.98	148
18	6.7	0.230	0.67	1.34	0.09	0.06	2.16	0.18	0.11	1.75	0.28	2.14	120
19	6.5	0.230	0.63	1.37	0.07	0.06	2.13	0.24	0.46	0.71	1.01	2.18	167

20	7.3	0.151	0.65	0.73	0.03	0.02	1.43	0.20	1.03	0.25	0.13	1.41	104
21	7.3	0.150	0.68	0.08	0.05	0.13	0.94	0.22	0.95	0.36	0.12	1.43	99
22	7.0	0.164	0.80	0.62	0.06	0.02	1.50	0.19	1.25	0.20	0.06	1.51	113
23	6.9	0.138	0.45	0.62	0.16	0.04	1.27	0.53	0.92	0.33	0.04	1.29	93
24	7.2	0.252	1.10	1.15	0.08	0.03	2.36	0.33	1.95	0.25	0.16	2.36	177
25	7.0	0.442	1.71	1.80	0.25	0.38	4.14	0.19	2.86	0.98	0.28	4.12	307
26	7.0	0.440	2.19	1.75	0.12	0.05	4.11	0.08	3.42	0.50	0.24	4.16	317
27	6.9	0.667	1.77	2.25	1.75	0.35	6.12	0.56	5.19	0.50	0.58	6.27	489
28	7.2	0.818	2.55	2.58	2.20	0.39	7.72	0.52	6.19	0.93	0.72	7.84	604
Media	6.87	0.263	0.98	1.11	0.31	0.09	2.49	0.26	1.83	0.49	0.22	2.54	188.8
Mín	6.5	0.109	0.45	0.08	0.03	0.02	0.97	0.08	0.11	0.10	0.04	0.99	76
Máx	7.3	0.875	2.56	3.15	2.20	0.38	8.24	0.63	6.19	1.75	1.01	8.54	660
Med	6.90	0.164	0.74	0.84	0.10	0.05	1.76	0.21	1.12	0.35	0.16	1.78	118.0
Mode	6.90	0.164	0.50	0.62	0.05	0.02	1.93	0.19	1.03	0.25	0.16	1.97	95.00

D.R.E = Dry Evaporated Residue.

Min = Minimum Max = Maximum

Med = Medium

This study was carried out in a rural area in which the only discharges found were, practically, from agriculture and stockbreeding, which did not increase the ionic concentration of water in a significant way. However, in 25% of the sampling points, water presented alterations of the physical and chemical parameters that could potentially cause damages to some crops. These points were located in places of urban and industrial discharge, where the contributions of waste increased the concentration of the ions B, Na^{+}, CO_3^{-2} and HCO_3^{-}.

Distribution of anions and cations

The distribution of the cations and anions in the 28 points showed that the ion Mg covered the greatest surface, since it stood out in almost all sampling stations. This ion represented 44.57% of the total of cations, followed by Ca^{+2}, with 39.3% and Na^{+}, with 12.44%; this was determined by the origin of the waters from melting and from the underground. The water presented a relation $(Mg^{+2} + Ca^{+2})/Na^{+} > 3.5$, which is why the use of this water in agricultural irrigation has, to date, not caused any problems in the physical and chemical properties of the soil. The content of Na indicates that the probability of reaching dangerous levels of exchangeable sodium is low, and therefore, in a medium and short term, this water is adequate for irrigation, from the viewpoint of this variable (Richards, 1982).

The content of bicarbonate (HCO_3^{-}) ions in the water gave an average of 1.83 meq L^{-1} and a ratio of $HCO_3^{-}/(Cl^{-} + SO_4^{-2})$ of 2.57. This ratio was influenced more by the biological activity, and less by the presence of Na ions; furthermore, the 1:2 ratio represents sodification processes in the soil. While the content of Ca^{+2} ions was 0.98 meq L^{-1} on average, and content of Mg reached a value of 1.11 meq L^{-1}. The variations in the concentration of the Ca^{+2} and Mg^{+2} ions modified the values of the sodium adosrption rate (SAR) favorably. Results coincide with those by Paliwal & Gandhi (1976) and by Torres & Acevedo (2008), who mention that when the variations of Ca^{+2} and Mg^{+2} are balance, they avoid SAR from increasing and causing damage due to sodicity and salinity. The water used to irrigate ornamental flower crops contains a moderate amount of bicarbonate ions (<7.5 meq L^{-1}). This situation is favorable, since the bicarbonates have an influence on the development of flowers and, if they are excessive, white spots may appear on the leaves as a result of the aerobic and anaerobic biological activity which gives rise to most of the bicarbonate ions (Buyatti & Pilatti, 1997).

Total concentration of dissolved solids

Values showed an EC of 0.7006 dS m^{-1} obtained between the relation between total solids dissolved (TSD; mg L^{-1}) and EC (dS m^{-1}), indicating that the water of the Atoyac River tributaries contains bicarbonate ions (Ramírez, Ortega-Escobar, Rodríguez, Ramírez-Ayala, & Rone, 1989). However, the EC values obtained were within those allowed by the (Diario Oficial de la Federación (DOF), (1989), which is between 0.9 and 1.1 dS m^{-1}. The EC was determined by the origin of the water, since 92.8% of the water used to irrigate in the Texmelucan valley area are from melted ice, springs and underground well water, whereas only 7.14% corresponds to wastewater (points in which the drainages from factories and urban wastes discharge). Due to this, all the water samples presented a low EC and were classified as adequate for irrigation, considering only this variable (Olías, Cerón & Fernández, 2005), with the exception of the points in which wastewaters are discharged.

In general, EC fluctuated between 0.109 and 0.875 dS m^{-1} and the distribution of the samples was 64% between 0.1 and 0.25 dS m^{-1}, 28.57% between 0.25 and 0.75 dS m^{-1}, and 7.14% between 0.75 and 1.0 dS m^{-1} (Table 4). It is important to point out that the highest percentages came from points 13 (San Martín Texmelucan), where wastewaters from textile factories and drainage are discharged; 25 and 26 (San Cristóbal Tepatlaxco), which incorporates wastes from textile factories, farms and urban wastes; 27 (City of Puebla), in which the main source of water is the discharge of the drainage that discharges all along the river, and finally, point 28 (Manuel Ávila Camacho dam), where all the waste incorporated along the Atoyac River, accumulate.

Concentration of boron

Boron is found in all natural water, and in the region studied, boron is an abundant element, since the water runs across volcanic soil surfaces and lithological strata (Rhoades, Kandiah & Mashali, 1992). Out of all the samples taken, 85.71% had between 0.082 and 0.33 mg L^{-1}, and according to the norms by the National Water Commission (DOF, 1989), this concentration is damaging to very sensitive crops. The remaining 14.28% had between 0.33 and 0.67 mg L^{-1}. These concentrations damage crops such as avocado, lemon, raspberry, etc. (Ayers & Wescot, 1989), while in ornamental flower crops (such as gladiola) damage only occurs when the tolerance limit of 2 mg L^{-1} is surpassed. In general, we can say that the boron concentrations are found in amounts that have no toxic effects on most crops irrigated in the Texmelucan Valley and that this type of water may only damage crops that are very sensitive to this element (Torres & Acevedo, 2008). A concentration of B of over 0.3 mg L^{-1} causes toxicity in most crops, and in the area under study, only in four points was it found to surpass this concentration level. These points were located in the city of Puebla, San Cristóbal Tepatlaxco, San Martín Texmelucan, and the Manuel Ávila Camacho dam, which are places in which water from factories and urban waste are discharged.

In regards to the remaining 24 points, the boron concentration was found to change with the addition of wastewater. It began with a concentration of 0.082 mg L^{-1}, where the main source of boron were volcanic materials the water runs through (Ameyal), which emerges at the foot of the Popocatépetl volcano, while, in the path of the flow, the concentration of boron decreases, since part of this boron is fixed onto the clay complex. However, point four presented a considerable increase (0.63 mg L^{-1}) in relation to the initial concentration, mainly influenced by the incorporation of wastewater with high amounts of detergents in the town of San Felipe Teotlalzingo (28).

Concentration of sulfates

Ayers 6 Westcot (1989) mention that the water originated from urban waste normally contain between 0.01 and 2.0 mg of SO_4^{-2} L^{-1}, which has berought benefits to the soils on which this water is used, due to the sulfur in its different forms. The sulfate ion does not generally damage plants, although it does contribute to the increase in salinity in the soil solution (Glover, 1993). In this study, 96.4% of the water had a SO_4^{-2} concentration between 0.1 and 0.6 mg L^{-1}; only point 19, located in the Ex-hacienda de Chautla (3.57%) had a concentration of 1.01 mg L^{-1}. It is at this point that the discharge of wastewater from textile factories and drainages from nearby towns is incorporated. These concentrations lead to no phytotoxicity in the crops (Kowalska & Sady, 2003) and therefore the concentration of sulfates is not a risk for the soil and/or crops irrigated with this water. On the contrary, they provide significant amounts of sulfur (SO_4^{-2}) to the soils irrigated with this water, so there is the advantage that the content of sulfur provided by the water to the different crops can be subtracted from the fertilization formula used by farmers.

Classification of the water in relation to the EC and SAR (SARc, SARaj, SAR°)

The water samples from the Atoyac River tributaries were classified according to the original SAR, corrected and adjusted (Table 5). Out of all the samples, 64.28% displayed low salinity and sodium content, making them adequate for irrigation (C1-S1). However, problems may arise in soils with a low permeability and in sodium-sensitive crops; 28.57% was for water with a medium salinity and a low sodium concentration, also adequate for irrigation (C2-S1), although in certain cases, it may be required to use excessive volumes of water and use crops that are tolerant to salinity; also, some soils may present permeability problems. The remaining 7.14% was for water high in salinity (C3-S1), which may be used to irrigate soils with an adequate drainage, using excessive volumes of water to wash the excess salts from the soil and use crops that are tolerant to salinity.

Table 5. Geographic location of the sampling sites and values of the indices derived from the Sodium Adosrption Ratio (SARo, SARaj and SARc) in the tributaries of the Atoyac River.

Site	LN*	LO*	RASo	RASaj	RASc	Classification
1	19° 17' 32"	98°32' 15"	0.042	0.268	0.040	C1-S1
2	19° 17' 32"	98°32' 15"	0.059	0.398	0.056	C1-S1
3	19° 17' 32"	98°32' 15"	0.071	0.464	0.068	C1-S1
4	19° 13' 49"	98°30' 05"	0.253	0.063	0.254	C2-S1
5	19° 13' 49"	98°30' 05"	0.254	1.445	0.256	C2-S1
6	19° 16' 41"	98°31' 09"	0.092	0.562	0.088	C1-S1
7	19° 17' 31"	98°31' 50"	0.053	0.323	0.054	C1-S1
8	19° 16' 08"	98°30' 52"	0.067	0.414	0.064	C1-S1
9	19° 16' 41"	98°31' 09"	0.106	0.651	0.102	C1-S1
10	19° 16' 41"	98°31' 09"	0.147	0.920	0.139	C1-S1
11	19° 16' 41"	98°31' 09"	0.111	0.708	0.106	C1-S1
12	19° 20' 56"	98°28' 53"	0.108	0.284	0.121	C1-S1
13	19° 17' 00"	98°26' 00"	0.272	0.611	0.521	C2-S1
14	19° 17' 00"	98°26' 00"	0.273	0.613	0.523	C2-S1
15	19° 20' 56"	98°28' 53"	0.262	0.165	0.288	C2-S1
16	19° 19' 24"	98°29' 47"	0.181	0.955	0.190	C1-S1
17	19° 19' 40"	98°29' 39"	0.139	0.586	0.152	C1-S1
18	19° 18' 14"	98°28' 41"	0.090	0.465	0.047	C1-S1
19	19° 18' 14"	98°28' 41"	0.070	0.341	0.060	C1-S1
20	19° 14' 45"	98°27' 37"	0.036	0.202	0.036	C1-S1
21	19° 17' 23"	98°28' 04"	0.081	0.558	0.079	C1-S1
22	19° 15' 51"	98°28' 20"	0.071	0.374	0.076	C1-S1
23	19° 17' 23"	98°28' 04"	0.219	1.352	0.215	C2-S1
24	19° 16' 02"	098°26' 32"	0.275	0.416	0.286	C2-S1
25	19° 18' 10"	98°27' 08"	0.289	0.138	0.228	C2-S1
26	19° 18' 10"	98°27' 08"	0.085	0.073	0.061	C1-S1
27	19° 02' 36"	98°11' 50"	1.234	2.688	1.538	C3-S1
28	18° 55' 10"	98°08' 03"	1.374	2.706	1.499	C3-S1

LN = North Latitude LO = West Length.

C1-S1 = Water with low salinity and low sodium content suitable for irrigation.

C2-S1 = Water with medium salinity and low sodium content suitable for irrigation.

C3-S1 = High salinity water that can be used for irrigation of well drained soils, using excess water volumes to wash the soil and using crops that are very tolerant to salinity.

These results indicate that the entire Texmelucan Valley production area has water of a decent quality, adequate for irrigation, and there are no sodicity problems. Only in points in which wastewater is incorporated, such as San Martín Texmelucan and the Manuel Ávila Camacho dam, could there be salinity problems in soils with a low permeability and in crops with a low tolerance to salinity. Results coincide with Olías, Cerón & Fernández. (2005), who mention that there is no problem with the use of these waters due to their low EC (<0.75 dS m^{-1}) and SAR, and they can therefore be used in most soils, due to the low probability of reaching dangerous concentrations of exchangeable sodium. Meanwhile, Levy, Goldstein, & Mamedov (2005) mention that waters with a low SAR are ideal for agricultural use due to their minimum or null probability of causing salinity.

The results for the SAR obtained in this study in the different sampling points, with values that fluctuated between 0.035 (point 4: San Felipe) and 1.374 (point 28: Manuel Ávila Camacho dam), were very similar to those for SAR**c**, with values ranging between 0.036 (point 20: Teotlatzingo) and 1.538 (point 27: Puebla de Zaragoza). However, in all cases, they differed significantly to the values for SARaj, (in the range of 0.063, in point 4: San Felipe, up to 2.706 in point 28: Manuel Ávila Camacho dam), which displayed values much higher than the first two variants of the Sodium Adsorption Ratio (SAR) parameter (Table 5). This coincides with García (2012), who indicates that this was also proven in studies carried out by the Salinity Laboratory of the USDA.

Conclusions

According to the norms of classification of the National Water Commission (DOF, 1989) and considering the physical and chemical parameters evaluated in this study, the water from the Atoyac River tributaries is, in general terms, of good quality and adequate for the irrigation of vegetables and ornamental flowers currently grwon in the Texmelucan Valley. The use of wastewater is of no risk for soil quality and its use for irrigation may contribute to a more efficient agricultural production and the adoption of irrigation for an important extension of the region, as long as a more detailed chemical analysis of heavy metals is carried out, complemented by microbiological analyses. The quality of these surface waters and their chemical composition of all the elements are the reflection of the minerals they come in contact with, due to processes such as weathering, with high levels of Ca^{2+} and Mg^{2+}being particularly noticeable. To date, the ionic concentration of sodium (Na^{+}) in the tributaries of the Atoyac River has not been enough to cause sodicity problems. The concentration of SO_4^{-2} is considered a significant nutritional contribution for vegetable and ornamental flower crops. The water from deep wells is adequate for use in agriculture, since the concentrations of specific ions (potentially toxic), such as Cl and B, have not, to date, affected crops established in the Texmelucan Valley. Regarding the Sodium Adsorption Ratio (SAR), both the SARc and the corrected SAR^{o} gave more realistic values than the adjusted SARaj.

References

American Public Health Association APHA. (1998). *Standard methods for the excamination of water and wastewater.* Washington, USA: APHA-AWWA-WEF.

Ayers, R. S., & Westcot, D. W. (1989). *La calidad del agua y su uso en la agricultura.* Roma, Italia: Food and Agriculture Organization.

Bower, C. A., & Wilcox, L. V. (1965). Precipitation and solition of calcium carbonate in irrigation operations. *Soil Sci. Soc. Am., 29*, 93-94.

Buyatti, M., & Pilatti, R. A. (1997). Influence of irrigation with bicarbonates and low relation Ca/Mg water on the production of tomato seedling. *Revista FAVE, 11*.

Can Chulin, A., Ramirez, C. A., Ortega-Escobar, H. M., Trejo, L. C., & Cruz, J. D. (2008). Evaluacion de la relación adsorción de sodio en las aguas del río Tulancingo, Estado de Hidalgo, Mexico. *Terra Latinoamericana, 26*, 243-252.

Castellanos-Ramos, J. Z. (2015). La calidad del agua para fertirriego. *Intagri*, 6.

Cortés-Jiménez, J. M., Troyo-Diéguez, E., Murillo-Amador, B., García-Hernández, J. L., Garatuza-Payán, J., & Lee, S. S. (2008). Índices de la calidad del aguadel acuífero del Valle del Yaqui, Sonora. *Terra Latinoamericana, 27*, 133-141.

Cortés-Jiménez, J. M., Troyo-Diéguez, E., & Garatuza-Payán, J. (2009). *Correlación entre indicadores de la calidad del agua para uso agrícola.* (Vol. Folleto técnico 66). Centro de Investigación Regional del Noroeste. Campo Experimental Valle del Yaqui. Cd. Obregón, Sonora, México.: INIFAP.

De Pascale, S., & Barbieri, G. (1995). Effects of soil salinity from long-term irrigation with saline-sodic water on yield and quality of winter vegetable crops. *Sci. Hortic., 64*(1195), 145-157.

Diario Oficial de la Federación (DOF). (13 de Diciembre de 1989). Diario Oficial de la Federación. Recuperado el 22 de Julio de 2015, de http://www.dof.gob.mx/nota_detalle.php?codigo=4837548&fecha=13/12/1989

Eaton, A. D., Clesceri, L. S., Rice, E. W., Greenberg, A. E., & Franson, M. H. (2005). *Standard methods for the examination of water and wastewater.* Washington, USA: American Public Health Association.

García, E. (2004). *Changes to the Köeppen climate classification system* (Vol. 5a). D.F, México: Books series.

García, O. A. (2012). *Criterios modernos para la evaluación de la calidad del agua para riego (Segunda parte).* (Vol. Segunda parte). International Union of Soil Sciences (IUSS).

Glover, C. R. (1993). *Irrigation water classification systems.* New Mexico, USA: Cooperative Extension Service. New Mexico State University.

González-Pérez, E., Carrillo-Salazar, J. A., García de los Santos, G., Yáñez-Morales, M. J., & Juárez-Muñoz, J. (2011). A study of development, flower quality and fertilization in gladiolus (Gladiolus grandiflorus Hort.). *Revista Fitotecnia Mexicana, 34*, 277-283.

Greenberg, A. E., Clesceri, L. S., & Eaton, A. D. (1992). *Standard methods for the examination of water and wastewater. .* Washington, USA: American Public Health Association.

Kowalska, I., & Sady, W. (2003). Effects of different sulphate levels at the root zone on the concentration of mineral compounds in the leaves of greenhouse tomato grown on NFT. *Acta Hort, 604*(2), 499-504.

Letey, J., Sojka, E. R., Upchurch, R. D., Cassel, K. D., Olson, K. R., Payne, W. A.& Triplett, G. B. (2003). Deficiencies in the soil quality concept and its application. *Journal Soil Water Conservation, 58*(4), 180-187.

Levy, G., Goldstein, D., & Mamedov, A. I. (2005). Saturated hydraulic conductivity of semiarid soils: Combined effects of salinity, sodicity and rate of wetting. *Soil Science Society American Journal, 69*, 653-662.

Olías, M., Cerón, J. C., & Fernández, E. I. (2005). Sobre la utilización de la clasificación de las aguas de riego del U.S. Laboratory Salinity (USLS). *Geogaceta, 37*, 111-113.

Organización de las Naciones Unidas para la Agricultura y la Alimentación (FAO). (2013). *Reutilización del agua en la agricultura: Beneficios para todos* (Vol. 29). Roma, Italia: Organización de las Naciones Unidas para la Agricultura y la Alimentación.

Page, A. L., Miller, R. H., & Keeney, D. R. (1982). *Methods of soil analysis* (Vol. No. 9). Wisconsin, USA: Agronomic.

Paliwal, K. V., & Gandhi, A. P. (1976). Effect of salinity, SAR, Ca:Mg ratio in irrigation water and soil texture on the predictability of exchangeable sodium percentage. *Soil Science, 122*, 85-90.

Ramírez, M., Ortega-Escobar, H. M., Rodriguez, J. L., Ramírez-Ayala, C., & Rone, J. L. (1989). Determinación experimental de la capacidad germinativa de algunos cultivos agrícolas en soluciones salinas de diferente concentración total y composición cualitativa. *Agrociencia, 78*, 249-264.

Rhoades, J. D., Kandiah, A., & Mashali, A. M. (1992). *The use of saline waters for crop production* (Vol. Paper No. 48). Roma, Italia: Organización de las Naciones Unidas para la Agricultura y la Alimentación.

Richards, L. A. (1982). *Diagnóstico y rehabilitación de suelos salinos y sódicos* (Vol. 6ta). California, USA: Limusa.

Rodier, J. (1978). *Análisis de las aguas.* Barcelona, España: Omega.

Römheld, V. (2002). Boron in plant biology. *Plant Biology, 4*, 211-229.

Suarez, D. L. (1981). Relation between pHc and sodium adsorption ratio (SAR) and an alternate method of estimating SAR of soil or drainage waters. *Soil Sci. Soc. Amer. J., 45*, 469-475.

Torres, H. A., & Acevedo, H. E. (2008). El problema de salinidad en los recursos suelo y agua que afectan el riego y cultivos en el Valle de Lluta y Azapa en el norte de Chile. *Idesia*, 31-44.