Chemistry Research Journal, 2020, 5(6):221-234

Available online www.chemrj.org

Research Article

ISSN: 2455-8990
CODEN(USA): CRJHA5

Physicochemical Determination of the Quality of Surface Waters in the Highlands Region of Jalisco, Mexico

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Abstract The Highlands region is located in the north-eastern part of the state of Jalisco, it has a territorial area of 15,549 km², which corresponds to 19.4 % of the total area of the state, at the Río Verde basin, at the Hydrological region "Lerma-Santiago", in the western centre of Mexico, for the year 2020 a population of 873,731 inhabitants is forecast (2019), is located within the Río Verde basin, in the "Lerma-Santiago" Hydrological region, in central western Mexico. The agricultural activity in the region is of great relevance at the national level, which also generates high volumes of organic waste (solid and liquid), which in many cases are not handled properly causing serious environmental damage.

This paper presents advances in the determination of the contamination of the surface waters of the 20 municipalities that make up the Jalisco Highlands region, making comparisons with available information for the years 2014 and 2016, physicochemical parameters such as: Dissolved Oxygen, Specific Conductivity, Salinity, Oxide-Reduction Potential, Ammonia Nitrogen and Chemical Oxygen Demand. In general, a certain degree of contamination is perceived in most of the bodies of water studied, exposing evidence of the gradual contamination of dams and rivers, mainly due to the discharge of wastewater (domestic and industrial) without treatment, as well as by dragging of waste organic solid, mainly in the municipalities of: Lagos de Moreno, San Juan de los Lagos, Union de San Antonio, Villa Hidalgo, Acatic, Tepatitlan and Arandas, the municipalities that presented less pollution in their surface waters were Teocaltiche, Jesus Maria and San Ignacio Cerro Gordo.

Keywords Highlands of Jalisco, Pollution of bodies of water, Water quality parameters

Introduction

The Highlands region of Jalisco is located in the northeast part of the state, collimated to the north with the states of Zacatecas and Aguascalientes, to the east with the states of San Luis Potosí and Guanajuato, to the south with the Jalisco municipalities of Tototlan, Atotonilco el Alto and Degollado and to the west with the municipalities of Zapotlanejo, Cuquio and the state of Zacatecas, has a territorial area of 15,153.77 km², which corresponds to 18.44% of the total area of the state (Table 1).

Table 1: Total area by municipality of the Jalisco Highlands region, in reference to the state total. Source: Jalisco 2030 Regional Development Plan. Second edition

Municipality	Surface (Km²)	State percentage
Encarnacion de Diaz	1,204.97	1.52
Lagos de Moreno	2,803.48	3.54
Ojuelos	1,316.62	1.54
San Diego de Alejandria	318.09	0.40
San Juan de los Lagos	928.01	1.17
Teocaltiche	894.39	1.13
Union de San Antonio	699.97	0.88
Villa Hidalgo	473.54	0.60
Acatic	331.04	0.42
Arandas	984.06	1.24
Cañadas de Obregon	249.40	0.32
Jalostotitlán	527.48	0.67
Jesús María	684.08	0.86
Mexticacan	278.57	0.35
San Julian	250.23	0.32
San Miguel el Alto	864.99	1.09
Tepatitlan de Morelos	1,252.43	1.58
Valle de Guadalupe	375.50	0.47
Yahualica de Gonzalez Gallo	588.11	0.74
San Ignacio Cerro Gordo	228.02	0.29
Regional total	**15,153.77**	**18.44**

In 2015, the regional population amounted to 827,250 inhabitants, it is estimated that by 2020 it will increase to 873,731 inhabitants, maintaining 5.2% of the total population of the state [1].

Livestock production in the region is of state and national importance, in the 2013 cycle there was a production of bovine milk of the order of 1,316,955 million litres which represented 63.45% of state production and 12% of national production, likewise, in that year 1,155,200 tons of eggs were generated for dishes, contributing to 88.1% of state production and 46% of national production (Table 2).

Table 2: Main livestock products in the Jalisco Highlands, according to their volumes of production, compared with State and National production, 2013 cycle. Source: AEDRJ, 2020 [2].

Product	Units	Regional volume	State volume	Percentage state	National volume	National percentage
Bovine milk	Thousands of liters	1,316,965	2,078,203	63.45	10,965,632	12.0
Goat milk	Thousands of liters	644	6,667	9.6	152,332	0.4
Egg for plate	Tons	1,155,200	1,311.542	88.1	2,516.094	46.0
Honey	Tons	837	6,635	12.6	56,907	1.5
Raw wax	Tons	66	541	12.3	2,010	3.4

Likewise, in 2014 the volume of live pig and poultry production reached 184,205 and 242,852 tons respectively (Table 3).

Table 3: Production volume (tons) of live cattle and fowl 2014. Source: Agro-Food and Fisheries Information Service [3]

Municipality	Bovine	Porcine	Sheep	Goat	Fowl
Encarnacion de Diaz	11,226	3,671	353	23	16,238
Lagos de Moreno	22,626	26,179	177	278	113,344
Ojuelos	4,838	208	94	159	8,356
San Diego de Alejandria	1,866	475	9	8	274
San Juan de los Lagos	7,848	52,375	273	9	22,859
Teocaltiche	3,790	1,678	107	52	89
Union de San Antonio	2,067	789	20	21	799
Villa Hidalgo	3,804	370	7	56	49
Acatic	5,391	20,061	8	6	29,806
Arandas	10,607	31,286	149	50	2,893
Cañadas de Obregon	1,030	255	6	5	40
Jalostotitlan	3,402	327	60	6	2,741
Jesus Maria	2,944	1,228	16	10	42
Mexticacan	750	142	22	4	9
San Ignacio Cerro Gordo	ND	ND	ND	ND	ND
San Julian	2,309	3,797	5	6	190
San Miguel el Alto	8,293	865	4	5	56
Tepatitlan de Morelos	16,755	35,785	29	26	41,895
Valle de Guadalupe	1,545	2,379	6	6	2,797
Yahualica de Gonzalez Gallo	1,894	2,336	98	109	381
Regional total	**112,985**	**184,205**	**1,443**	**840**	**242,858**
State of Jalisco	**378,569**	**313,347**	**6,341**	**2,773**	**411,455**
State percentage	**29.84**	**58.79**	**22.76**	**30.29**	**59.02**

In contrast, the National Water Commission (CONAGUA, by its acronym in Spanish) updated the average annual availability of groundwater, published in April 2015 in the Official Gazette of the Federation (OGF), where it is recognized that of the 59 aquifers that are located in the state of Jalisco, 26 present conditions of overexploitation. Likewise, the South Highlands region is located on 11 aquifers, of which nine present overexploitation conditions, with a total volume for the region of 90.08 million cubic meters (MCM) per year of deficit. In the region, an annual extraction volume of 636.71 MMC is concessioner, while the average annual recharge volume is 620.20 MCM; of the two aquifers that do not present overexploitation, the available volume is 5.96 MCM, it is in this way that it is determined that the South Highlands region presents a condition of overexploitation of underground water resources [1].

The current problem in the region focuses on the fragile environmental situation, considering that it is one of the areas with the greatest risk of drought, likewise there is a deficit in the aquifers of almost 110 MCM of water per year, on the other hand, it generates more than 25,500 tons of organic livestock waste per day and more than 184,600 tons of methane annually, derived from the intense activity of the agricultural sector [1].

One of the main factors for the contamination of bodies of water in the region is directly related to the discharges of domestic wastewater without treatment into rivers and streams, for example, two of the eight municipalities of North Highlands region do not carry out water treatment (Encarnacion de Diaz and Union de San Antonio), of the six remaining municipalities that have a system for the treatment of wastewater, the one with the lowest coverage is Ojuelos with just 5%.

This situation is further complicated by the lack of adequate infrastructure for the treatment of wastewater since, of the 27 treatment plants in the region, only eight are operating and only two comply with the current official standard (Table 4).

Table 4: Wastewater treatment plants in North Highlands
Source: State Water Commission of the state of Jalisco, 2014.

Municipality	**Total plants**	**Plants out of operation**	**Plants in operation**	**Plants within the standard**
Encarnacion de Diaz	1	1	0	0
Lagos de Moreno	14	10	4	1
Ojuelos	3	2	1	0
San Diego de Alejandria	1	0	1	0
San Juan de los lagos	3	3	0	0
Teocaltiche	3	3	0	0
Union de San Antonio	0	0	0	0
Villa Hidalgo	2	0	2	1
Total	**27**	**19**	**8**	**2**

Similarly, the number of municipal systems for the adequate treatment of domestic effluents in the South Highlands is limited (Table 5).

Table 5: Municipal wastewater treatment plants in South Highlands (2015). Source: http://www.ceajalisco.gob.mx/contente/plantas_tratamiento/

Municipality	**Out of operation**	**In operation**
Acatic		2
Arandas	3	1
Cañadas de Obregon	1	1
Jalostotitlan		4
Jesus Maria	1	3
Mexticacán		2
San Ignacio Cerro Gordo		1
San Julian		1
San Miguel el Alto	2	3
Tepatitlan de Morelos		2
Valle de Guadalupe		1
Yahualica de Gonzalez Gallo	1	
Total	**8**	**21**

The main objective of this study is to periodically quantify the degree of contamination of the main surface water bodies such as dams and rivers, of the 20 municipalities that make up the Highlands region in the state of Jalisco, to detect their behaviour and trends in the short and medium term.

Materials and Methods

Through field trips and geographic information, such as the hydrological features of each of the 20 municipalities in the Highlands of Jalisco region, 60 monitoring and sampling points were established, the location and description of which are included in table 6.

Table 6: Main contaminants by municipality in underground water supplies in the Jalisco Highlands. Source; Agua.org.mx, 2016.

Municipality	**Main contaminants**
Encarnacion de Diaz	Fluorine
Lagos de Moreno	Fluorine
San Juan de los Lagos	Iron, Manganese and Fluorine
Teocaltiche	Turbidity, color and Arsenic

Union de San Antonio	Fluorine
Villa Hidalgo	Fluorine
Acatic	Iron and Manganese
Arandas	Fluorine
Cañadas de Obregon	Fluorine
Jalostotitlan	Fluorine
Jesus Maria	Fluorine
Mexticacan	Fluorine
San Julian	Fluorine
San Miguel el Alto	Iron, Manganese, Fluorine, turbidity and color
Tepatitlan de Morelos	Fluorine and Arsenic
Yahualica de Gonzalez Gallo	Iron, Manganese, turbidity and color
San Ignacio Cerro Gordo	Fluorine

From February to May 2019, several field trip and monitoring campaigns were carried out. The main walls evaluated were:

1) Dissolved Oxygen (DO): it is a measure of the amount of oxygen present in the water and available for respiration, this concentration is controlled by several factors, including the consumption of aerobic organisms such as bacteria and fish, the consumption of plants such as algae, temperature and depth, is a fundamental parameter to classify the level of contamination in surface waters when comparing its values at the same temperature conditions with water saturated with dissolved oxygen, for example at 20 ºC and an atmosphere of pressure , the oxygen saturation in water is 9.1 mg / l [4].

2) Specific Conductivity (SC): it is the ability of water to conduct electric current and depends on the amount of dissolved solid matter, it is an indirect measure of the amount of ions in solution (mainly nitrate, sulfate, phosphate, sodium, magnesium and calcium), untreated wastewater discharges to bodies of water tend to increase their conductivity, the basic unit for measuring specific conductivity is milli Siemens per centimeter (mS / cm), SC is an important measure of water quality, since it indicates the amount of matter dissolved in it; significant changes can be indicators of specific pollution events.

3) Chlorides (Cl^-): they are anions commonly present in fresh water, their maximum allowable concentration for drinking water is 250 mg / l [5].

4) Ammoniacal Nitrogen or ammonia(Ammon.N): it is one of the transitory components in water since it is part of the nitrogen cycle and is influenced by biological activity, as well as the natural decomposition product of nitrogenous organic compounds, surface waters should not naturally contain ammonia, in general the presence of free ammonia or ammonium ion is considered as a chemical proof of recent and dangerous contamination, its main origin is; to industrial and livestock wastewater (animal excreta, fertilizers) and plant putrefaction, its maximum permissible value in drinking water is 0.50 mg / l [5]

5) Oxygen Reduction Potential or Redox potential (ORP): it is a measure of the oxidation state of a system, it measures the tendencies of the electrons when flowing to / from a noble metal electrode, it is quantified in millivolts (mV), its presence is a common indicator of contamination in water.

6) Chemical Oxygen Demand (COD): consists of the indirect measurement of the amount of substances that can be oxidized by chemical means that are dissolved or in suspension in a liquid sample, it is very useful to quantify the degree of water pollution. COD differs from Biochemical Oxygen Demand (BOD), which is based on the use of microorganisms that break down organic material in the sample through aerobic respiration during a given incubation period (usually 5 days). COD and BOD have a correlation in practically all samples, but BOD is always lower than COD, since the biochemical decomposition of organisms is often not as complete as with the chemical method (NMX-AA-030 / 1- SCFI-2012).

For the analysis of the surface water samples, the following equipment was used:

-Probe Hydrolab, model DS5X of the OTT Hydromet brand, Surveyor 4A interface, for evaluation of parameters in the field, according to the precision and resolution specified by the manufacturer (Table 7).

Table 7: Parameters and specifications of the equipment used. Source: DS5X Probe User Manual, Sension + Meters / DR-2800 Spectrophotometer

Parameter	Accuracy	Resolution	Range
Temperature (ºC)	± 0.10	0.01	-5 to 50
SC (mS/cm)	±1%	0.0001	O to 200
pH	±0.2	0.01	0 to 14
ORP (mV)	± 20	1	-999 to 999
DO (mg/l)	±0.01 from 0-8, ±0.2 > 8	0.01	0 to saturation
Ammon. N (mg/l-N)	± 2	0.001	0 to 100
Cl- (mg/l)	± 2	0.0001	0.5 to 18,000
COD	±5%	0.001	O to 1000

HACH brand portable meters, Sension + EC5 and Sension + DO6 models with 5060 and 5130 probes, complementing the field measurements of SC and DO.

-Digital digestion reactor DRB-200 and spectrophotometer DR-2800 (HACH) for evaluation of COD in laboratory.

At present, there are several ways to evaluate the parametric quality and / or contamination of the water, however to carry out a practical analysis of the data obtained in this study (basic parameters), a Quality Indicator (QI) is established as a reference. with three classifications for the general quality of surface water: Acceptable (A), Contaminated (C) and Very Contaminated (VC), based on the 6 parameters evaluated, as well as the current official standards (NOM-SSA1-127-1996 and NMX-030-SCFI-2001) (Table 8).

Table 8: Parametric reference for Water Quality Indicator (QI) (Source: own construction based on current official regulations

Parameter	Units	Acceptable (A)	Contaminated (C)	Very Contaminated (VC)
OD	mg/l	More of 4.7	from 4.69 to 2.4	Less than 2.39
SC	mS/cm	Less than 80	from 81 to 200	More of 201
Cl-	mg/l	Less than 25	from 26 to 249	More of 250
N ammon.	mg/l	Less than 0.50	from 5 to 19	More of 20
ORP	mV	±100	±150	±200
COD	mg/l	Less than 40	From 41 to 199	More of 200

Results

In the Jalisco Highlands region, the potable water coverage reaches 84.52% in general average (86.89 % at North Highlands and 82.15% for South Highlands), in reference to the drainage network the coverage is 78.23% (75.35 % at North Highlands and 81.12% for South Highlands) and in general the coverage for wastewater sanitation is 48.38% (48.43% at North Highlands and 48.32% for South Highlands).

In summary, the municipalities that show the greatest lags in the coverage of the services mentioned above are: Encarnacion de Diaz, Union de San Antonio, Ojuelos, Villa Hidalgo, Cañadas de Obregon, Arandas, Jesus Maria and San Miguel el Alto (Table 9).

Table 9: Coverage of piped water, drainage and sanitation services by municipality.
Source: Integrated Water Coverage Information System of the State of Jalisco. CEA.Jal, 2019 [6].

Municipality	Coverage of water Piped (%)	Coverage of drainage connected to the public network (%)	Sanitation (%)
Encarnacion de Diaz	86.78	81.09	0
Lagos de Moreno	88.49	77.39	66.23
Ojuelos	86.21	55.15	6.63

San Diego de Alejandría	89.72	75.83	77.48
San Juan de los Lagos	79.64	79.29	75.31
Teocaltiche	90.73	70.49	71.41
Unión de San Antonio	86.15	64.74	0
Villa Hidalgo	89.93	81.71	0
Acatic	78.0	82.9	64.7
Cañadas de Obregon	86.9	72.4	0
Arandas	82.3	84.6	4.2
Jalostotitlan	91.2	88.9	76.5
Jesus Maria	80.3	69.2	11.0
Mexticacan	89.1	79.5	65.9
San Ignacio Cerro Gordo	83.8	68.8	65.9
San Julian	93.2	86.3	61.3
San Miguel el Alto	86.5	85.9	11.4
Tepatitlan	91.8	91.1	74.7
Valle de Guadalupe	88.7	82.5	83.1
Yahualica	71.2	81.3	61.1
Regional total	**84.52**	**78.23**	**48.38**

The campaigns for the collection of surface water samples, as well as the field trips were carried out between the months of February and May 2019, monitoring 60 points, in the main bodies of water (dams, rivers and streams) of the 20 municipalities that make up the Jalisco Highlands region, the geographical location of each of these sampling points appears in Table 10.

Table 10: Location of sampling points for water quality in Los Altos de Jalisco. Source: self-made

North Highlands Municipality	**Code of identification**		**Location of sampling points**			**Type**
			North	**West**	**Altitude (m)**	
Lagos de Moreno	L	1	21° 22.664’	101° 54.479’	1876	Lagos River
		2	21°21.071’	101°55.741’	1870	Lagos River
		3	21°20.660’	101°56.288’	1867	Lagos River
		4	21°17.089’	102°00.025’	1851	Lagos River
		5	21° 31.203’	101° 43.349’	1963	Cuarenta Dam
		6	21° 22.880’	101° 56.646’	1871	Dam
San Juan de los Lagos	SJL	1	20°13.891’	102°18.698’	1714	San Juan River
		2	21°14.851’	102°20.329’	1713	San Juan River
		3	21°15.397’	102°20.748’	1712	San Juan River
		4	21° 22.319’	101° 56.638’	1718	Dam
		5	21° 13.449	102° 18.138’	1726	San Juan River
Encarnacion de Diaz	E	1	21°31.454’	102°14.461’	1806	Encarnacion River
		2	21°31.389’	102°13.559’	1845	San Pedro dam
Union de San Antonio	U	1	21°08.467’	102°00.690’	1904	El Ranchito dam
		2	21° 07.556’	102° 00.501’	1929	Morelos dam
Villa Hidalgo	VH	1	21°40.440’	102°35.610’	1918	Rio Arroyo Seco
		2	21°41.888’	102°36.507’	1941	Guadalupe dam
		3	21° 41.921’	102° 32.605’	1875	Juiquinaqui dam
Teocaltiche	TE	1	21°25.58’1	102°34.449’	1717	Teocaltiche River
		2	21°30.176’	102°35.676’	1797	Calera dam
Ojuelos	O	1	21°31.203’	101°43.349’	1982	Cuarenta dam
		2	21°52.038’	101°35.325’	2216	Ojuelos dam
San Diego de Alejandria	SD	1	20°59.981’	102°01.586’	1960	Amapola dam
		2	20°59.306’	101°59.975’	1943	Parque dam

North Highlamds Municipality	Code of identification		Location of sampling points			Type
			North	West	Altitude (m)	
Tepatitlan	T	1	20°51’19.63”	102°42’51.35”	1904	Jihuite dam
		2	20°51’21.51”	102°48’11.33”	1888	Carretas dam
		3	20°49’11.64”	102°45’19.29”	1777	Tepatitlan River
		4	20°48’15.35”	102°45’47.40”	1767	Tepatitlan River
		5	20°47’20.67”	102°48’54.23”	1742	Tepatitlan River
		6	20°49’22.08”	102°35’01.10”	2052	Arboledas dam
Acatic	AC	1	20°43’12.82”	102°49’19.35”	1738	Red dam
		2	20°41’25.15”	102°57’42.59”	1620	Calderon dam
		3	20°45’41.79”	102°52’46.43”	1697	Lagunillas dam
		4	20°45’40.25”	102°54’43.16”	1688	Tepatitlan River
		5	20°47’08.03”	102°56’56.58”	1670	Tepatitlan River
Arandas	AR	1	20°44’05.39”	102°25’34.39”	2014	Tule dam
		2	20°43’15.64”	102°19’58.81”	2085	Arandas River
		3	20°44’05.39”	102°20’23.93”	2059	Arandas River
		4	20°41’13.42”	102°19’55.75”	2026	Arandas River
Yahualica	Y	1	21°10’59.03”	102°54’08.54”	1817	Estribon dam
		2	21°13’47.52”	102°51’02.21”	1671	Verde River
		3	21°00’25.62”	102°49’05.39”	1473	Verde River
San Miguel el Alto	SMA	1	20°59’33.01”	102°24’23.81”	1866	San Miguel dam
		2	21°01’16.36”	102°23’56.62”	1847	San Miguel River
		3	21°01’40.58”	102 23 59.43”	1843	San Miguel River
Cañadas de Obregon	CO	1	21°11’33.81”	102°41’26.52”	1620	Verde River
		2	21°11’35.32”	102°42’04.12”	1612	Verde River
San Ignacio Cerro Gordo	SI	1	20°46’05.10”	102°32’07.73”	2069	Mezquite dam
Jalostotitlan	J	1	21°09’20.75”	102°27’26.84”	1749	Jalostotitlán dam
		2	21°09’25.34”	102°25’03.48”	1752	Jalostotitlán River
		3	21°09’47.23”	102°28’02.85”	1738	Jalostotitlán River
		4	21°10’26.72”	102°28’11.57”	1733	Jalostotitlan River
San Julian	SJ	1	20°58’13.18”	102°10’54.57”	2093	San Isidro dam
		2	21°00’46.57”	102°11’18.89”	2052	San Julian River
Mexticacan	M	1	21°16’34.83”	102°46’41.91”	1756	Paloma dam
		2	21°15’57.88”	102°46’26.30”	1756	Mexticacan River
Jesus Maria	JM	1	20°43’17.75”	102°09’00.33”	2207	Ojo Zarco dam
		2	20°39’01.39”	102°08’49.26”	2171	Luz dam
Valle de Guadalupe	VG	1	21°01’48.16”	102°42’01.04”	1812	Salto dam
		2	21°00’39.02”	102°37’09.21”	1820	Valle de Guadalupe River

The parametric results and the QI´s of the monitored points appear in table 11.

Table 11: Results of surface water analysis in the Jalisco Highlands (2019)

Code	Temp. (°C)	pH	DO (mg/l)	Ammon N mg/l-N	Cl- (mg/l)	ORP mV	SC ms/cm	COD mg/l	QI
L.1	20.55	7.54	3.11	1.71	73982	-182	372.8	188	**C**
L.2	21.34	7.78	2.45	2.45	75734	-221	559.0	356	**VC**
L.3	21.45	8.05	2.12	2.67	76784	-232	896.8	388	**VC**
L.4	20.22	7.78	1.45	1.56	32980	-117	83.5	192	**C**
L.5	20.23	7.77	8.54	2.03	12003	-104	54.7	-	**A**
L.6	21.23	7.69	4.65	1.61	17542	-114	223	178	**C**
SJL.1	19.34	8.47	4.56	1.12	89345	-245	874.4	-	**A**
SJL.2	19.78	8.98	2.56	1.89	98904	-290	935.4	168	**C**
SJL.3	20.23	7.59	2.03	2.34	99034	-489	1060	405	**VC**
SJL.4	19.12	7.17	4.56	1.67	23456	-201	137.9	-	**C**
SJL.5	20.21	7.37	4.51	1.83	20234	-208	198.3	149	**C**
E.1	21.34	7.34	3.78	1.23	63243	-319	601.3	163	**C**
E.2	19.23	7.56	5.87	0.67	26745	-273	189.2	-	**A**
U.1	21.03	8.45	0.02	4.98	99999	-762	776.8	455	**VC**
U.2	21.34	8.21	1.23	2.45	56324	-385	534.4	312	**VC**
VH.1	19.56	7.67	2.44	2.67	62934	-453	434.8	365	**VC**
VH.2	19.72	7.45	4.73	0.55	17435	-109	94.4	171	**C**
VH.3	18.45	7.23	8.15	0.23	9234	-93	72.1	-	**A**
TE.1	19.27	8.36	2.45	1.84	66345	-402	493.7	-	**A**
TE.2	19.67	7.76	6.12	0.43	11934	-139	88.4	-	**A**
O.1	18.78	8.42	2.34	4.12	72934	-342	372.7	155	**C**
O.2	19.23	7.11	7.11	0.53	8231	-105	73.9	-	**A**
SD.1	21.34	7.90	6.56	0.53	9342	-78	125.9	-	**A**
SD.2	20.86	7.92	2.73	3.71	69222	-372	393.8	160	**C**
T.1	19.34	7.23	3.16	2.13	82934	-241	179.1	152	**C**
T.2	18.89	8.02	4.22	1.79	35873	-218	134.3	122	**C**
T.3	18.72	7.38	4.17	1.67	34212	-229	273.0	-	**C**
T.4	19.03	7.83	3.23	2.36	47231	-383	452.9	-	**C**
T.5	19.12	8.13	0.78	5.73	87034	-452	873.7	420	**VC**
T.6	18.12	8.09	3.11	1.34	22983	-192	634.4	133	**C**
AC.1	18.29	7.35	7.23	0.82	31298	-162	137.9	-	**A**
AC.2	18.76	7.72	7.18	1.79	56231	-283	301.2	-	**A**
AC.3	18.93	8.67	2.67	3.48	99923	-451	452.9	125	**C**
AC.4	19.21	7.78	3.12	3.08	56231	-289	367.4	88	**C**
AC.5	20.02	8.64	1.78	4.02	86239	-523	874.7	385	**VC**
AR.1	19.33	6.79	5.54	0.43	12034	-86	237.2	-	**A**
AR.2	20.34	7.56	5.04	1.04	38001	-221	172.3	-	**A**
AR.3	20.67	7.23	3.45	1.56	49231	-230	292.3	183	**C**
AR.4	19.45	6.74	2.11	2.89	64234	-421	605.4	378	**VC**
Y.1	20.12	6.74	4.23	1.36	9236	-125	163.7	106	**C**
Y.2	19.34	7.27	5.32	2.23	31784	-234	277.3	-	**A**

Y.3	19.78	7.59	3.12	3.36	47212	-312	721.6	163	**C**
SMA.1	18.23	7.12	5.66	0.40	21310	-221	185.8	-	**A**
SMA.2	19.72	7.45	4.04	0.92	48543	-284	339.4	105	**C**
SMA.3	18.34	7.73	3.03	2.43	65342	-326	523.9	170	**C**
CO.1	18.03	7.81	3.42	2.48	87728	-417	1071	82	**C**
CO.2	19.72	8.04	6.67	0.38	30310	-226	96.3	-	**A**
SI.1	18.15	6.68	8.13	10.85	28886	-198	132.6	-	**A**
J.1	18.12	7.21	7.34	0.21	8231	-98	145.6	-	**A**
J.2	20.35	7.76	3.43	0.54	11877	-229	98.6	132	**C**
J.3	17.55	7.56	3.12	2.12	59222	-319	552.3	154	**C**
J.4	18.56	8.57	2.45	2.31	67231	-452	816.4	171	**C**
SJ.1	18.34	8.31	4.56	1.72	23123	-201	134.6	-	**A**
SJ.2	18.54	8.43	3.23	1.98	32416	-303	298.3	123	**C**
M.1	19.23	6.96	6.45	1.03	9834	-109	278.1	-	**A**
M.2	18.56	7.30	3.23	3.78	87342	-783	1006	98	**C**
JM.1	19.45	7.12	6.89	1.21	12342	-132	177.7	-	**A**
JM.2	19.78	6.57	7.43	0.34	7321	-78	155.1	-	**A**
VG.1	18.34	6.78	7.23	0.34	10923	-129	232.6	-	**A**
VG.2	19.56	7.45	3.56	1.93	34243	-289	453.5	122	**C**

In general terms and with the above information, it is possible to observe a certain degree of contamination in most of the water bodies in practically the entire study area, the most affected surface water bodies are: the Lagos River as it passes through the city de Lagos de Moreno (L.2 and L.3), the San Juan River as it passes through San Juan de los Lagos (SJL.3), dams in the municipal head of Unión de San Antonio (U.1 and U. 2), the Arroyo seco River in Villa Hidalgo (VH.1), the Tepatitlan River as it passes through Tepatitlan city (T.5), the Tepatitlan River at the exit of Acatic (AC.5) and the Arandas River at the exit de Arandas city (AR.4). Likewise, to know the behavior of surface water quality in the study region, the results obtained were compared with evaluations carried out at the same sampling points in 2014 and 2016 of parameters such as COD (Tables 12 and 13).

Table 12: Summary of surface water analysis results in Altos de Jalisco (Sept / 2016)

Code 2016	**Temp °C**	**pH**	**DO mg/l**	**Ammon N mg/l-N**	**Cl- mg/l**	**ORP mV**	**SC mS/cm**	**COD mg/l**
L.2	19.02	8.03	2.05	1.89	48734	-221	657.6	255
L.3	19.78	8.15	1.98	1.78	59890	-323	689.7	281
SJL.3	19.34	8.11	1.83	2.12	97232	-376	911.4	291
U.1	17.78	8.43	1.27	1.98	88045	-256	734.0	312
U.2	16.89	8.45	1.98	1.45	46903	-221	345.4	201
VH.1	17.45	7.45	3.45	1.34	44903	-256	254.8	210
T.5	18.23	7.77	3.23	2.66	67545	-362	658.2	330
AC.5	17.17	7.81	2.46	1.89	45125	-257	701.3	378
AR.4	17.86	7.33	3.90	2.12	48521	-302	515.2	273

Table 13: Summary of results of surface water analysis in the Jalisco Highlands (Oct / 2014)

Code 2014	**Temp °C**	**pH**	**DO mg/l**	**Ammon N mg/l-N**	**Cl- mg/l**	**ORP mV**	**SC mS/cm**	**COD mg/l**
L.2	19.76	7.78	2.80	1.04	52186	-211	753.3	210
L.3	19.23	8.63	2.36	2.36	56362	-301	723.8	222
SJL.3	18.33	8.23	2.15	1.56	99326	-315	925.2	232
U.1	20.56	8.21	1.66	2.36	90236	-325	852.6	250
U.2	20.96	7.56	4.69	0.36	36253	-188	254.7	131
VH.1	16.83	7.73	4.66	0.40	31310	-221	133.5	149

T.5	17.23	7.11	3.89	1.88	54212	-300	521.3	312
AC.5	18.23	7.56	3.78	1.11	40235	-204	611.3	333
AR.4	17.56	7.21	4.12	1.21	41325	-221	356.2	302

In the Lagos River at the exit of the city of Lagos de Moreno, a sustained decrease in the quality of its surface waters can be observed (Fig. 1).

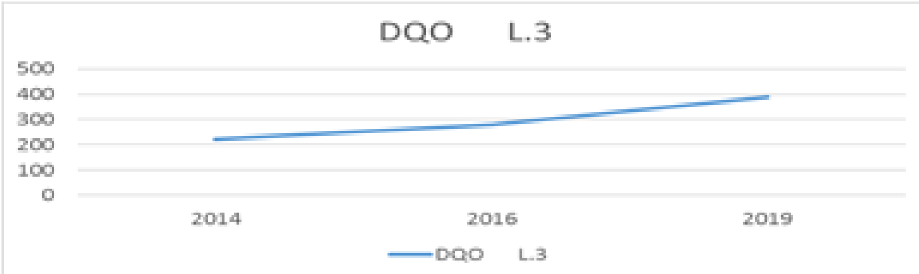

Figure 1: Behavior of the COD in the Lagos River at the exit of the city (L.3)

In the San Juan River, progressive contamination is also observed in the period from 2014 to 2019 (Fig. 2).

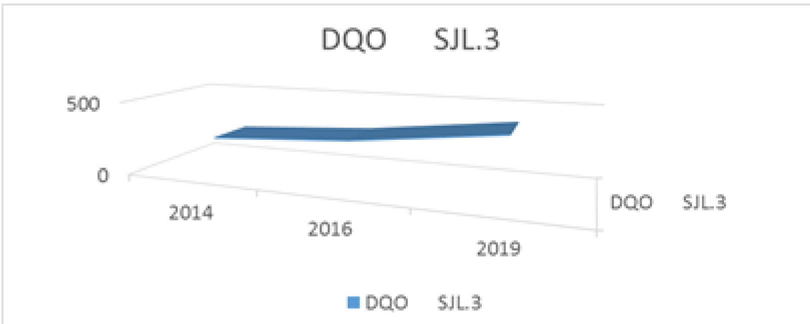

Figure 2: Behavior of the COD in the San Juan River at the exit of the city (SJL.3)

Likewise, in the El Ranchito dam located within the town of Union de San Antonio, the quality of its waters has drastically decreased (Fig. 3).

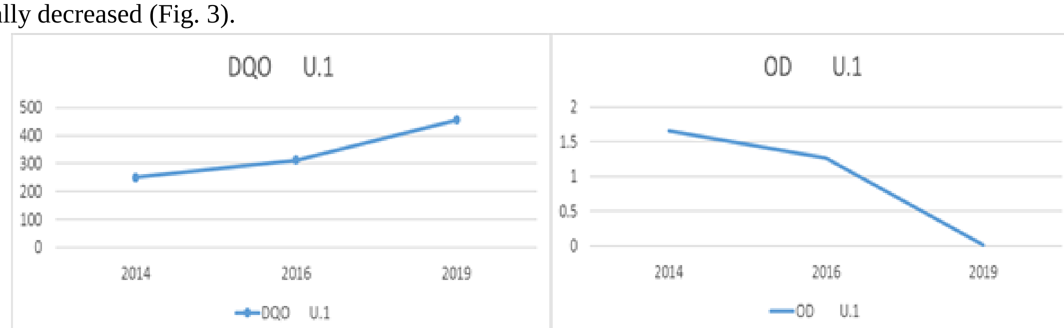

Figure 3: Behavior of COD and DO in the El Ranchito dam in Union de San Antonio (U.1)

In the Arroyo seco River in Villa Hidalgo, gradual contamination is also evident (Fig. 4).

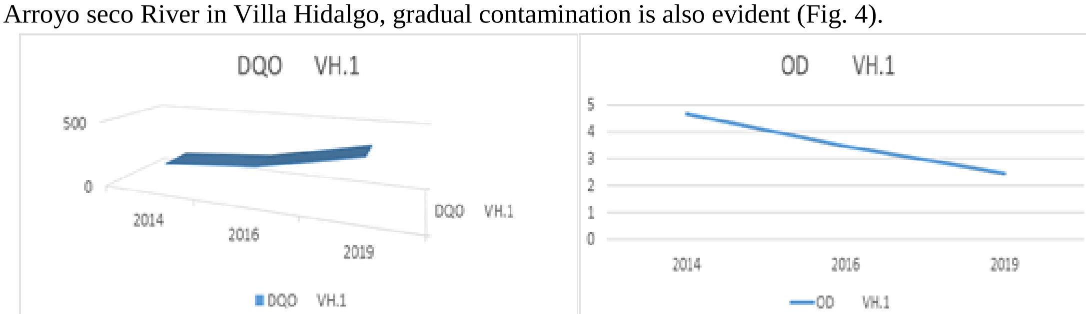

Figure 4: Variation of COD and DO in Arroyo Seco River in the center of city of Villa Hidalgo (VH.1).

In the municipality of Tepatitlan, low QIs are presented in the 6 sampled points, highlighting the behavior of the Tepatitlan River at the exit of the municipality in which an increase in the COD of almost 35% from 2014 to 2109 can be seen, as well as the decrease of DO in the same period reached 80% (Fig. 5).

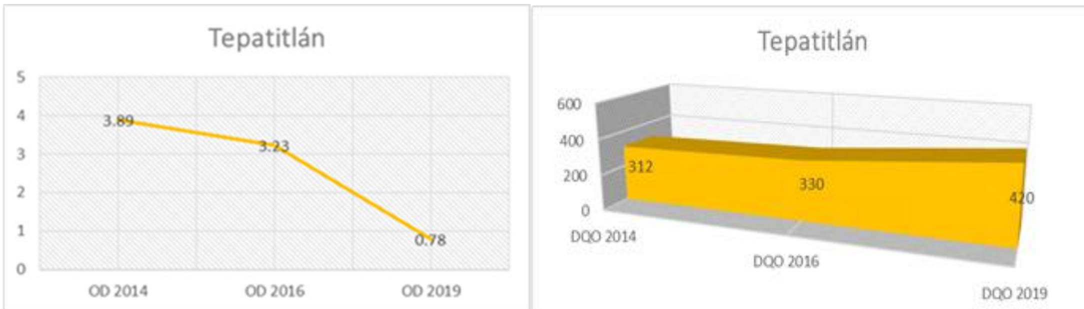

Figure 5: OD and COD in the Tepatitlan River at the exit of the municipality of Tepatitlan (T.5).

The Tepatitlan River at the exit of Acatic shows an increase in COD of 13.5% in the same period, likewise the DO increased by 1.85% (Fig. 6).

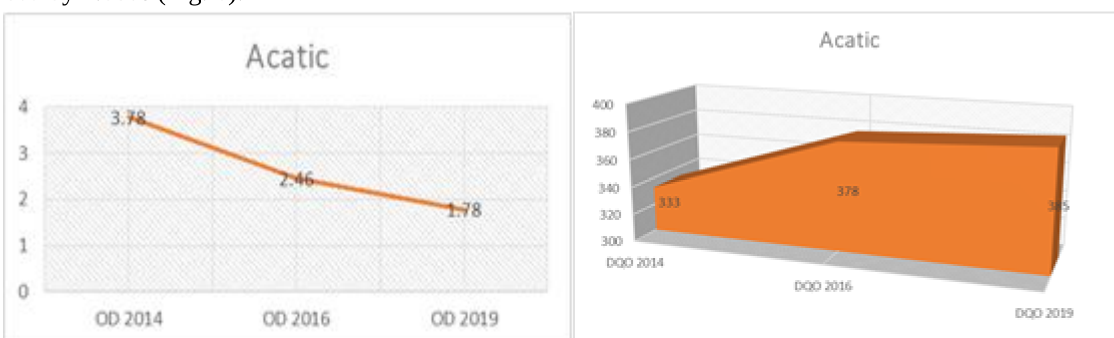

Figure 6: Behavior of the DO and COD of the Tepatitlan River at the Acatic outlet (AC.5).

In Arandas it can be seen that the Arandas River at the height of the southern bypass of the Arandas urban area, its COD decreased by 9.6%, however, from 2016 to 2019 it increased notably by more than 38%, the low DO by more than 48 % from 2014 to 2019 (Fig. 7).

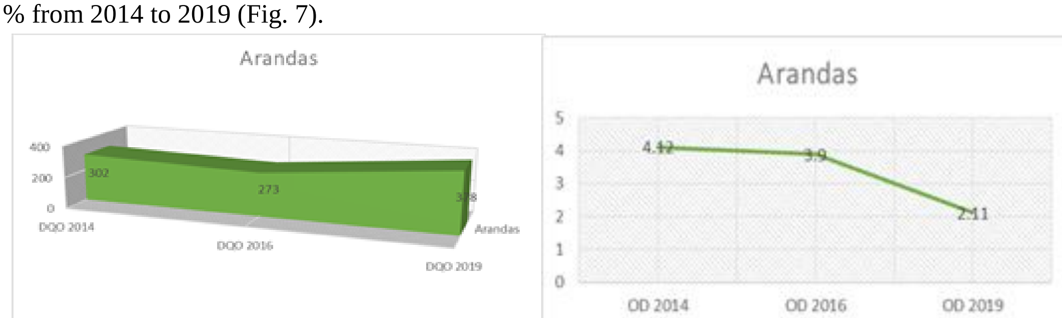

Figure 7: COD and DO gradients in the Arandas River (AR.4) in Arandas Jal.

Figure 8 shows the location of both the most polluted surface water bodies, as well as the main point sources of contamination detected, which basically correspond to untreated domestic wastewater discharges and livestock farms in operation. In summary, the municipalities that presented the best quality indicators in their surface waters were: Teocaltiche, Jesus Maria and San Ignacio Cerro Gordo.

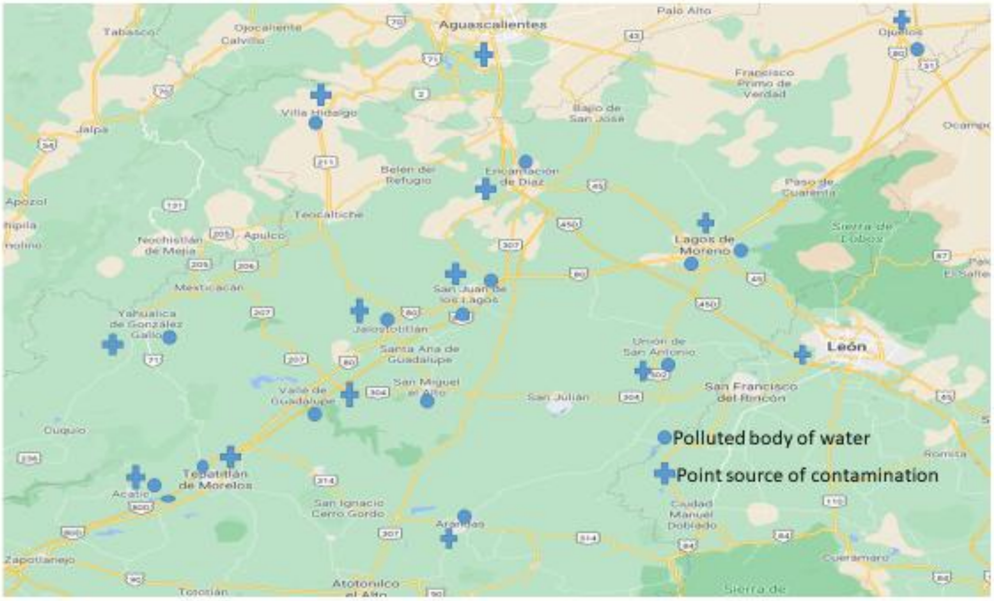

Figure 8: Location of the most polluted surface water bodies and the main point sources of contamination in the Jalisco Highlands. Source: self-made.

Discussion

In reference to the determination of the quality of surface water in the Jalisco Highlands region, there is very limited information, however, it is possible to identify that, during the last 20 years of the 20th century, the population of Highlandso modified their practices in such a way In this way, water runoff through rivers and streams became surface drains, thus at the beginning of the 21st century, competition for water with large cities, but also with industry, agriculture, consolidated in the region and livestock [7]. In 2012, Flores and collaborators identified areas of environmental risk due to the impact of agricultural production systems in the region, based on the microbiological quality of the water due to diffuse contamination from the application of manure in corn and grass, which coincide with the bodies of water detected with greater contamination. The quality indicators (QI) of the monitoring points that presented the highest degree of contamination in the present study coincide with those reported in evaluations carried out in both 2014 and 2016 [8], corresponding to bodies of water. surface areas in the municipalities of: Union de San Antonio, Villa Hidalgo, Lagos de Moreno, San Juan de los Lagos, Tepatitlan, Acatic and Arandas.

Conclusions

Although the Jalisco Highlands region has great relevance at the state and national level, there is relatively little quantitative information on the evolution of the contamination of its surface waters. The advances presented on this occasion reveal the increase in the contamination of various surface water bodies in most of the municipalities of the study area, a situation that puts not only the well-being and health of its inhabitants at risk, but also the sustainable development of this strategic part of the country.

Likewise, there is evidence of the need to incorporate strategies for the continuous monitoring of water quality in the main bodies of water in the region, timely quantifying the impacts of the economic activities of each municipality and evaluating the efficiency of public policies in conservation. of natural resources.

The municipalities that present the greatest contamination in their surface waters are precisely the most economically dynamic and in which most of the population is concentrated, such as: Lagos de Moreno, San Juan de los Lagos, Union de San Antonio, Villa Hidalgo, Tepatitlan, Acatic and Arandas. Comparing the results obtained with determinations at the same monitoring points in the last 5 years, trends of greater deterioration in the quality of surface waters can be seen, mainly in the rivers of: Lagos, San Juan, Villa Hidalgo, Tepatitlán and Arandas especially after the corresponding urban areas.

Some of the factors detected that are contributing to the contamination of water bodies in the region are: the limited infrastructure for the sanitation of wastewater, mainly in the municipal capitals and the diffuse and punctual discharges of waste from livestock farms and companies. processors and manufacturers.

It is evident the need to carry out more and more frequent studies that also include microbiological analyzes that complement the information, in order to have a better overview of both the quality of surface water in the region and its point and diffuse sources of contamination, as well as the dynamics of pollutants and their effects both on the environment and on the people of the region in the short and medium term.

Acknowledgments

The realization of this research was possible thanks to the collaboration of the Guadalajara University, with the technical support of the UDG-561 Academic Group and the Lab for Water Analysis from the CUAltos and the support of the Prodep-SEP program 2018 call.

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