Article

Characterization of treated wastewater from the Lagunera Region and its viability in agricultural irrigation

Flor Valeria Galindo Pardo[1]
María del Rosario Jacobo-Salcedo[2]
José Antonio Cueto-Wong[3§]
David Guadalupe Reta Sánchez[4]
José Luis García Hernández[5]
Cirilo Vázquez-Vázquez[5]

[1]FAZ-UJED-INIFAP. Highway Gómez Palacio-Tlahualilo km 32, Venice, Gómez Palacio, Durango, Mexico. (valery0510@hotmail.com). [2]CENID-RASPA-INIFAP. Industrial Park II, Gómez Palacio, Durango, Mexico. CP. 34079. [3]FAZ-UJED. Carretera Gómez Palacio-Tlahualilo km 32, Venice, Gómez Palacio, Durango, Mexico. [4]FAZ-UJED-INIFAP. Boulevard José Santos Valdez 1200 Poniente, Centro, Matamoros, Coahuila. (reta.david@inifap.gob.mx). [5]FAZ-UJED. Highway Gómez Palacio-Tlahualilo km 32, Venice, Gómez Palacio, Durango, Mexico. (luis_garher@hotmail.com; cirvaz60@hotmail.com).

[§]Corresponding author: cueto_J_A@outlook.com.

Abstract

The use of treated wastewater of urban origin to irrigate agricultural soils destined for the production of fodder, is an alternative that favors the contribution of nutrients to the crop and minimizes pollution at the discharge sites; however, knowledge about the quality of this water is required. The objective of the study was to determine the effluent quality of four wastewater treatment plants (WWTP) of the Lagunera Region. Quality analyzes were carried out with the methodologies of various national standards. Samples to the treatment plants were carried out for eleven months (April 2014 to February 2015). The results show little monthly variation except for the LA1 plant. The tributaries of WWTP LO1 and LO2 have 22 to 25 mg L^{-1} of N, while WWTP LA1 has a higher concentration of P 4 mg L^{-1} and K 22 mg L^{-1}, as long as the agronomic quality is questionable due to the high salinity and sodicity. With regard to microbiological parameters, all WWTP exceed the maximum permissible limits (MPL) of NOM-003-ECOL-1997 in terms of the content of helminth eggs, also exceeding MPL heavy metals, of NOM-001-SEMARNAT- 1996 in Pb and Cd.

Keywords: activated sludge, heavy metals, oxidation lagoons, sustainability.

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Introduction

The United Nations report (ONU, 2015) on the development of water resources in the world, indicates that the planet's capacity to sustain the growing demand for fresh water is being challenged. Climate change scenarios foresee future problems in the water cycle, the intensity and frequency of droughts, will become more acute, generating changes in the world's watersheds, which leads to severe socio-economic and environmental problems (Deryugina, 2017; Sadoff, 2017).

The agricultural sector is currently responsible for 70% of the world's water use (WWAP, 2017). 62% of the water in Mexico comes from surface sources and the rest from underground sources. Of the latter, 75% is water concessioned for agricultural use. The growing demand for water in consumptive uses will cause wastewater to increase as well as its level of pollution; since the greatest final recipient of these wastewater without prior treatment is the environment: call rivers, seas, lakes, soil or subsoil (WWAP, 2017).

The application of the concept of sustainability in terms of water use is a benchmark of international priorities (Seguí, 2004). An alternative proposed is the reuse of wastewater treated in agricultural irrigation (FAO, 2017) among the benefits that could be expected is a decrease in environmental pollution (Escalante *et al*., 2003).

Research such as those carried out by Garzón-Zuñiga *et al*. (2014); Vera *et al*. (2016) indicate that the type of treatment and the materials used are determinants in the quality of the effluent. The crop yield is an important condition, in the study carried out by Libutti (2018) it mentions that productivity is not negatively affected by the use of wastewater coupled with it could save up to 6 000 m^3 ha^{-1} of groundwater by year and collaterally lessen the pressure for the water resource.

The application of the effluent in the agricultural sector generates not only the water supply but also the nutrients for the plants, which is reflected in better nutrition and food supply, coupled with a lower use of chemical fertilizers (Toze, 2006; Veliz *et al.*, 2009; Lasso *et al.*, 2011). An important contribution made by Escalante *et al*. (2003) on the potential reuse of the treated water in Mexico found that just over 70% of this water is discharged to a natural body as also mentioned final receiving the treated wastewater is three times cheaper than drinking water.

Mexico has a record of 2 337 wastewater treatment plants (WWTP), of which 30% are activated sludge. The total treated effluent is 111.25 m^3 s^{-1}, approximately 53% of the wastewater generated. In the Lagunera Region (CL) 31 treatment plants have been identified, which together treat a flow of 2.42 m^3 s^{-1} (CONAGUA, 2014) where it is intended for agricultural uses of areas adjacent to the discharge sites as well as the garden irrigation.

The CL is an important dairy region, so that agricultural production became fodder with a total of 123 642.57 ha; that is, 48% of the total planted area (SIAP, 2018), in addition agricultural production is the main consumer of water in the region, 45% of this water is from underground sources and 55% from surface areas, where the most important aquifers they are the principal and oriente aguanaval, which supply the urban area (Cervantes and Franco, 2007).

The water used in the agricultural sector must have desirable physical, chemical and microbiological characteristics, to define it as of agronomic quality, parameters such as salinity, sodicity, alkalinity and presence of specific ions that could generate toxicity are considered. Sodicity is a determining parameter in the quality of water for irrigation, it is measured by the sodium absorption ratio (RAS), sodium soils tend to disperse when wetted, while drying their structure is hard and massive, the main problems this causes low infiltration and permeability (Tartabull and Betancourt, 2016).

Echeverri *et al*. (2012) compared the agronomic quality of the effluent from a treatment plant against groundwater for sugarcane production, concluding that the effluent from the treatment plant was similar to the groundwater for comparison. The absence of pathogens and helminth eggs are also a quality parameter (NOM, 003) to avoid future problems such as low water infiltration, low productivity, soil contamination and health problems for consumers due to the presence of pathogens.

It is worth mentioning that the uncontrolled use of this type of water is related to negative impacts to the environment, due to the presence of pathogens (Veliz-Lorenzo *et al*., 2009) and heavy metals. Various chemical compounds can alter the natural conditions of the soil that at some point compromise agricultural production or affect public health (Toze, 2006; Olivas-Enriquez *et al*., 2011).

The objective of this study was to evaluate the effluent of four wastewater treatment plants with different treatment processes of the Lagunera Region to define their quality in agronomic uses and establish their nutritional contribution. Additionally, determine the possible risk of contamination by potentially toxic elements.

Materials and methods

Study area

This work was carried out in the municipalities of Torreon, Gomez Palacio and Lerdo of the states of Coahuila and Durango in the region known as Lagunera Region (CL). Its location is between the coordinates 101° 41’ and 104° 61’ west longitude, and 24° 59’ and 26° 53’ north latitude, its climate is dry desert, with a rainfall of 258 mm and an evaporation of 2 000 mm, the average temperature is 21 °C with a maximum of 33.7 °C and a minimum of 7.5 °C (García, 1973).

The research consisted of carrying out measurements in four wastewater treatment plants (WWTP) distributed in the CL, which are shown in Table 1, and were selected for their location and type of treatment (activated sludge and oxidation lagoons).

Table 1. Location of treated water sampling points.

Identification	Location	Ubication	Type of treatment	Treated flow (L s^{-1})	Receiver
LO1	Torreon	25° 30’23.02” N 103° 20’8.03” W	Oxidation lagoon	1400	RA
LO2	Gomez Palacio	25° 38’26.87” N 103° 28’18.95” E		500	RA

Identification	Location	Ubication	Type of treatment	Treated flow (L s^{-1})	Receiver
LA1	Gomez Palacio	25° 36’45.01” N 103° 26’7.73” E	Muds activated	100	RA and RP
LA2	Lerdo	25° 32’25.85” N 103° 33’1.21” E		180	RA and UI

RA= agricultural irrigation; RP= irrigation of parks; UI= Industrial use.

Sampling

The sampling was developed from April 2014 to February 2015. With the objective of observing the fluctuations in the quality of the treated water during the passage of time (climate) and observing the types of treatment of WWTP. This to be able to compare the quality of the effluent. It was carried out according to the specifications of NMX-AA-003-1980 ‘wastewater-sampling’. Samples were taken over 24 hours with a time interval between samples of 4 hours. Each sample was kept for transport in an ice bath and in refrigeration (4 °C) until its analysis respecting the maximum allowable times for its analysis.

Approximately 3 L of sample were collected in each sample to make a composite mixture in which the corresponding determinations were made; additionally, a simple and independent sample was collected in the glass bottle for fat and oil analysis. In total, 24 analytical determinations were carried out on 44 samples composed of treated wastewater, which allowed monitoring the quality of the water generated.

The methodological development is based on national standards: NMX-AA-003-1980 sampling, total solids (ST), volatile total solids (STV), total suspended solids (SST), total dissolved solids (SDT) NMX-AA-034 -SCFI-2015, fats and oils (GA) NMX-AA-005-SCFI-2000, pH NMX-AA-008-SCFI-2011, electrical conductivity (CE) NMX-AA-093-SCFI-2000, total nitrogen (NT) NMX-AA-026-SCFI-2001, total phosphorus (P) NMX-AA-029-SCFI-2001, carbonates (CO_3) and bicarbonates (HCO_3).

By internal method, chlorides (Cl-) NMX-AA-073-SCFI-2001, sulfates (SO4) NMX-AA-074-SCFI-1981, calcium (Ca), magnesium (Mg), sodium (Na), potassium (K), copper (Cu), manganese (Mn), iron (Fe), zinc (Zn), lead (Pb) and cadmium (Cd) NMX-AA-051-SCFI-2001. All analyzes were performed in the laboratory of the National Center for Disciplinary Research on Water, Soil, Plant, Atmosphere (CENID RASPA).

Statistical analysis

The data collected during the sampling and after the laboratory analysis were subjected to a normality analysis with the Shapiro Wilk’s test, as it turned out to have non-normal data it was decided to make an analysis of variance by means of a non-parametric Kruskal-Wallis test using the InfoStat statistical program (student version), where $p < 0.05$ values, are considered significant.

In addition to the above, a principal component analysis (ACP) was performed, for the discrimination of variables, considering only those that explain at least 70% of the variance, which is considered an acceptable percentage (León *et al*., 1996; Terrádez-Gurrea, 2006).

Results and discussion

Based on the official Mexican standards NOM-001 and NOM-003 SEMARNAT, for the discharge and reuse of treated wastewater, the regulated parameters for application in agricultural irrigation are scarce. Within the regulated quantifications, there are total suspended solids (SST) with maximum permissible limits (MPL) of 20 mg L^{-1} for direct contact and 30 mg L^{-1} for indirect contact, in this investigation an average of 106 mg L^{-1} was found which exceeds the MPL. Works reported by Garzón-Zúñiga *et al*. (2016); Montero-Aguirre *et al*. (2016) report similar data of 139.4 mg L^{-1} and 112 mg L^{-1} respectively. In the research conducted by Campos *et al*. (2018) evaluated residual water for agricultural irrigation and concluded that a high content of SST has a strong correlation with the presence of helminth eggs (HH), generating health problems when reusing water.

The MPL of the NOM-001 and NOM-003 for the fat and oil content is 15 mg L^{-1}, in this work we found contents of up to 50 mg L^{-1}, this amount of fats and oils exceeds the MPL, a high content of them in the irrigation water causes low levels of oxygenation and as a consequence the proliferation of anaerobic bacteria. In the study carried out by Bonilla (2013), two wastewater discharge sites from two industrial parks were evaluated in them, values of 56 mg L^{-1} were detected.

In this investigation the degree of fecal contamination was measured through the quantification of total coliforms (CT) resulting in $1.6*10^6$ NMP/100 ml which demonstrate microbiological contamination in water. Additionally, the presence of fecal coliforms (CF) was observed from the presumptive tests performed. In reference to the MPL of the official Mexican standards, regulations for agronomic use in particular are lacking. However, other authors report similar values.

Carmona (2016) evaluated treated wastewater and found values of $1*10^4$ NMP/100 ml CT, while Valencia (2012) reports $1*10^6$ NMP/100 ml CT the variation between these concentrations may be due to the type of treatment. USEPA, (2004) mentions that the coliform count cannot be greater than 4 000/100 ml in the state of Arizona, when the water is applied to feed forage of dairy cattle. Therefore, the biological quality of water is questionable as it is outside international regulations.

The concentration of helminth eggs has an average of 27 h L^{-1}; while the NOM- 003 stable as MPL 5 h L^{-1}. It should be noted that all the treatment plants evaluated exceed these limits. Hernández-Acosta (2014) evaluated 16 wastewater discharge sites for agricultural irrigation and found concentrations of up to 24 h L^{-1}, in turn Valencia *et al*. (2012) reports 21 h L^{-1}. The removal of these parasites is of the utmost importance, since it can affect public health, for diseases that are easily spread by not restricting the type of irrigation.

The MPL for Cu is 4 to 6 mg L^{-1}, Zn 10 to 20 mg L^{-1}, these limits allow to establish that both elements are within regulations with concentrations of 0.08 mg L^{-1} and 0.1 mg L^{-1} respectively. As for heavy metals, the MPL for Cd is from 0.05 to 0.1 mg L^{-1} and Pb from 5 to 10 mg L^{-1}, with concentrations of 2.9 mg L^{-1} of Cd and 21.7 mg L^{-1} of Pb (Table 2).

Table 2. Variables evaluated and MPL of official standards.

Variables	Mean	Median	Min	Max	p	NOM 001	NOM 003	
							CD	CI or O
SST (mg L^{-1})	106.02	70	3	394	<0.0001	nd	20	30
GA (mg L^{-1})	52.02	50.45	5.7	136.6	0.0728	15	15	15
Cu (mg L^{-1})	0.03	0.02	$1*10^{-3}$	0.08	0.001	4		
Zn (mg L^{-1})	0.03	0.02	$2.7*10^{-3}$	0.1	<0.0001	10		
Pb (mg L^{-1})	11.75	11.4	Nd	21.7	0.7197	5		
Cd (mg L^{-1})	2.29	2.3	Nd	2.9	<0.0001	0.05		
Total coliforms			2400	$16*10^5$	<0.0001			
Helminth eggs	27	21	11	65	<0.0001		≤ 1	≤ 5

$p \leq 0.05$= are considered normal values, Kruskal-Wallis test; NOM 001= NOM-001-SEMARNAT-1996; NOM-003-SEMARNAT-1997; CD= direct contact to the public; CI or O= indirect or occasional contact.

The latter are considered as trace metals and are found outside the MPL. Vera *et al*. (2016) evaluated effluents from aerated lagoon treatment plants and on average they found values of Cd< 0.01 mg L^{-1} and Pb< 0.05 mg L^{-1}, which differ from those found in this research.

As the results of the analysis of variance of Table 3 can be observed, the solids analyzed (ST, SST and SDT) in the wastewater treatment plants (WWTP) there is a significant difference for the Lerdo WWTP with an activated sludge process, this is possibly due to the pretreatment suffered by the influent, (section of fine sieves for solids removal and sand filters that are arranged at the end of the secondary clarifier).

Table 3. Analysis of variance with Kruskal Wallis.

Variable	LO1	LO2	LA1	LA2
ST (mg L^{-1})	932 ab	1105 b	1875 c	614 a
SST (mg L^{-1})	132 c	67 b	174 bc	12 a
SDT (mg L^{-1})	710 a	946 b	1578 c	707 a
PH	8.09 b	7.99 b	7.27 a	7.3 a
EC (µS cm^{-1})	1237 b	1267 b	2355 c	758 a
N (mg L^{-1})	25.3 c	22.3 c	8.8 b	2.2 a
P (mg L^{-1})	2.6 b	2 b	4.2 c	0.2 a
HCO_3 (mg L^{-1})	10.6 b	10 b	9.3 b	4.6 a
CL (mg L^{-1})	2.88 b	2.81 b	13.62 c	1.5 a
SO_4 (mg L^{-1})	3.66 a	5.74 b	4.33 ab	3.23 a
K (mg L^{-1})	10.13 a	6.16 a	22.57 b	6.33 a
Na (mg L^{-1})	31.54 a	28.56 a	60.1 a	28.45 a
Mg (mg L^{-1})	2.54 a	6.69 b	4.64 b	2.84 a
Ca (mg L^{-1})	10.38 bc	9.33 a	13.25 c	9.32 ab
Fe (mg L^{-1})	0.16 b	0.13 b	0.17 b	0.05 a
Mn (mg L^{-1})	0.12 b	0.04 a	0.06 a	0.04 a
RAS (mmol L^{-1})$^{1/2}$	11.9 a	10.1 a	11.4 a	20.3 a

Different letters in the same row indicate significant differences, according to the Kruskal-Wallis test ($p \leq 0.05$); LO1= Torreon oxidation lagoons; LO2= oxidation lagoons Gomez Palacio; LA1= activated sludge Gómez Palacio; LA2= sludge activated Lerdo.

The pH is important for the availability of nutrients and its value shows a difference between treatments, varying from pH= 8 slightly alkaline the plants with oxidation lagoons process, while in the activated sludge process the pH is close to neutrality 7. The EC value also differs between treatment, in stabilization lagoons values of 1200 µS cm^{-1} are presented, while in activated sludges the values are 758 µS cm^{-1} in Lerdo and 2300 µS cm^{-1} in the WWTP GP, the latter being the highest value registered and with slight restriction for irrigation if combined with a high number of SDT (Ordóñez, 2018).

Bonilla *et al*. (2013), in his research he found EC of 2300 µS cm^{-1}, similar to that reported by Vera (2016) who characterized effluent from a wastewater treatment plant with aerated lagoon treatment finding pH and EC values of 7.4 and 2300 µS cm^{-1} respectively, these values similar to those detected in WWTP GP.

Analyzing the variance table, it can be seen that the anions and cations have a significant difference between the WWTP, LA2 has the lowest ranges in almost all ions, except for SO_4 whose value ranges in 3.23 mg L^{-1} similar to that of WWTP LO1 with 3.66 mg L^{-1}. While the determination of total nitrogen (N), shows significant difference being greater in the stabilization lagoons plants with values of 22 to 25 mg L^{-1}, in the LA2 plant there is a minimum value of 2.2 mg L^{-1}, while in the LA1 plant of activated sludge a value of 8.2 mg L^{-1}.

Umaña (2006) cited by Acosta *et al*. (2013) mentions that the concentration N in corn leaves increased when irrigated with ART. The P is an element of great importance in the treatment of wastewater and especially when considering the discharge site since it favors eutrophication and is one of the main elements for crop nutrition, it has been shown that the absence of this element is more important than nitrogen to limit the growth of planktonic algae, especially in some types (blue-green algae).

Capable of fixing atmospheric nitrogen (Ronzano and Dapena, 2013), which would affect the treatment by oxidation lagoons. The analysis of variance shows significant difference in WWTP of LA2 with respect to the rest, this is because in one of the stages of treatment of this plant there is a stirrer that allows the elimination of phosphorus and as a result we have this low concentration 0.2 mg L^{-1}.

Agronomic quality of the effluent from the treatment plants

The parameters evaluated to measure the quality of water for agricultural irrigation are salinity, sodicity, alkalinity and toxicity by specific ions (Tartabull, 2016; Intagri, 2018; Ordoñez, 2018). Salinity is determined by the combination of two parameters EC and total dissolved solids (SDT). According to Tartabull (2016), the EC indicates the concentration of salts, which represent a problem by not allowing plants to absorb the water and nutrients they need.

In Figure 1 and 2 it can be seen how the EC and the SDT have important variations over time, however all the WWTP are within the limits recommended by Ayers and Westcot (1976); Tartabull and Betancourt (2016), WWTP LA2 has the lowest concentration and fluctuation throughout the year on average EC 758 µS m^{-1} and SDT 707 mg L^{-1}, its degree of restriction is mild to moderate (Intagri, 2018).

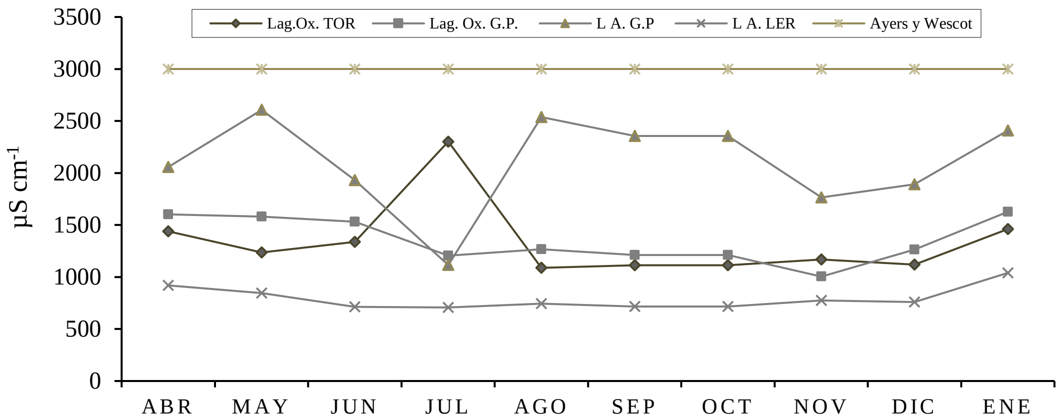

Figure 1. Electrical conductivity of the four treatment plants over time (April 2014-January 2015).

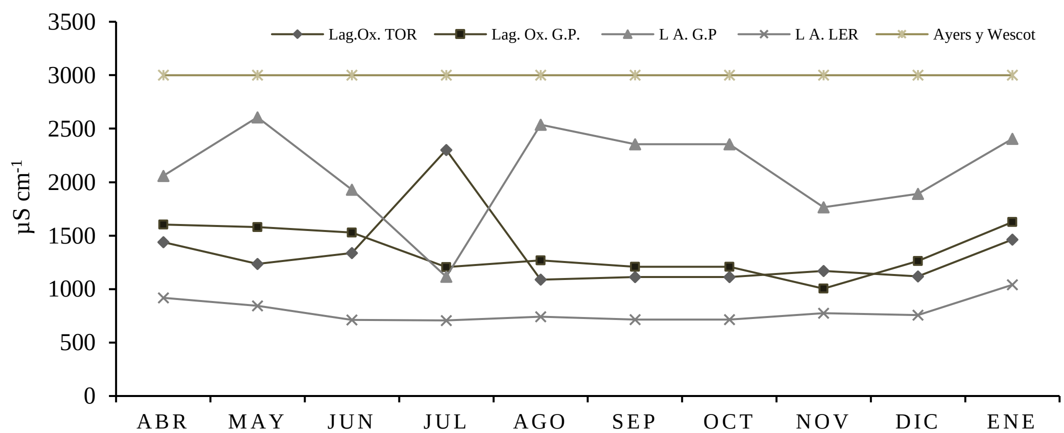

Figure 2. Total dissolved solids of the four treatment plants over time (April 2014-January 2015).

Being the same classification for the four WWTP analyzed in this study. It should be noted that WWTP LO1 and LO2, both with oxidation lagoons process, do not show significant fluctuations either and have a similar behavior among them, however, WWTP LA1 has the highest EC values 2 355 µS cm^{-1} and SDT= 1 578 mg L^{-1}.

The USLS classification for irrigation waters shows that WWTP with oxidation lagoon processes have a C3-S2 risk rating of medium sodification and high salinity, while LA1 WWTP is classified with very high risk C4-S2 for salinity and a half by sodicity, finally the LA2 plant is identified as C3-S3 presents a high risk of salinity and sodicity.

Toxicity by specific ions, such as chlorides and sodium, the latter being not an essential element can cause crop toxicity, even more so if it is a poorly tolerant crop, as shown in Table 3, there is no significant difference between treatment plants as Na, however all plants have a high concentration of 28 to 60 mg L^{-1}, while the concentration of chlorides is shown in Figure 3, the WWTP have a similar behavior except for LA1.

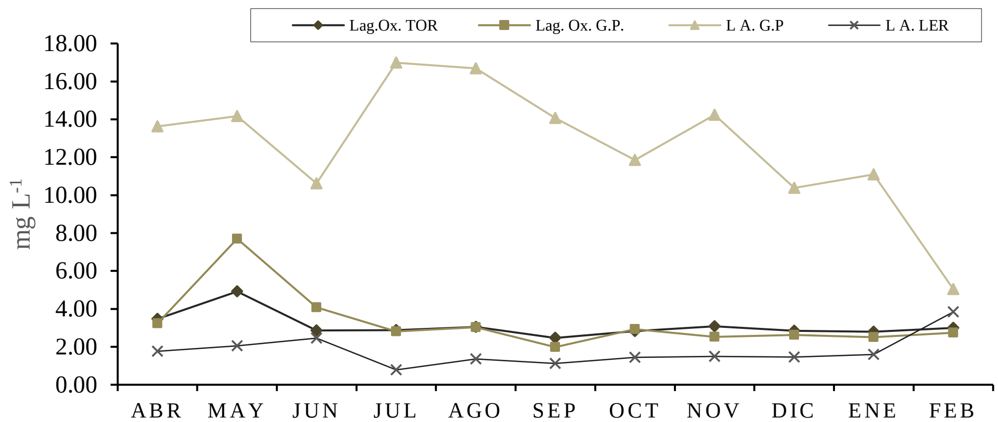

Figure 3. Chloride behavior in the four treatment plants through time April 2014-January 2015.

Main components that characterize treatment plants

The main component test yielded 6 main components (CP) that explained 73% of the variance, which is considered a satisfactory percentage (Terrádez-Gurrea, 2006). Table 4 presents the CP, the variance that each one explained, as well as its accumulated variance and the value of each of the variables that were correlated with the CP.

Table 4. Main components selected based on the analysis of the main component, the eigenvalues, proportion of the variance, cumulative variance and the indicators of multiple correlation with the different CP.

	Own value	Proportion (%)	Cumulative proportion (%)	Correlation indicator with the CP	
CP1	6.26	0.26	0.26	ST	0.8
				SST	0.74
				EC	0.84
				P	0.93
				HCO_3	0.7
				Cl	0.83
				K	0.78
CP2	3.37	0.14	0.4	SO_4	0.58
				Ca	-0.56
				Fe	0.66
				Mn	0.8
				Cu	0.82
CP3	2.88	0.12	0.52	SDT	0.44
				PH	0.76
				N	0.61
				CO_3	0.59

	Own value	Proportion (%)	Cumulative proportion (%)	Correlation indicator with the CP	
CP4	2.05	0.09	0.61	FATS	0.64
				RAS	-0.23
CP5	1.56	0.06	0.67	STV	0.53
				Zn	0.46
				Pb	-0.53
CP6	1.39	0.06	0.73	Na	-0.47
				Mg	0.65
				Cd	0.44

Main component 1. A positive correlation is observed between 7 variables (ST, SST, EC, P, HCO_3, Cl and K). Phosphorus in the effluent can be organically present in organic matter and related to total solids. The presence of potassium and chlorine in the form of salts, can form the compound potassium chloride which is a salt and also correlate with the amount of total solids and also the dissolved salts would have an important influence with the EC, just like HCO_3.

Meanwhile, component 2 groups the variables SO_4, Ca, Fe, Mn and Cu. SO_4, Fe and Ca, are important elements that influence water hardness, which is a parameter of agronomic relevance, both for the dissolution of fertilizers, and for the irrigation system. Main component 3 groups four total dissolved solid variables (SDT), pH, N and CO_3.

This group explains 12% of the variance, the pH has a strong relationship with the N, since there are fluctuations in the pH the microbial activity decreases and therefore the availability of nitrogen. Carbonates are related to total dissolved solids. Component 4. It is made up of fats/oils and RAS (sodium adsorption ratio), although the latter has a negative influence. Total volatile solids (STV), Zinc and Pb, are the variables that make up component number 5, where Pb is negatively related. And finally, component 6, which explains 6% of the variance, the variables are grouped are Sodium in a negative way.

Conclusions

The wastewater treatment plants analyzed in this research, show significant difference in most of the parameters evaluated, not finding a relationship between the type of treatment. These present variability over time, fluctuation is attributed to the plant' s own management and to the influencer's characteristics. The ACP showed six main components that explain 73% of the variance.

In general, WWTP have great potential to be used in agricultural irrigation, due to their contribution of essential elements such as N, P and K 15.35, 2.2 and 12 mg L^{-1} respectively. Thus, a lower amount of chemical fertilization would be applied, and sustainable use of water would be made. However, before applying it, it should be considered that the four WWTP are restricted by high salinity and WWTP LA2 in the same way by sodicity, for which the type of irrigation used must be evaluated and a pretreatment must be used to avoid soil erosion and low productivity.

The heavy metal concentrations Pb 11.75 mg L^{-1} and Cd 2.29 mg L^{-1} exceed the MPL established by NOM-001-SEMARNAT-1996, this may restrict its use and application, due to its high potential for accumulation in the soil and possible migration to the crop, it is recommended to monitor these parameters and establish a pretreatment to the effluent before application.

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