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Study on Phreatic Wastewater from Temascalcingo Irrigation District, Mexico State, Mexico

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Abstract

Groundwater and its effect on soil quality were studied on the Temascalcingo Irrigation District, State of Mexico, Mexico; irrigated with wastewater from the Lerma River and located at 19°54'10.5''N and 100°01'20.9''W. A sampling of the network of existing observation wells and collection sources was carried out in the Spring of 2009 (April) and Summer of 2010 (August). Physicochemical properties of the waters, depth, and height of water table were estimated. In the Spring of 2009, it was found that 16.2% and 37.8% of the study area had a water table depth between 0.0 to 0.5 m, and 0.5 to 1.0 m respectively, allowing it to accumulate salts on surface horizons, because of action of the direction of the underground flow. In Spring 2009, 67% of the study area (1,340 hectares) was found with electrical conductivity between 750 to 1,250 μScm^{-1} and 23.3% (466 hectares) between 1,250 to 2,250 μScm^{-1}; increasing up to 70.6% (1,412 hectares) the range from 750 - 1,250 in Summer 2010. Regarding content of cations and anions, the order of predominance of hypothetical salts was: $NaCl > Ca(HCO_3)_2 > NaHCO_3 > MgSO_4 > Mg(HCO_3)_2 > KHCO_3$. Generally, more than 54% of the water table presented high values of electrical conductivity (μScm^{-1}) total dissolved solids (mgL^{-1}), osmotic pressure (*atm*) and water table depth less than 1m; representing a high risk of salinity or sodicity for the soil.

Keywords: Irrigation districts, groundwater, sewage, isobaths, isohypses, hypothetical salts.

I. INTRODUCTION

Rapid development of irrigation agriculture has led to excessive use of easily accessible water sources, such as rivers, lakes and groundwater. Consequently, there is currently a problem of scarcity of water sources of good agricultural quality, associated with other problems such as over-exploitation of aquifers, salinity and sodicity of soils and contamination of surface and underground sources. To solve the scarcity problem, various alternatives have been proposed, ranging from optimization of available sources to use of unconventional sources, such as use of urban-industrial wastewater [1, 2], which contains compounds derived from industrial processes, such as toxic metals and soluble salts, and have adverse effects on soils, e.g., accumulation of soluble salts, sodification and presence of heavy metals. The predominance of sodium (Na^+) over calcium (Ca^{2+}) and magnesium (Mg^{2+}) ions in the soil solution, favors an alkaline reaction (pH> 8.0 to 9.0), due to the gradual solubilization of the clay systems from the soils by hydrolysis, and with it, the destruction of the structure. Affectation degree of soils by sodification processes, is a function of the physicochemical and mineralogical characteristics of these and the waters used for irrigation [3].

In general terms water quality, refers to characteristics that may affect its adaptability to a specific use, determined by its physical, chemical, and biological properties. Quality of irrigation water is determined by quantity and type of salts within, formed by specific ions of Ca^{2+}, Mg^{2+}, K^+, Na^+, CO_3^{2-}, HCO^{3-}, SO_4^{2-}, Cl^- and others of lower proportion, such as B^{3-}, Si^{4-}, PO_4^{2-} y NO^{3-} [4]. Thermodynamic theory makes it possible to predict how components will react in systems of different complexity, even multiphase and multi components, and what the final state of the system will be once the reactions have ended.

The application of these concepts is very useful in waters, allowing to understand the origin of their composition and the cause of their spatial and temporal variations [2, 3]. Water quality considers three criteria; salinity, sodicity and toxicity. The salinity criterion assesses the risk that use of water causes high concentrations of salts, with the corresponding osmotic effect and decreased crop yield. The sodicity criterion analyzes the risk of inducing a high exchangeable sodium percentage (ESP), with deterioration of the soil structure. Toxicity studies the problems that certain ions may create. The sodium adsorption ratio (SAR) of the soil solution, saturation extract, irrigation water and groundwater; has been used as a fundamental parameter for diagnosing soil sodicity risks; determined by the absolute and relative concentrations of calcium, magnesium, and sodium cations. If the proportion of sodium is high, risk of sodification will be greater and, conversely, if calcium and magnesium predominate, risk of sodium is lower [5].

The theoretical demonstration from the Gapon equations for cationic exchange, in irrigation waters with a maximum ionic concentration of 50, has made it possible to determine different formulations to calculate the SAR; such as original or explicit SAR (SARor), adjusted SAR (SARaj) and corrected SAR (SAR°); which provide for the probability that concentrations of calcium ions Ca^{2+} in soil solutions, increase or decrease due to different physical and chemical processes occurring in soils. The SAR that will participate and have the capacity to interact with the cation exchange complex will be the one formed by real concentrations of sodium (C_{Na+}) and calcium (C_{Ca+}), which will be the negative charge compensating ions ($\sum n^-$) of the colloidal systems of the soils, complying with the law of mass action [6, 7]. The objective of this research study was to evaluate the effect of the dynamics of water tables with recharge of wastewater on soil quality.

II. METHOD

II.I Area of study

The study area is shown in figure 1, corresponding to the Riego Temascalcingo District, State of Mexico, Mexico, irrigated with wastewater from the Lerma River, and which has a network of observation wells for depth monitoring and salinity of the water table.

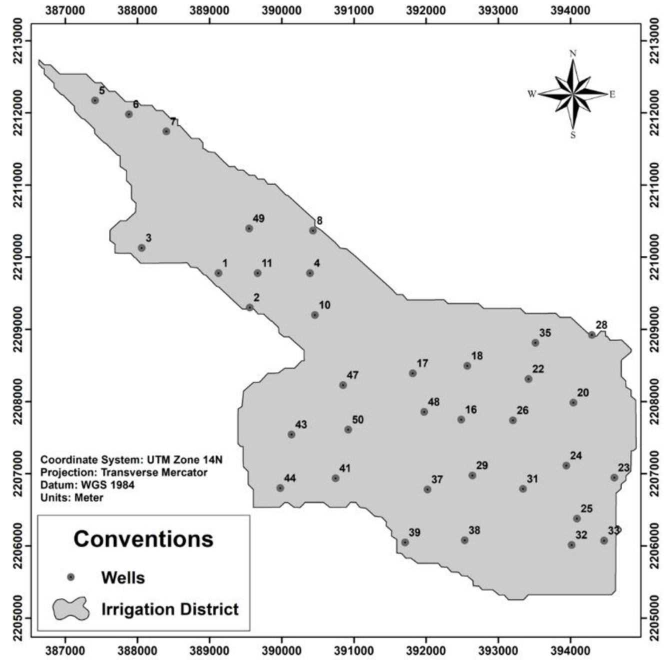

Fig. 1. Temascalcingo irrigation district, State of Mexico, Mexico.

II.II Water Table Sampling

Depth and Height of the water table were measured in each of the observation wells from the study area (Figure 1), and samples were taken for physicochemical analysis for the groundwater and the catchment of wastewater in the Lerma river (Table 1). Two samplings were carried out: one in Spring 2009, in April, and another in Summer 2010, in August.

II.III Evaluation parameters

Using the procedures of [6] and [2], the following parameters were estimated for each water sample: distribution of cations and anions, total dissolved solids (TDS), electrical conductivity, osmotic pressure (OP), sodium adsorption ratio (SAR_{or}, SAR_{aj}, Mexico, Mexico, has a defined domain with an area of 2,000 hectares [8], the measurements for each sample were possible to be carried out, for the preparation of isobaths, isohypses and the main parameters regarding quality of waters. For the interpolation the simple Kriging method was used, with the Surfer 8.0 Software, an impartial spatial prediction method that is based on the minimization of the mean square error [9-14].

Table 1. Analytical methods used for the different measurements.

Determination	Method	Reference
pH	Beckman brand potentiometer, Hoffmann Pinther Boswork model.	APHA, 1995. 4500-H+B
Electric Conductivity	Wheatstone bridge conductivity meter with glass cell.	APHA, 1995. 25108
TDS	Gravimetry by stove Hot-Plate brand, 2200 Thermolyne model.	APHA, 1995. 2540 D
Sodium & Potassium	Flamometry Flamemeter IL Autocal Flame Photometer 643, l = 589 nm, calibrated with standard solutions of 140 $meqL^{-1}$ Na and 5 $meqL^{-1}$ for K.	APHA, 1995. 3500-Na and K, D
Calcium & Magnesium	Volumetric. Through titration with EDTA and Eriochrome Black T, as indicator.	APHA, 1995. 3500 Ca D
Carbonates	Volumetric. By titration with sulfuric acid and phenophthalein as indicator.	APHA, 1995. 2320 B
Bicarbonates	Volumetric. By titration with sulfuric acid and Methyl Orange as indicator.	APHA, 1995. 2320 B
Chlorides	Titration with Silver Nitrate and 5% Potassium Chromate as indicator.	APHA, 1995. 4500-Cl B
Sulphates	Turbidimetry Perkin Elmer 35 model spectrophotometer, L = 420 nm.	APHA, 1995. 4500-SO4 E
Osmotic Pressure	Wescor Osmometer, model VAPRO 5520, calibrated with Optimol (100, 290 and 1000 *mmol* Kg^{-1}).	

III. RESULT

III.I Shallow water table dynamics

Variation in depth of water tables is closely linked to precipitation, recharge due to irrigation, and to a lesser extent to surrounding causes. In Temacalcingo Irrigation District, the main source of recharge of water tables is gravity irrigation with wastewater from the Lerma River. According to the information spatial analysis in Table 2, variation of the groundwater for the samplings from the Spring of 2009 and the Summer of 2010, was found with areas with groundwater levels between 0.0-0.5 m and 0.5-1.0 m, which are considered critical, for the adverse effect on soil and plants; being its highest value in Spring 2009 (See Figure 2), with 16.2% (324 hectares) and 37.8% (756 hectares) respectively. In Summer 2010, the areas with these ranges (0-0.5 m and 0.5-1.0 m), were reduced to 5.0% (100 hectares) and 11.1% (220 hectares) respectively. This behavior agrees with studies conducted in this Irrigation District by [8] and with the experiments in sand columns carried out by [15], regarding induced variability of the fluctuation of the water table as a function of the moisture retention curve. Fluctuation of water table allows to infer that salinization of surface horizons is possible, due to evaporation of groundwater containing high concentrations of solutes, process in total agreement with the research of [16], referring to the analysis of evapotranspiration with the fluctuation of the water table, using the Drainmod model.

Table 2. Samples of the Water Table of the Temacalcingo Irrigation District, Mexico State, Spring 2009 and Summer 2010.

Source	Sample	GL (m)	WTD (m)	T_w (°C)
Spring 2009				
Well 1	1	991.566	2.01	17.5
Well 2	2	992.722	0.62	16.2
Well 3	3	992.111	1.05	17.0
Well 4	4	988.362	0.42	16.5
Well 5	5	987.174	0.40	18.0
Well 6	6	987.154	0.60	18.5
Well 7	7	986.872	0.53	18.6
Well 8	8	987.788	0.10	18.9
Well 10	9	990.927	0.61	19.0
Well 11	10	989.741	0.00	19.5
Well 16	11	988.931	0.58	19.0
Well 17	12	988.937	0.70	15.5
Well 18	13	988.34	1.72	15.6
Well 20	14	991.284	1.32	16.0
Well 22	15	991.892	1.21	17.0
Well 23	16	993.85	1.17	17.8
Well 24	17	991.869	1.18	19.0
Well 25	18	994.079	1.93	20.5
Well 26	19	989.634	1.45	21.1
Well 28	20	990.633	1.22	15.5
Well 29	21	991.622	1.34	16.5
Well 31	22	990.38	0.66	16.4
Well 32	23	992.092	1.90	16.9
Well 33	24	991.488	0.37	17.3
Well 35	25	988.64	0.93	18.6
Well 37	26	990.641	1.40	19.2
Well 38	27	991.388	1.12	19.0
Well 39	28	990.776	1.27	19.6
Well 41	29	991.167	0.97	19.6
Well 43	30	990.072	0.51	15.6
Well 44	31	990.817	0.56	14.9
Well 47	32	988.581	0.33	15.6
Well 48	33	988.224	0.93	15.9
Well 49	34	988.832	0.64	16.1
Well 50	35	990.558	0.54	16.3

Source	Sample	GL (m)	WTD (m)	T_w (°C)
Lerma River, derivadora Andaró	36	-	-	17.5
Summer 2010				
Lerma River, Derivadora Andaró	1	-	-	17.5
Well 33	2	991.488	0.45	15.0
Well 23	3	993.850	0.97	19.0
Well 26	4	989.634	1.48	19.1
Well 20	5	991.284	1.57	22.6
Well 28	6	990.633	1.33	18.5
Well 35	7	988.640	1.26	14.0
Well 22	8	991.892	1.79	16.0
Well 17	9	988.937	0.90	20.1
Well 4	10	988.362	1.37	18.8
Well 11	11	989.741	1.53	18.1
Well 7	12	986.872	1.38	18.8
Well 6	13	987.154	1.68	19.1
Well 16	14	988.931	1.41	20.1
Well 37	15	990.641	1.44	21.0
Well 41	16	991.167	1.35	22.2
Well 44	17	990.817	1.00	21.1
Well 43	18	990.072	1.29	20.6
Well 50	19	990.558	1.60	22.7

GL= Ground level; WTD= Water Table Depth; T_w = Water temperature

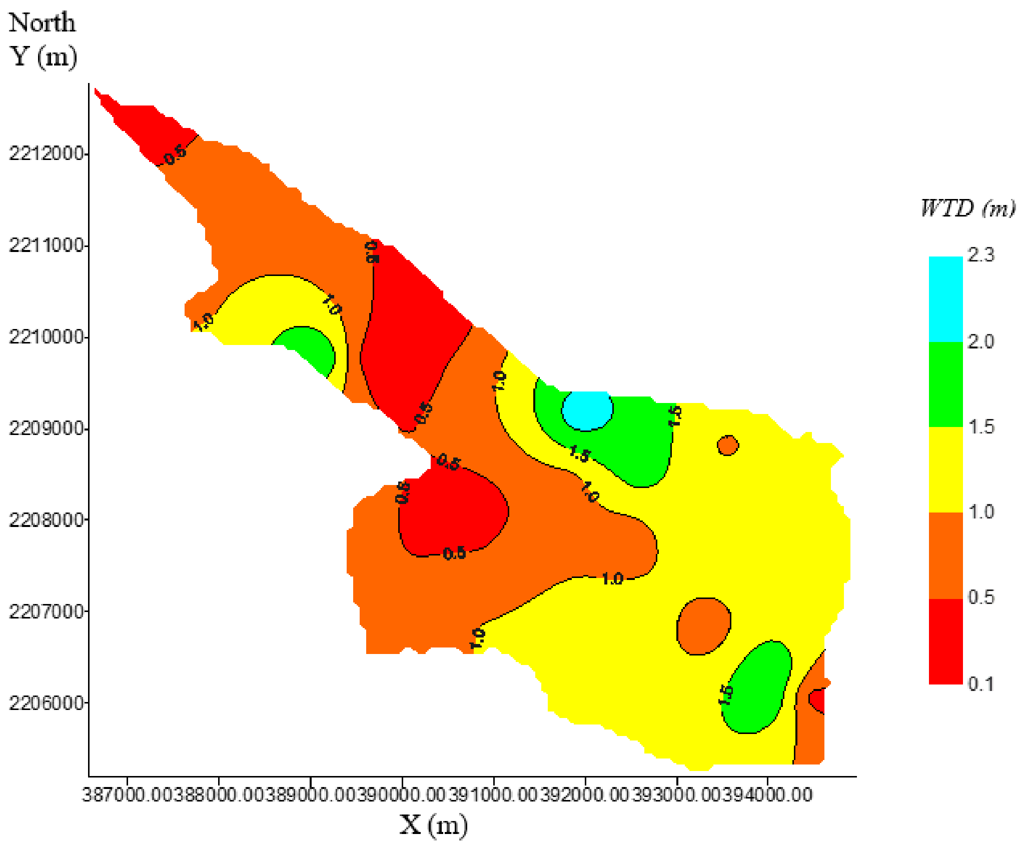

Figura 2. Isobaths chart, Temacalcingo Irrigation District, State of Mexico, Spring 2009.

When analyzing isohypses charts of Spring 2009 and Summer 2010, and those reported by [17], it was found that the direction trend of the underground flow observed is from Southeast and Southwest towards the central part of the Southeast of the Temacalcingo Irrigation District. This indicates that the groundwater loading area is in the Southeast and Southwest, and the groundwater discharge zone, in the Central part. Figure 3 shows the isohypses chart for the sampling from Spring 2009; where the convective macro-scale flow is evident to occur in the direction of the Darcy flow, which describes the direction of the underground flow, i.e., allowing the possibility to transport salts from the loading zone to the groundwater discharge zone, which agrees with the research from [18], in the Irrigation District of La Doctrina, Colombia, where the transport of salts was found to occur in the direction of the water table and to be responsible for the soil progressive salinization.

III.II Ionic Composition of Water Tables

Based on the results of the carried-out samplings (Table 3), regarding types of water according to ionic relationship, it was found that 69.10% of the groundwater (38 samples), have hydrochloric composition, and 30.90% (17 samples) have Sulphate-hydrochloric composition. On the ionic ratios $\frac{Ca^{2+}}{Mg^{2+}}, \frac{Na^{+}}{Ca^{2+}}, \frac{Na^{+}}{Mg^{2+}}$; it was observed that in 78.2% (43 samples) the $\frac{Ca^{2+}}{Mg^{2+}}$ ratio is greater than 1, indicating that there are considerable amounts of calcium with respect to magnesium. On the other hand, regarding the $\frac{Na^{+}}{Ca^{2+}}$ and $\frac{Na^{+}}{Mg^{2+}}$ ratios; 96.4% (53 samples) and 92.7% (51 samples) respectively, have values less than 1, which indicates predominance of sodium with respect to calcium and magnesium, reflected in the values of the sodium adsorption ratio (SAR).

Regarding distribution of cations and anions of the sampling of Spring 2009 and Summer 2010, it was found that in the water table, sodium (Na^{+}), calcium (Ca^{2+}), Magnesium (Mg^{2+}) and bicarbonate (HCO_3^-) occupy the largest area; allowing to infer the predominance of bicarbonate salts of sodium, calcium and magnesium. These results agree with the research from [19], regarding estimation of salinity in groundwater around the area of influence of the mouth of the Sinú River on the North of Colombia; where the waters were found to be markedly saline in the areas near the mouth of the Sinú River and to be associated with contents of Cl^{-1}, Na^{+}, and Mg^{2+}.

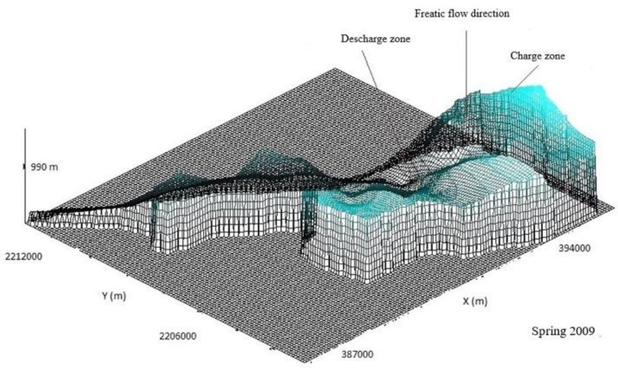

Figura 3. Isohypses Chart, Temacalcingo Irrigation District, Mexico State, Spring 2009

Table 3. Water Tables ionic composition from Temacalcingo Irrigation Module, Mexico State, Spring 2009 and Summer 2010.

Sample	pH	Ec	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	Σ	CO_3^{2-}	HCO_3^{-}	Cl^{-}	SO_4^{2-}	Σ	Error %	RSE
		μScm^{-1}	$mmol_c L^{-1}$					$mmol_c L^{-1}$					ΣmgL^{-1} / $\Sigma mmolL^{-1}$	mgL^{-1}
Spring 2009														
1	6.7	1449	4.40	2.20	7.25	0.46	14.31	0.00	7.39	4.30	2.25	13.94	1.31	973.4
2	7.2	890	2.68	1.34	4.49	0.28	8.79	0.00	4.62	2.62	1.37	8.61	1.03	597.9
3	7.2	1144	2.70	1.70	6.70	0.20	11.30	0.00	5.92	3.10	1.98	11.00	1.35	768.5
4	7.0	1233	3.20	2.90	5.84	0.24	12.18	0.00	6.32	3.50	2.04	11.86	1.33	828.3
5	7.1	1032	2.90	2.40	4.69	0.20	10.19	0.00	5.75	2.20	1.98	9.93	1.29	693.3
6	6.9	1041	3.60	1.70	4.76	0.22	10.28	0.00	5.20	2.70	2.10	10.00	1.38	699.3
7	6.4	709	2.45	1.01	3.24	0.30	7.00	0.00	3.27	2.50	1.04	6.81	1.38	476.3
8	6.7	864	2.99	1.58	3.50	0.18	8.25	0.00	4.49	2.24	1.74	8.47	1.32	580.4
9	6.8	672	2.34	0.82	3.09	0.22	6.47	0.00	3.66	2.00	0.98	6.64	1.30	451.4
10	6.8	995	2.40	1.50	5.06	0.87	9.83	0.00	4.91	2.84	1.82	9.57	1.34	668.4
11	6.9	1391	4.00	2.60	5.63	1.51	13.74	0.00	7.23	3.85	2.30	13.38	1.33	934.5
12	6.9	1740	3.73	6.10	5.75	1.60	17.18	0.00	7.45	6.40	2.88	16.73	1.33	1168.9
13	6.9	1202	4.23	2.57	3.97	1.10	11.87	0.00	5.28	3.50	2.77	11.55	1.37	807.5
14	7.2	1217	3.60	2.50	4.80	1.12	12.02	0.00	5.48	3.65	2.60	11.73	1.22	817.6
15	6.7	1103	4.02	3.10	2.47	0.98	10.57	0.00	5.77	3.80	1.32	10.89	1.49	741.0
16	6.8	1748	4.00	3.30	7.96	1.55	16.81	0.00	8.46	6.12	2.68	17.26	1.32	1174.3

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		Ec	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	Σ	CO_3^{2-}	HCO_3^{-}	Cl^{-}	SO_4^{2-}	Σ	Error %	RSE
Sample	pH	μScm^{-1}	$mmol_cL^{-1}$					$mmol_cL^{-1}$					ΣmgL^{-1} / $\Sigma mmolL^{-1}$	mgL^{-1}
17	6.7	956	2.20	1.82	4.38	1.04	9.44	0.00	4.38	3.37	1.47	9.22	1.18	642.2
18	7.0	866	2.44	1.90	3.45	0.76	8.55	0.00	3.92	3.06	1.34	8.32	1.36	581.8
19	6.7	1272	3.30	2.40	6.40	0.46	12.56	0.00	5.77	4.60	1.85	12.22	1.37	854.5
20	6.8	952	2.10	1.80	4.89	0.35	9.14	0.00	4.63	3.20	1.57	9.40	1.40	639.6
21	6.9	1205	3.10	3.00	5.17	0.63	11.90	0.00	5.80	3.80	2.00	11.60	1.28	809.5
22	6.7	1333	3.41	2.20	6.86	0.69	13.16	0.00	6.42	4.18	2.20	12.80	1.39	895.5
23	6.7	921	2.01	1.80	4.81	0.48	9.10	0.00	4.37	2.93	1.54	8.84	1.45	618.7
24	7.2	2146	5.54	7.73	7.23	0.87	21.37	0.00	12.5	6.73	2.65	21.93	1.29	1441.7
25	7.2	1086	3.70	2.80	3.78	0.44	10.72	0.00	5.40	3.43	1.65	10.48	1.13	729.6
26	6.9	998	2.40	1.70	5.35	0.41	9.86	0.00	5.21	3.15	1.24	9.60	1.34	670.5
27	6.8	1306	3.40	2.47	6.21	0.47	12.55	0.00	6.49	4.50	1.91	12.90	1.38	877.4
28	6.9	884	2.31	1.80	4.30	0.32	8.73	0.00	4.89	2.30	1.30	8.49	1.39	593.9
29	6.8	681	1.50	0.90	3.92	0.25	6.57	0.00	3.31	2.40	1.02	6.73	1.20	457.5
30	6.7	754	1.67	1.02	4.34	0.42	7.45	0.00	3.48	2.64	1.13	7.25	1.36	506.5
31	6.9	1180	2.93	4.39	3.44	0.59	11.35	0.00	5.13	4.79	1.73	11.65	1.30	792.7
32	6.5	1204	3.14	2.45	5.86	0.44	11.89	0.00	6.42	4.13	1.02	11.57	1.36	808.8
33	6.7	1035	2.70	3.11	3.76	0.37	9.94	0.00	5.50	3.20	1.52	10.22	1.39	695.3
34	6.9	764	2.60	1.38	3.20	0.27	7.45	0.00	3.92	2.20	1.12	7.24	1.43	513.3
35	6.8	933	2.80	2.07	4.01	0.33	9.21	0.00	4.90	2.68	1.37	8.95	1.43	626.8
36	6.8	1046	2.73	2.12	5.10	0.38	10.33	0.00	5.28	3.60	1.20	10.08	1.22	702.7
37	6.6	717	2.03	1.58	2.84	0.63	7.08	0.00	3.69	2.10	1.11	6.90	1.29	481.7
38	6.7	701	1.98	1.54	2.78	0.62	6.92	0.00	3.17	2.48	1.09	6.74	1.32	470.9
39	6.6	700	2.02	1.36	2.80	0.54	6.72	0.00	3.33	2.50	1.08	6.91	1.39	470.3
40	6.6	705	2.08	1.49	2.85	0.54	6.96	0.00	3.27	2.46	1.06	6.79	1.24	473.6
41	6.6	713	2.01	1.56	2.92	0.55	7.04	0.00	3.20	2.44	1.24	6.88	1.15	479.0
Summer 2010														
1	9.6	471.0	2.21	0.82	1.35	0.27	4.65	0.20	2.69	1.12	0.52	4.53	1.31	316.4
2	9.91	427.0	1.74	0.96	1.24	0.28	4.22	0.16	2.32	1.14	0.48	4.10	1.49	286.9
3	8.23	1148.0	2.10	2.50	6.45	0.29	11.34	0.00	5.70	4.25	1.10	11.05	1.30	771.2
4	7.85	911.0	2.60	2.10	3.84	0.46	9.00	0.00	4.70	3.20	0.86	8.76	1.32	612.0
5	8.13	641.0	1.60	1.63	2.80	0.30	6.33	0.00	3.55	2.25	0.37	6.17	1.28	430.6
6	8.27	1232.0	3.12	2.90	5.73	0.42	12.17	0.00	6.57	4.12	1.16	11.85	1.33	827.7
7	7.79	1124.0	2.80	2.86	5.12	0.32	11.10	0.00	5.94	3.86	1.02	10.82	1.28	755.1
8	7.81	963.0	3.29	2.04	3.76	0.42	9.51	0.00	5.46	3.08	0.72	9.26	1.33	646.9
9	8.17	1167.0	2.28	2.62	6.29	0.33	11.52	0.00	5.60	4.38	1.24	11.22	1.32	784.0
10	7.85	1349.0	3.20	3.12	6.54	0.46	13.32	0.00	7.09	4.28	1.61	12.98	1.30	906.3
11	7.74	802.0	1.60	1.80	4.20	0.32	7.92	0.00	4.26	2.82	0.63	7.71	1.34	538.8
12	7.54	1046.0	3.60	2.42	3.95	0.36	10.33	0.00	5.74	3.22	1.10	10.06	1.35	702.7
13	8.15	883.0	2.54	1.92	3.86	0.40	8.72	0.00	5.11	2.65	0.72	8.48	1.40	593.2
14	8.12	954.0	1.92	2.16	4.98	0.36	9.42	0.00	5.42	3.20	0.56	9.18	1.29	640.9
15	7.69	991.0	1.86	2.24	5.27	0.42	9.79	0.00	5.66	3.26	0.62	9.54	1.29	665.8
16	7.56	743.0	2.12	1.96	2.94	0.32	7.34	0.00	4.07	2.70	0.38	7.15	1.31	499.1
17	7.70	702.0	2.08	1.82	2.75	0.28	6.93	0.00	3.83	2.56	0.36	6.75	1.32	471.6
18	8.10	1639.0	3.20	3.38	9.09	0.52	16.19	0.00	8.86	5.18	1.72	15.76	1.35	1101.1
19	7.88	708.0	2.10	1.60	3.03	0.26	6.99	0.00	3.82	2.65	0.34	6.81	1.30	475.6
20	7.68	1030.0	2.36	2.60	4.78	0.43	10.17	0.00	4.97	3.96	0.96	9.89	1.40	692.0
21	8.00	868.0	2.45	2.12	3.62	0.38	8.57	0.00	4.44	3.24	0.68	8.36	1.24	583.1
22	7.68	810.0	2.36	2.16	3.06	0.42	8.00	0.00	4.37	3.02	0.42	7.81	1.20	544.2

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III.III Electric conductivity (μScm^{-1})

According to the results from Table 3; 12.70% (7 samples) was water C_2 (250–750 μScm^{-1}) and 87.30% (48 samples) was C_3 (750-2,250 μScm^{-1}). It is important to note that an average value of 1,055 μScm^{-1} and a maximum value of 2,146 μScm^{-1} were found. Bearing in mind that the main source of recharge of water tables is the wastewater from the Lerma river, derived at the Andaró station and supplied by the left bank and right bank channels to the irrigation zone, which is of low concentration (Table 3); it is possible that there is a gradual salinization process of the water table, caused by fluctuations of these water tables. Figure 4 shows a map of the phreatic level, corresponding to the sampling from Spring 2009; where 67% (1,340 hectares) has electrical conductivity of 750-1,250 μScm^{-1} and 23.3% (466 hectares) between 1,250-2,250 μScm^{-1}. The range between 750 and 1,250 increased to 70.6% (1,412 hectares) in the Summer of 2010, due to a process of re-concentration of the phreatic solutions by evaporation and subsequent decrease in the phreatic levels. These results are consistent with the trends reported by [16], when analyzing the response of the fluctuation of the water table to evapotranspiration using the Drainmod model.

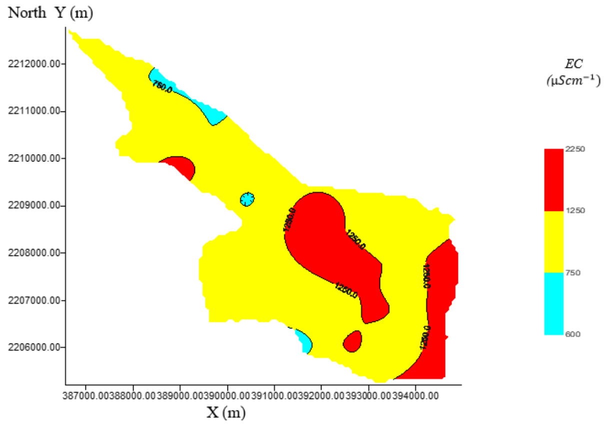

Fig. 4. Electrical conductivity plan (μScm^{-1}), Temacalcingo Irrigation District, Mexico State, Mexico, Spring 2010.

III.IV Total dissolved solids TSD (mgL^{-1})

The functional ratio between TSD and EC showed a slope of 0.6926, which corresponds to solutions rich in bicarbonate (HCO_3). In this case, due to the predominance of salts such as $NaHCO_3$, $Ca(HCO_3)_2$ and $Mg(HCO_3)_2$, which agrees with [2], who found the same trend when performing the physicochemical characterization of urban-industrial wastewater in the Mexquital valley, Mexico. In the water tables of Temacalcingo irrigation district, concentration of the solution in the range of 500-1,000 mgL^{-1} increased from 79% (1,580 hectares) in Spring 2009 to 82.4% (1,648 hectares) in Summer 2010; due to occurrence of a process of re-concentration of the phreatic solution, due to lower groundwater levels.

III.V Osmotic Pressure OP (atm)

For the osmotic pressure of the groundwater in Spring 2009, it was found that 67.6% (1,352 hectares) had values from 0.3 to 0.5 atmospheres, and 23.5% (470 hectares) had values from 0.5 to 1.0 atmospheres. These ranges of osmotic pressure coincide with the phreatic areas of higher electrical conductivity; evidence of the functional ratio between the OP and the EC and its probable adverse effect on the water potential of soil water, making it difficult for plants to use. plants. These results totally agree with the research from [2], regarding the physicochemical characterization of urban-industrial wastewater in the Mezquital Valley in Mexico.

III.VI Hypothetical salts

Hypothetical salts were calculated considering solubility of salts, the Langelier index and geochemistry of ions. Tables 4 and 5 presents the estimation of the hypothetical salts, corresponding to sample of observation well No. 5, from the 2009 Spring sampling.

Values of the hypothetical salts of Table 6, are equal to 0.0022ML^{-1} of $NaCl$, 0.00249ML^{-1} of $NaHCO_3$, 0.00020ML^{-1} of $KHCO_3$, 0.00145ML^{-1} of $Ca(HCO_3)_2$, 0.00008ML^{-1} of $Mg(HCO_3)_2$ and 0.00099 ML^{-1} of $MgSO_4$. With this procedure, hypothetical salts of each of the samples from Spring 2009 and Summer 2010 were estimated, finding that the order of predominance was: $NaCl > Ca(HCO_3)_2 > NaHCO_3 > MgSO_4 > Mg(HCO_3)_2 > KHCO_3$, which, due to their physical and chemical properties can generate soil salinity.

Table 4. Ionic composition. Well Sample No. 5, Water Tables from Temacalcingo Irrigation Module, Mexico State, Spring 2009.

pH	CE μScm^{-1}	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	$\sum_{cationes}$	CO_3^{2-}	HCO_3^{-}	Cl^{-}	SO_4^{2-}	$\sum_{aniones}$	$\Delta\sum$
		$mmol_cL^{-1}$										
7.10	1032	2.90	2.40	4.69	0.20	10.19	0.00	5.75	2.20	1.98	9.93	0.26

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Table 5. Estimation of Hypothetical Salts. Well Sample 5, Water Tables of the Temacalcingo Irrigation Module, State of Mexico, Spring 2009.

Reactives ($mmol_c L^{-1}$ **)**			**Hypothetical salts (** $mmol_c L^{-1}$ **)**	**Residues (** $mmol_c L^{-1}$ **)**	
Na^{+}	+	Cl^{-}	$NaCl$	Na^{+}	Cl^{-}
4.69		2.20	2.20	2.49	0.00
Na^{+}	+	HCO_3^{-}	$NaHCO_3$	HCO_3^{-}	Na^{+}
2.49	+	5.75	2.49	3.26	0.00
K^{+}	+	HCO_3^{-}	$KHCO_3$	HCO_3^{-}	K^{+}
0.20		3.26	0.20	3.06	0.00
Ca^{2+}	+	HCO_3^{-}	$Ca(HCO_3)_2$	HCO_3^{-}	Ca^{2+}
2.90		3.06	2.90	0.16	0.00
Mg^{2+}	+	HCO_3^{-}	$Mg(HCO_3)_2$	Mg^{2+}	HCO_3^{-}
2.40		0.16	0.16	2.24	0.00
Mg^{2+}	+	SO_4^{2-}	$MgSO_4$	Mg^{2+}	SO_4^{2-}
2.24		1.98	1.98	0.26	0.00

These results are consistent with the work from [20], regarding the impact of the use of wastewater in agriculture; in the sense that there is little research about its effect on crops and on the physical and chemical properties of the soil.

III.VII Sodium Adsorption Ratio SAR

Although in larger proportion, the SAR values indicate minimal risk of sodicity, in the spatial distribution of SAR_{aj}, it was found that 47% of the water table (940 hectares) have values of 3-6, and 53% (1,060 hectares) values of 6-12, which, with conditions of low electrolyte concentration of the solution, can cause problems of dispersion in the soil by sodium (Na^{+}). For RAS_{or}, RAS_{aj}, and $RAS°$, it was found that they can cause a slight to moderate reduction of water infiltration in 65.4, 96.4 and 72.7% respectively. These results agree with the research of [20], regarding the evaluation of the quality of residual water for agricultural irrigation in the Mezquital Valley, Hidalgo, Mexico.

According to [2], in the cationic exchange process, a soil with adsorbed calcium (Ca^{2+}) and sodium (Na^{+}) ions in soluble phase; interacts with the sodium ions in the solution, according to the law of mass action, obtaining the highest values of RAS, when sodium increases, and calcium tends to zero, and its lowest values when the opposite happens. This behavior agrees with the results from this research study and can be explained with equations 1, 2, 3 and 4; obtained from the RAS trend analysis in the groundwater of the Temascalcingo irrigation district, State of Mexico, Mexico.

$$RAS = \lim_{C_{Ca^{2+}} \to \infty} \frac{C_{Na^{+}}}{\sqrt{C_{Ca^{2+}}}} = 0 \qquad (1)$$

$$RAS = \lim_{C_{Ca^{2+}} \to 0} \frac{C_{Na^{+}}}{\sqrt{C_{Ca^{2+}}}} = +\infty \qquad (2)$$

$$RAS = \lim_{C_{Na^{+}} \to \infty} \frac{C_{Na^{+}}}{\sqrt{C_{Ca^{2+}}}} = +\infty \qquad (3)$$

$$RAS = \lim_{C_{Na^{+}} \to 0} \frac{C_{Na^{+}}}{\sqrt{C_{Ca^{2+}}}} = 0 \qquad (4)$$

IV. CONCLUSIONS

In the water tables, the order of content of cations is $Na > Ca > Mg$ and of anions is HCO_3, with a predominance of bicarbonate sodium, calcium and magnesium salts. Average concentration of groundwater solutions is greater than average concentration of waters from the Lerma River, the main source of recharge for water tables levels; allowing to infer that there is a process of gradual salinization of the water tables. The functional ratio between concentration and electrical conductivity has a slope of 0.6926, which corresponds to solutions with high bicarbonate contents, i.e. salts such as $NaHCO_3$, $Ca(HCO_3)_2$ and $Mg(HCO_3)_2$. More than 54% of the water table has high values of electrical conductivity (μSc^{-1}), concentration (mgL^{-1}), osmotic pressure (atm) and water table depth less than 1 m, which represents a high risk of salinity or sodicity for the soil.

The transport of salts on a macro-scale occurs in the direction of the water table, which causes progressive salinization or sodification of the soil.

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Nomenclatures	
$\mu S\ cm^{-1}$	Microsimens per centimeter
$Mg\ L^{-1}$	Milligrams per liter
$M\ L^{-1}$	Moles per litre
$Mmol_c\ L^{-1}$	Millimoles of charge per litre
Abbreviations	
APHA	American public health association
atm	Atmospheres
EC	Electrical conductivity
EDTA	Ethylenediaminetetraacetic acid
ESP	Exchangeable sodium percentage
GL	Ground level
N	North
OP	Osmotic Pressure
SAR	Sodium adsorption ratio
SAR°	Corrected sodium adsorption ratio
SAR_{aj}	Adjusted sodium adsorption ratio
SAR_{or}	Original sodium adsorption ratio
TDS	Total dissolved solids
W	West
WTD	Water table depth

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