HYDROCHEMICAL COMPOSITION AND IRRIGATION WATER QUALITY OF LERMA-CHAPALA RIVER SYSTEM, MÉXICO

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ABSTRACT

The Lerma River originates in the Almoloya lagoon, in Mexico State. It is 750 km. long and belongs to the Lerma-Santiago-Pacífico basin, one of the most important in Mexico due to its intense agricultural and industrial activity. To carry out this research, during the summer and autumn of 2013, water samples were collected and analyzed from 39 sampling stations the Lerma-Chapala river system. The objective was to know the hydrochemical composition and agronomic quality of the water in the Lerma river and lake Chapala through the determination of variables: Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, CO_3^{2-}, HCO_3^{-}, Cl^{-}, SO_4^{2-}, total dissolved solids (TDS), hydrogen potential (pH), electrical conductivity (EC) and sodium adsorption ratio (SAR). The results indicated that the type of water is sodic-bicarbonated and mixed-bicarbonated, which was attributed to the discharges of wastewater and the water supply from tributary rivers in the Lerma-Chapala Basin. The concentration of TDS was low (< 674 mg L^{-1}). The EC displayed values between 0.307 and 1.129 dS m^{-1}, which is why, in 66.6% of the sampling stations, water has no use restriction for agricultural irrigation. SAR average was 2.2 meq L^{-1}; the joint EC-SAR values suggested the classification of water as C2-S1 (74.4%) and C3-S1 (25.6%), indicating its suitability for agricultural irrigation.

Keywords: *Lerma River, Hydrogeochemistry, Salinity, Sodicity*..

1. INTRODUCTION

In Mexico and other countries, water demand has the aim of satisfying the needs of industry, the food production and, in general, the population and its consumption patterns (Rodríguez *et al*., 2009). Such is the case of the Lerma-Santiago-Pacífico basin, one of the most important in Mexico (Cotler *et al*., 2006), which due to the industrial, agricultural, and domestic use, generates water of residual origins, which is poured into the Lerma river. In this regard, Jiménez (2001) mentioned that the residual water represent sources of infection and toxicity to the human health and the environment, which, depends on its composition, concentration, time and type of contact.

In addition to the above, due to water being one of the limiting factors for agricultural production, in some cultivation areas in Mexico, wastewater is used for agricultural irrigation (Velázquez *et al*., 2002). Likewise, water from the Lerma river is used for irrigation, and in this sense, information is provided on its composition and agronomic quality through the criteria proposed by Richards *et al*. (1954) and, Ayers and Westcot (1987), who consider the risk of the salinity and sodicity of the soils and crops due to the application of water to agricultural irrigation. Regarding this, Kovda (1973) mentioned that all natural water contains dissolved substances, although the type and quantity depend on the origin and progress through the different channels. Doneen (1975) pointed out that the quality of agricultural irrigation water is determined by dissolved constituents contained, and consequently, Ayers and Westcot (1987) agreed that it depends on its ionic composition and some salinity levels. With these arguments, Velázquez *et al*. (2002), Can *et al*. (2008), Rodríguez *et al*. (2009), Can *et al*. (2011), Sánchez *et al*. (2014) considered estimating the risk of salinization and sodification of the soil due to application of the water to the irrigation, and also, the effect of the type of salinity on some crops (Can *et al*., 2014).

In relation with the hydrochemical composition, the main ions, in quite varied concentrations, are: Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, CO_3^{2-}, HCO_3^{-}, Cl^{-} and SO_4^{2-}, and therefore salinity is equal to the sum of the concentrations of all the constituents dissolved in the water, and can be expressed as EC. There are different combinations of main ions, although the predominant combinations define the type of water in which they are present. In this sense, the water type was classified as bicarbonated, due to the predominance of HCO_3^- in the sampling stations.

On the other hand, rain water contains carbonic acid which comes from the CO_2 dissolved from the atmosphere. This water comes into contact with the silicate of the rocks, which are converted into clays, releasing Na^+, K^+, Ca^{2+}, Mg^{2+} and undissociated silicic acid. In the waters in rivers and springs, HCO_3^- neutralizes the electric charges of the cations and is produced when carbonic acid is dissociated (Risacher and Fritz, 1995).

By water evaporation, the salts it contains are concentrated, and consequently, the carbonated minerals precipitate from the least soluble (calcite) to the most soluble (natron) (Risacher and Fritz, 1995; Mancilla *et al*., 2014). In this sense, the precipitation and dilution processes, the contribution of water from a different source and the el weathering of rocks bring about changes in the chemical composition of water during its flow downstream (Sánchez *et al*., 2014). In this regard, some studies agree that the water of the rivers Lerma, Zula, Santiago, and lake Chapala present changes in its chemical composition, as well as a high concentration of elements that, negatively valued, make its use impossible (Bogar, 2006; Duran and Hernández, 2010). CoWith this background, the aim of this study was to find the hydrochemical composition in the Lerma-Chapala river system, as well as to estimate some salinity and sodicity indices, and classify water according to these agronomic criteria.

2. METHODOLOGY

2.1. Study area

The Lerma-Santiago-Pacífico basin is located in the center-west portion of Mexico, and its geographic position is defined by the coordinates: 19°0´0´´, 23°0´0´´ N and 99°0´0´´, 105°0´0´´ W, approximately. Average annual temperature and rainfall in this region is 21 °C and 700 mm, respectively. The geological material of the basin is composed of andesitic and basaltic volcanic rocks (Demant, 1978; Velázquez *et al*., 2010).

The Lerma-Chapala river system is a part of this basin. The Lerma river begins in the Almoloya lagoon, in the Municipal area of Almoloya del Río, in the State of Mexico, and it flows into lake Chapala, in the state of Jalisco. It is approximately 750 kilometers long and it runs between the states of Mexico, Querétaro, Guanajuato, Michoacán and Jalisco; in these states, water is used in agriculture, to generate electric energy, for industry, and also for household uses (Cotler *et al*., 2006; Bogar, 2006; López *et al*., 2007). In its course, this river receives industrial, agricultural, and household wastewater, as well as water from several rivers (La Laja, Guanajuato, Turbio, Tigre, Duero, amongst the most important). The main dams that are part of this river system are: Antonio Alzate, Tepuxtepec and Solís.

2.2. Water sampling and chemical analysis

To carry out this investigation, water samples were gathered and analyzed from 39 sampling stations in the Lerma-Chapala river system (**Figure 1**). The samples were taken during the summer and autumn of 2013, and to do this, the methodology proposed by the ministry of trade and industry (SCFI, 1980) was considered.

The pH determination was carried out using a potentiometer [Hanna Instruments® pH 210]. The CE, expressed in dS m^{-1} in 25 °C (Richards *et al*., 1954), was determined using a bridge of electric conductivity [Hanna Instruments® HI 255]. The concentrations of Ca^{2+}, Mg^{2+}, CO_3^{2-}, HCO_3^- and Cl^-were measured by titration, and for SO_4^{2-}, by spectrophotometry (Spectronic® 20 Genesys). The concentrations of Na^+ and K^+ were determined using a flame spectrometer [Instrumentation Laboratory® Auto Cal Flame Photometer 643], and the value of TDS, by gravimetry, by evaporating the water samples at 105 °C (Richards *et al*., 1954; APHA, 1998).

2.3. Type of Water and Agronomic Quality

According to the method proposed by Piper (1944) for the interpretation of water analyses, a hydrochemical diagram was created to establish the type of water by its relative ionic dominance. The quality of water for agricultural irrigation was determined according to the criteria proposed by Richards *et al*. (1954), and Ayers and Westcot (1987) from the values of EC and SAR. The latter was calculated with the concentrations of Na^+, Ca^{2+}, and Mg^{2+} with the following mathematic expression (Richards *et al*., 1954):

$$SAR = \frac{Na^+}{\sqrt{\frac{Ca^{2+}+Mg^{2+}}{2}}} \tag{1}$$

Which SAR is the sodium adsorption ratio (meq L^{-1}).

Na^{+}, Ca^{2+}, and Mg^{2+}: corresponds to the concentration (meq L^{-1}) of these ions in water.

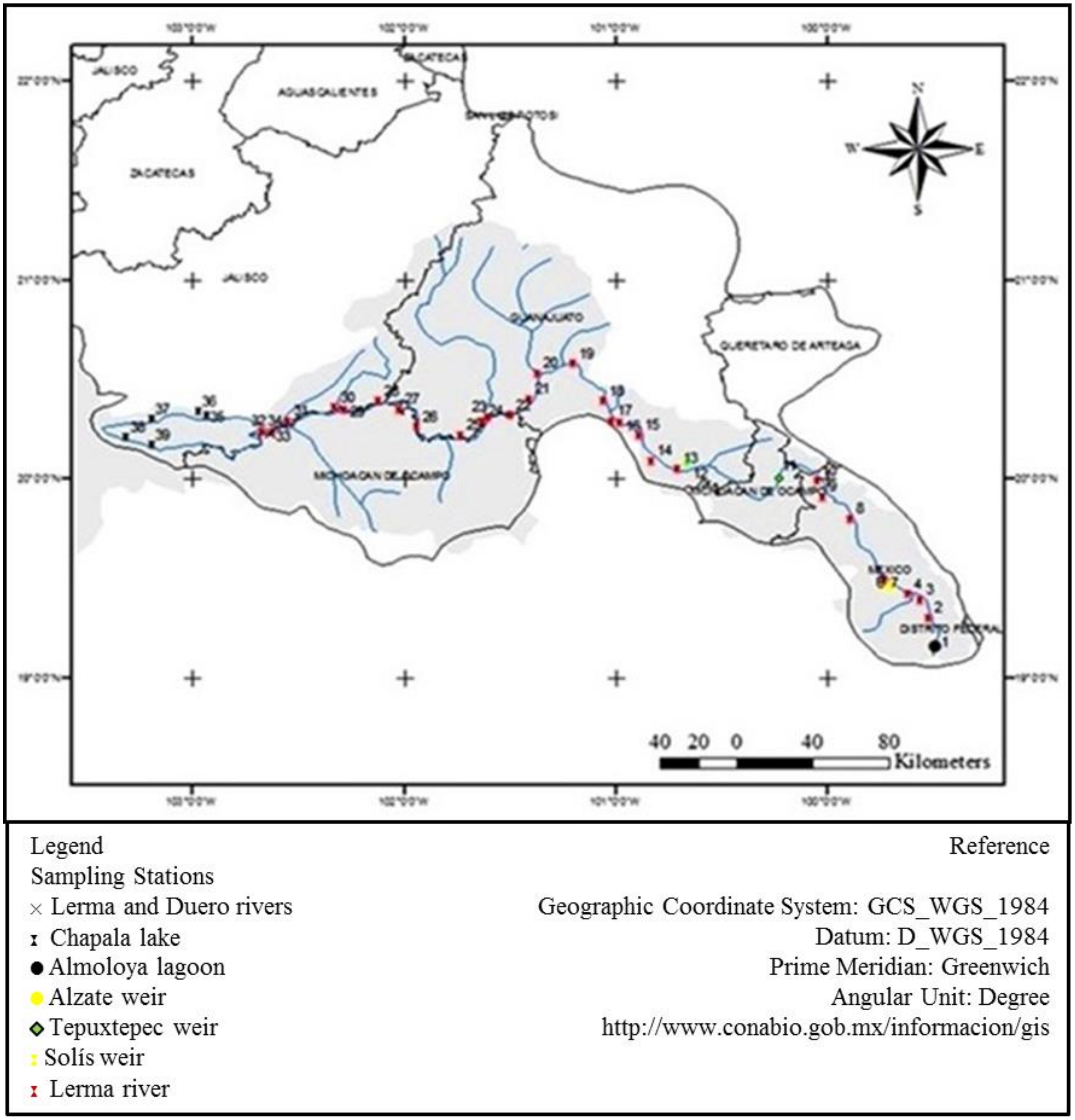

Figure 1. Location of the study area and water sampling stations in the Lerma-Chapala river system.

3. RESULTS AND DISCUSSION

3.1. Hydrochemistry of the Lerma-Chapala river system

The determination and interpretation of the chemical parameters of water indicate that the Lerma river is low in ionic concentration (STD < 674 mg L^{-1}). **Table 1** shows the type of water in the Lerma-Chapala river system and **Figure 2** shows the relative ionic composition, which is bicarbonate-sodium and bicarbonate-mixed. According to this, Velázquez *et al*. (2010), Chávez *et al*. (2011), Bing *et al*. (2012), and Sánchez *et al*. (2014) agree that ionic concentration depends on the rocks that predominate in the water source, the weather of the area, the nature of the soil on which it flows, and occasional pollution caused by human activities.

Table 1. Frequency distribution in the type of water in the Lerma-Chapala river system.

Type of water	f_i‡	P_i&	F_i†
		%	%
Bicarbonated-Sodic	20	51.3	51.3
Bicarbonated-Mixed	19	48.7	100
Total	39	100	

‡f_i: Absolute frequency; &P_i: Relative frequency; †F_i: Accumulated relative frequency

The HCO_3^- ions predominate in surface waters; in this sense, Mancilla *et al*. (2014) reported water with a low concentration, and with low HCO_3^- dominance, which they attributed to the weathering of sedimentary rocks, shales, tuffs, and basaltic and rhyolitic thicknesses from regions of the Neovolcanic Axis. Likewise, the Lerma river maintains its flow on geological materials of the Neovolcanic Axis, composed mostly of basalt and andesite (Demant, 1978; Velázquez *et al*., 2010), and because the water is in contact with these materials, it acquires a low ionic concentration, due to their low solubility. Following this, Can *et al*. (2008) report the study of the Tulancingo Hidalgo river waters as having low concentration and bicarbonated, as in this work.

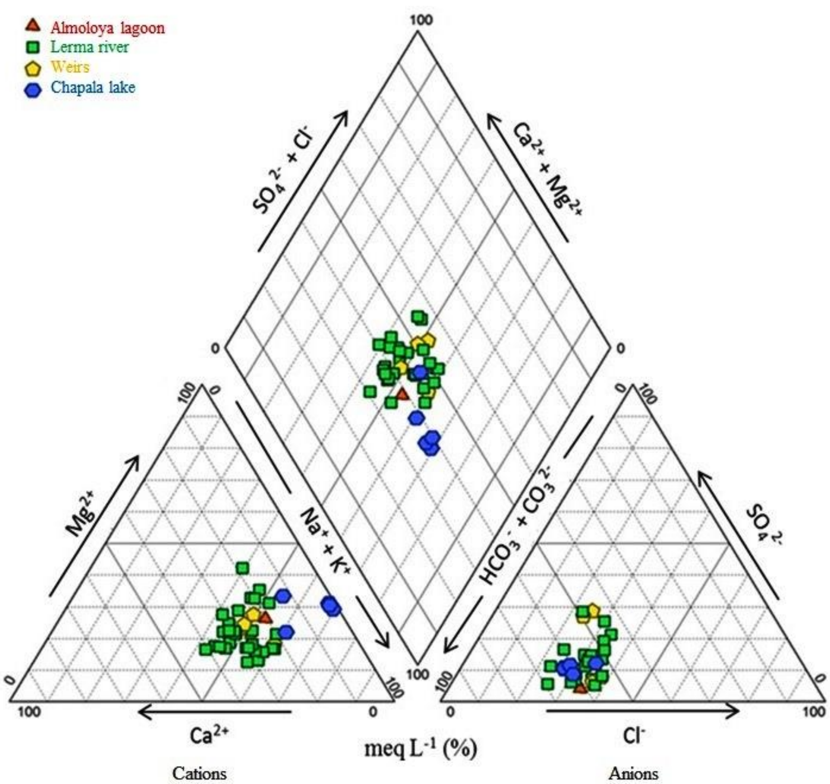

Figure 2. Diagram of the ionic composition in the Lerma-Chapala river system.

On the other hand, Sánchez *et al*. (2014) found bicarbonated-calcic waters and indicated that its composition is due, mostly, to the weathering of metamorphic rocks. Likewise, Arenal (1985) found the predominance of a hydrogeochemical group that corresponds to the family of bicarbonated-sodic waters, and attributed the values of HCO_3^- to the presence of organic matter and biological activity generated by CO_2 in water. This paper does not determine the organic matter content. The presence of bicarbonated-mixed water was attributed to the discharge of wastewater, rainfall contributions, as well as contributions by the tributaries of the Lerma river that provide this mixture of waters, while diluting its concentration. Lecomte *et al*. (2011), as in the present paper, classified water by ionic dominance as bicarbonated-mixed in some rivers. The studies performed by Kovda (1973), and Ayers and Westcot (1987) displayed a low ionic concentration in surface waters, and provide evidence of the dominance of HCO_3^- and Na^+ in the rivers in several regions of the world.

The results of the ionic composition found by Chávez *et al*. (2011) in lake Chapala, coincide with those reported by this work and can be attributed to the mixture of water with agricultural drainages and to the discharge of wastewater from a different source.

The ionic composition of the water is shown in **Table 2**. The values of Ca^{2+} and $Mg^{2+}$are lower compared to Na^+, which is the dominant cation. Its highest value (6.3 meq L^{-1}) is found in lake Chapala. The concentration of K^+ is lower than 1.2 meq L^{-1}. The dominant anion is HCO_3^-, and no CO_3^{2-} was found since the pH is lower than 8.4 in most cases. The discharge of wastewater modifies these concentration values, therefore the water mixture found.

Sukumaran (2000) mentioned that river water presents a dominance of HCO_3^-. Can *et al*. (2011) on the other hand, indicated, as Kovda (1973), that these contain considerable amounts of dissolved sodium bicarbonate and calcium, which they attribute to the washing of the tuffaceous and sedimentary deposits. These rocks are weathered during the flow of the water, which is why they acquire a similar composition to the minerals with which they come into contact.

Table 2. Ionic composition of water and and geographical location of the sampling stations in the Lerma-Chapala river system.

Sampling stations	Geographical position		Altitude	Ca^{2+}	Mg^{2+}	Na^+	K^+	CO_3^{2-}	HCO_3^-	Cl^-	SO_4^{2-}
	Latitude N	Longitude W	m	meq L^{-1}							
01. Almoloya Lagoon (Almoloya del Río, Edo. de México)	19°09'18.3''	99°29'35.3''	2588	1.80	2.28	3.45	1.20	0.00	5.24	2.90	0.36
02. Lerma River (Cd. Lerma, Edo. de México)	19°17'10.2''	99°31'19.4''	2586	0.90	2.08	1.50	0.45	0.00	2.85	1.15	0.79
03. Lerma River (Xonacatlán, Edo. de México)	19°22'43.7''	99°33'21.5''	2585	1.60	2.92	4.05	0.78	0.00	5.96	2.10	1.03
04. Lerma River (Tlachalaya, Edo. de México)	19°24'40.8''	99°37'6.7''	2579	1.40	2.20	2.50	0.61	0.00	2.91	1.95	1.66
05. Alzate weir (glass), (Antonio Alzate, Edo. de México)	19°27'57.6''	99°42'11.7''	2569	1.40	1.18	2.20	0.55	0.00	2.39	1.30	1.47
06. Alzate weir (drain), (Antonio Alzate, Edo. de México)	19°28'00.6''	99°42'19.9''	2564	1.30	1.57	2.20	0.61	0.00	2.71	1.30	1.48
07. Lerma River (Ixtlahuaca, Edo. de México)	19°28'31.5''	99°44'01.2''	2557	1.40	1.22	2.20	0.61	0.00	2.57	1.20	1.49
08. Lerma River (Atlacomulco, Edo. de México)	19°47'20.0''	99°53'38.8''	2510	1.20	0.94	1.25	0.49	0.00	2.07	1.12	0.56
09. Lerma River (Temascalcingo, Edo. de México)	19°54'12.1''	100°01'20.1''	2414	1.10	0.89	1.10	0.50	0.00	2.14	1.10	0.24
10. Lerma River (Ex-Hacienda de Solís, Edo. de México)	19°58'43.2''	100°03'09.2''	2367	0.59	1.20	1.10	0.51	0.00	1.88	1.18	0.24
11. Tepuxtepec weir (Michoacán)	19°59'52.8''	100°13'42.1''	2350	1.12	0.92	2.35	0.67	0.00	2.66	1.85	0.38
12. Solís weir (Acámbaro, Guanajuato)	20°04'06.7''	100°39'53.4''	1901	1.40	1.28	2.20	0.35	0.00	2.92	1.85	0.31
13. Lerma River (Acámbaro, Guanajuato)	20°02'21.9''	100°42'51.4''	1859	1.40	0.78	1.50	0.50	0.00	2.44	1.25	0.36
14. Lerma River (Chamácuaro, Guanajuato)	20°04'52.0''	100°49'42.8''	1855	0.60	0.98	0.97	0.45	0.00	1.83	0.90	0.18
15. Lerma River (Salvatierra, Guanajuato)	20°12'39.9''	100°53'10.2''	1787	1.40	0.65	1.10	0.55	0.00	2.49	0.90	0.20
16. Lerma River (El Capulín, Guanajuato)	20°16'13.4''	100°59'01.2''	1763	1.74	0.70	1.25	0.58	0.00	2.37	1.55	0.22
17. Lerma River (El Sabino, Guanajuato)	20°17'01.3''	101°01'17.2''	1752	1.70	0.80	1.65	0.62	0.00	2.49	1.75	0.38
18. Lerma River (Jaral del Progreso, Guanajuato)	20°22'35.5''	101°03'25.1''	1726	1.66	1.20	3.65	0.73	0.00	3.99	2.25	0.79
19. Lerma River (Salamanca, Guanajuato)	20°33'55''	101°11'59.1''	1738	2.01	0.90	3.25	0.77	0.00	3.69	2.15	0.91
20. Lerma River (Pueblo Nuevo, Guanajuato)	20°31'23.5''	101°22'6.4''	1732	1.54	1.10	3.20	0.71	0.00	3.26	2.25	0.85
21. Lerma River (Las Estacas, Guanajuato)	20°23'24.5''	101°24'43.6''	1717	1.77	0.70	2.40	0.68	0.00	2.84	1.75	0.78
22. Lerma River (Pastor Ortiz, Michoacán)	20°18'43.7''	101°29'58.2''	1709	1.93	1.15	3.45	0.79	0.00	3.46	2.40	1.25
23. Lerma River (Pastor Ortiz, Michoacán)	20°17'52.7''	101°36'9.6''	1701	2.10	2.30	3.15	0.44	0.00	3.50	2.61	1.64
24. Lerma River (La Calle, Michoacán)	20°16'59.5''	101°37'53.1''	1687	1.70	1.80	4.46	0.51	0.00	3.94	2.71	1.57
25. Lerma River (El Mármol, Guanajuato)	20°12'52.9''	101°43'50.7''	1682	2.10	1.20	3.65	0.49	0.00	3.57	2.50	1.18
26. Lerma River (Numarán, Michoacán)	20°15'4.5''	101°56'24.0''	1676	1.90	1.22	3.20	0.46	0.00	3.63	2.15	0.83
27. Lerma River (La Piedad, Michoacán)	20°20'34.8''	102°1'11.6''	1683	1.50	0.84	2.20	0.43	0.00	2.66	1.54	0.62
28. Lerma River (Palo Blanco del Salto, Jalisco)	20°22'44.5''	102°7'10.2''	1623	1.50	0.87	2.30	0.44	0.00	2.70	1.59	0.64
29. Lerma River (La Rivera, Jalisco)	20°20'40.6''	102°16'51''	1534	1.50	1.05	1.90	0.46	0.00	2.56	1.53	0.70
30. Lerma River (La Concepción, Jalisco)	20°20'48.8''	102°19'46.0''	1533	1.50	1.33	1.55	0.46	0.00	2.60	1.51	0.60
31. Lerma River (Paso de Hidalgo, Michoacán)	20°16'30.5''	102°32'50.5''	1542	1.60	0.76	1.55	0.44	0.00	2.34	1.36	0.54
32. Lerma River (Ibarra, Michoacán)	20°14'3.2''	102°37'29.8''	1538	1.23	0.90	1.50	0.42	0.00	2.46	1.07	0.41
33. Lerma River (Ibarra, Michoacán)	20°13'58.2''	102°37'31''	1538	1.26	0.84	1.30	0.39	0.00	2.30	1.01	0.38
34. Lerma River (Maltaraña, Jalisco)	20°13'34.4''	102°40'24.4''	1524	1.20	0.85	1.30	0.43	0.00	2.30	1.01	0.37
35. Chapala Lake (Agua Caliente, Jalisco)	20°18'43.8''	102°55'51.8''	1527	0.15	3.05	6.25	1.01	0.30	6.29	2.83	1.14
36. Chapala Lake (San Pedro Itzicán, Jalisco)	20°19'31''	102°58'16.6''	1528	0.17	3.39	6.25	1.04	0.35	6.48	2.91	1.14
37. Chapala Lake (Chapala, Jalisco)	20°17'7.8''	103°11'36.9	1538	0.19	3.33	6.35	1.06	0.45	5.99	2.97	1.23
38. Chapala Lake (Soyatlán, Jalisco)	20°12'1.5''	103°18'19.1''	1528	1.20	3.21	4.45	0.81	0.00	5.02	3.25	1.14
39. Chapala Lake (Tuxcueca, Jalisco)	20°09'30.0''	103°11'06.4''	1523	1.80	2.30	5.50	0.87	0.90	5.30	3.05	0.88
			Mínimum	0.15	0.65	0.97	0.35	0.00	1.83	0.90	0.18
			Maximum	2.10	3.39	6.35	1.20	0.90	6.48	3.25	1.66
			Average	1.37	1.45	2.70	0.61	0.05	3.30	1.83	0.79
			Standard deviation	0.49	0.81	1.51	0.20	0.17	1.29	0.69	0.45

On the other hand, SO_4^{2-} comes from the oxidation of the sulfated minerals, including sodium sulfate, magnesium sulfate, and calcium sulfate; another source of sulfate is the discharge of industrial wastewater which contains sulfuric acid. The concentration of SO_4^{2-} was low in this case. The highest value (1.6 meq L^{-1}) is due to the discharge of industrial wastewater and to the agricultural drainages of the areas in which phosphated fertilizer is used. Regarding this, Chávez *et al*. (2011) attributed the concentration of Na^+ and SO_4^{2-} to agricultural drainages, the discharge of wastewater, and they also related Ca^{2+} and Mg^{2+} with Na^+ and SO_4^{2-}, and indicated that these ions come from the drains; in this sense, Cl^- also comes from wastewaters spilled into the Lerma river.

3.2. Classification of water for agricultural irrigation

Natural waters are not pure. They contain dissolved substances (Kovda, 1973), which can be measured in different ways using evaporated residue (TDS), although it is useful to verify results. The most adequate way to measure salinity refers to the sum of all ions found. Based on the salinity measurements (EC and TDS), **Table 3** shows that the relation between EC and the sum of ions is highly significant (r=0.881; α=0.01); the same applies to the sum of ions and TDS (r=0.859; α=0.01); similarly, the relation between EC and TDS is highly significant (r=0.987; α=0.01); as a verification, based on these relations, the results are correct (APHA, 1998).

Table 3. Matrix of correlation variables: sum of ions, electrical conductivity, and total dissolved solids.

	Ions (mg L^{-1})	EC (dS m^{-1})	TDS (mg L^{-1})
Ions (mg L^{-1})	1		
EC (dS m^{-1})	0.881**	1	
TDS (mg L^{-1})	0.859**	0.987**	1

N=39; α=0.01

Results on the pH display values from 6.74 to 8.43 (**Table 4**), which indicates that slightly neutral-alkaline conditions predominate. The highest values were found in lake Chapala (between 8.18 and 8.43); similar values were reported by Chávez *et al*. (2011). The importance of this indicator lies in the solubility of some substance, and is related to the concentration of CO_3^{2-} and HCO_3^-, since no CO_3^{2-} is found when the pH is lower than 8.4 (Richards *et al*., 1954) as observed in this work.

According to the TDS values (< 674 mg L^{-1}), the water is classified as sweet and low in salts (Larios, 1950). The salinity, expressed in terms of EC, displays values between 0.307 and 1.129 dS m^{-1}, and in this sense, salinity is low in most cases. The increase in EC is due to the concentration of ions derived from the mixture of water with household, industrial and agricultural, drainages (Velázquez *et al*., 2010).

Richards *et al*. (1954), indicated that EC expresses the total content of salts, although, with irrigation purposes, it is necessary to determine all of the ions, since the saline effect on crops is different with each salt, concentration, and type of crop (Can *et al*., 2014). In this regard, Sánchez *et al*. (2013) agree that it will depend on the tolerance of a specific crop at extreme levels of ionic concentration.

The quality of the water for agricultural irrigation is determined by the concentration and type of ions it contains, since the high concentration of salts may have harmful effects on the crops. Suitability of water for irrigation is based on its salinity, sodicity and toxicity (Hagras, 2013), in this sense, according to Ayers and Westcot, when the EC in the water is lower than 0.700 dS m^{-1}, there is no restriction on its use, the restriction is slight when the EC is between 0.700 and 3.00 dS m^{-1}. In this study, the values of EC show that there is no restriction of use in 67% of the water samples and the restriction of use is lighter in 33%. The SAR values found range between 1.09 and 4.94, which indicates, according to Richards *et al*. (1954), that there is a low risk of sodicity in these waters. The joint values of EC-SAR, as risk indicators of the relative reduction of water infiltration in the soil, suggest that 82% of the water samples have slight use restrictions of slight use for the agricultural irrigation application (Ayers and Westcot, 1987); the rest can be used without restriction.

Table 4. Physical parameters and water classification in the Lerma-Chapala river system.

Sampling stations	pH	EC¨	SAR¹	TDS'''	Type of water	Classification

		dS m^{-1}	meq L^{-1}	mg L^{-1}		EC-SAR‡	EC-SAR& (Restricted use)
01. Almoloya Lagoon (Almoloya del Río, Edo. de México)	7.26	0.893	2.415	592	Bicarbonate-Sodium	C3-S1	None
02. Lerma River (Cd. Lerma, Edo. de México)	6.88	0.504	1.229	290	Bicarbonate-Mixed	C2-S1	Light
03. Lerma River (Xonacatlán, Edo. de México)	6.98	0.956	2.694	556	Bicarbonate-Sodium	C3-S1	None
04. Lerma River (Tlachalaya, Edo. de México)	6.78	0.686	1.863	378	Bicarbonate-Mixed	C2-S1	Light
05. Alzate weir (glass), (Antonio Alzate, Edo. de México)	7.39	0.545	1.937	318	Bicarbonate-Sodium	C2-S1	Light
06. Alzate weir (drain), (Antonio Alzate, Edo. de México)	6.89	0.581	1.837	334	Bicarbonate-Mixed	C2-S1	Light
07. Lerma River (Ixtlahuaca, Edo. de México)	6.74	0.555	1.922	316	Bicarbonate-Sodium	C2-S1	Light
08. Lerma River (Atlacomulco, Edo. de México)	6.75	0.397	1.208	226	Bicarbonate-Mixed	C2-S1	Light
09. Lerma River (Temascalcingo, Edo. de México)	6.94	0.367	1.103	224	Bicarbonate-Mixed	C2-S1	Light
10. Lerma River (Ex-Hacienda de Solís, Edo. de México)	6.82	0.348	1.163	234	Bicarbonate-Mixed	C2-S1	Light
11. Tepuxtepec weir (Michoacán)	7.72	0.515	2.327	332	Bicarbonate-Sodium	C2-S1	Light
12. Solís weir (Acámbaro, Guanajuato)	7.81	0.535	1.901	322	Bicarbonate-Mixed	C2-S1	Light
13. Lerma River (Acámbaro, Guanajuato)	7.49	0.427	1.437	290	Bicarbonate-Mixed	C2-S1	Light
14. Lerma River (Chamácuaro, Guanajuato)	7.15	0.307	1.091	252	Bicarbonate-Mixed	C2-S1	Light
15. Lerma River (Salvatierra, Guanajuato)	7.10	0.378	1.087	262	Bicarbonate-Mixed	C2-S1	Light
16. Lerma River (El Capulín, Guanajuato)	7.10	0.437	1.132	266	Bicarbonate-Mixed	C2-S1	Light
17. Lerma River (El Sabino, Guanajuato)	6.90	0.488	1.476	326	Bicarbonate-Mixed	C2-S1	Light
18. Lerma River (Jaral del Progreso, Guanajuato)	7.30	0.740	3.052	460	Bicarbonate-Sodium	C2-S1	None
19. Lerma River (Salamanca, Guanajuato)	7.20	0.709	2.694	436	Bicarbonate-Sodium	C2-S1	None
20. Lerma River (Pueblo Nuevo, Guanajuato)	7.30	0.670	2.785	424	Bicarbonate-Sodium	C2-S1	Light
21. Lerma River (Las Estacas, Guanajuato)	7.30	0.568	2.160	374	Bicarbonate-Sodium	C2-S1	Light
22. Lerma River (Pastor Ortiz, Michoacán)	7.00	0.749	2.780	502	Bicarbonate-Sodium	C2-S1	None
23. Lerma River (Pastor Ortiz, Michoacán)	7.18	0.817	2.124	518	Bicarbonate-Mixed	C3-S1	None
24. Lerma River (La Calle, Michoacán)	6.99	0.867	3.371	508	Bicarbonate-Sodium	C3-S1	Light
25. Lerma River (El Mármol, Guanajuato)	7.03	0.761	2.842	476	Bicarbonate-Sodium	C3-S1	None
26. Lerma River (Numarán, Michoacán)	7.11	0.693	2.562	434	Bicarbonate-Sodium	C2-S1	Light
27. Lerma River (La Piedad, Michoacán)	7.73	0.508	2.034	336	Bicarbonate-Sodium	C2-S1	Light
28. Lerma River (Palo Blanco del Salto, Jalisco)	7.27	0.523	2.113	312	Bicarbonate-Sodium	C2-S1	Light
29. Lerma River (La Rivera, Jalisco)	7.04	0.502	1.683	312	Bicarbonate-Mixed	C2-S1	Light
30. Lerma River (La Concepción, Jalisco)	7.12	0.495	1.303	316	Bicarbonate-Mixed	C2-S1	Light
31. Lerma River (Paso de Hidalgo, Michoacán)	7.13	0.445	1.427	274	Bicarbonate-Mixed	C2-S1	Light
32. Lerma River (Ibarra, Michoacán)	7.25	0.418	1.454	276	Bicarbonate-Mixed	C2-S1	Light
33. Lerma River (Ibarra, Michoacán)	7.17	0.391	1.269	268	Bicarbonate-Mixed	C2-S1	Light
34. Lerma River (Maltaraña, Jalisco)	7.48	0.387	1.284	274	Bicarbonate-Mixed	C2-S1	Light
35. Chapala Lake (Agua Caliente, Jalisco)	8.32	1.080	4.941	670	Bicarbonate-Sodium	C3-S1	Light
36. Chapala Lake (San Pedro Itzicán, Jalisco)	8.43	1.109	4.685	674	Bicarbonate-Sodium	C3-S1	Light
37. Chapala Lake (Chapala, Jalisco)	8.40	1.129	4.786	670	Bicarbonate-Sodium	C3-S1	Light
38. Chapala Lake (Soyatlán, Jalisco)	8.18	0.989	2.997	588	Bicarbonate-Sodium	C3-S1	None
39. Chapala Lake (Tuxcueca, Jalisco)	8.34	1.071	3.841	644	Bicarbonate-Sodium	C3-S1	Light
Minimum	6.74	0.30	1.08	224.00			
Maximum	8.43	1.12	4.94	674.00			
Average	7.30	0.62	2.20	391.38			
Standard deviation	0.47	0.47	1.03	137.74			

”EC: electrical conductivity (dS m^{-1} a 25 °C); ⁞SAR: sodium adsorption ratio; ‴TDS: total dissolved solids; ‡EC-SAR: classification proposed by Richards *et al*. (1954); &EC-SAR: restricting use by the relative reduction in infiltration (Ayers and Westcot, 1987).

4. CONCLUSIONS

According to the results obtained, under the conditions in which this study was conducted, we conclude that the water in the Lerma-Chapala river system has a low ionic concentration of bicarbonate-sodium and bicarbonate-mixed.

Given that the water of the Lerma river is composed of surface runoff, the time of concatc with the rocks is very low, which is why there is not a high ionic concentration. The water mixture is due to this river not being the main flow, and therefore, it receives several tributary flows. Likewise, it receives wastewater in its entire course. The ionic concentration is higher in Chapala lake since it receives water carried by the Lerma river. Also, the time in which the water remains is higher that in the runoff water, which allows for a greater ionic concentration. For this reason, the hydrochemical characteristics of the Lerma-Chapala river system are influenced by the effects of the concentration and dilution by the evaporation effect, contribution of wastewater and rainwater.

Out of all the samples analyzed, according to the values of EC, 67% have no use restrictions. The SAR values shows that the application of the water doesn’t represent a risk of sodicity for the soil, and therefore, based on the combined results of EC-SAR, the water quality is acceptable for irrigation, in most cases.

Lastly, because this research was carried out during the rainy season, the values of ionic concentration in the water were influenced by this factor, and it is necessary to evaluate their composition and agronomic quality in different periods to have a broader view about the changes in chemical composition displayed by the Lerma-Chapala river system. It is also convenient to determine some microbiological quality parameters and concentration levels of toxic metals, which were not evaluated in this work.

5. ACKNOWLEDGEMENTS

By this means, the authors wish to thank the National Science and Technology Council of Mexico for assigning funds for the research during the Project with key and CVU registration number: 510203.

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