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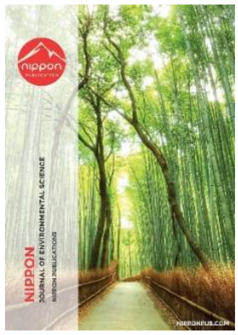

Full Length Research Paper

Evaluation of the physicochemical-microbiological quality of surface waters in The Highlands of Jalisco, Mexico

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Abstract. The Highlands is located northeast of the state of Jalisco (Mexico), concentrates a population of 829,313 Inhabitants (2020), which represents 9.93% of the state population, this area contributes with more than 35% of the state's agricultural GDP, the sources of waters contamination of the region are related to the economic activities that take place in each municipality. The objective of this work was to quantitatively evaluate the quality of the surface water of the 20 municipalities that make up the study area, by analytical determination physicochemical and microbiological parameters. 55 sampling points were established in the main water bodies; the samplings were carried out from November 2020 to March 2021. The results indicate that most of the water bodies sampled present different degrees of contamination, which is essentially related to the discharge of domestic, livestock and industrial wastewater, with insufficient, or no treatment to rivers, streams and dams.

Keywords: Highlands region, Jalisco Mexico, Surface water quality.

1. INTRODUCTION

In 2018, the state of Jalisco occupied the first places in agricultural, livestock and fishing production in the central-western area of the country, including at the national level (Table 1) **(**SEDER, 2019).

In that same year, livestock production in the state of Jalisco reached significant amounts, as in the case of goats, where it contributed 11.3% of national production (Table 2) (SIAP, 2019).

The Highlands region is located in the northeast part of the state of Jalisco (Figure 1), 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 (UASEJ, 2021).

The area of The Highlands region is 15,153.77 km², which represents 18.44% of the state territory (Table 3) (PED, 2020).

In 2020, the population in the Altos de Jalisco region amounted to 829,313 inhabitants, while the state total was 8,348,151 inhabitants (table 4), which represents 9.93% (INEGI, 2020).

This region is of national importance due to its agricultural and agro-industrial vocation; in 2013, a bovine milk production of the order of 1,316,955 million liters was achieved, which represented 63.45% of state production and 12% of national production. Similarly, in that year 1,155,200 tons of eggs for dishes were generated, contributing to 88.1% of state production and 46% of national production (table 5) (AEDRJ, 2020).

Likewise, in 2014 the volume of live pig and poultry production reached 184,205 and 242,852 tons respectively (table 6) (SAGARPA, 2015).

The current problem in the region focuses on the fragile environmental situation, considering that it is one of the areas with the highest risk of drought, the National Water Commission (CONAGUA) updated the average annual availability of groundwater, published in 2015 at 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. The Highlands region is located on 18 aquifers, of which 13 present overexploitation conditions, with a total volume for the region of 172.38 Million Cubic Meters (MMC) per year of deficit. Likewise, the region has concessional an annual extraction volume of 1,045.57 MMC, while the average annual recharge volume is 992 MMC, in general this zone presents a condition of overexploitation of underground water resources (CONAGUA, 2015). On the other hand, the region 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 (IIEG, 2019).

The main source of contamination for bodies of water in the region is directly related to domestic, agricultural and industrial wastewater discharges without any treatment or with inappropriate treatments in rivers and streams, in most municipalities in the region. The main objective of this study was to quantify the physicochemical and microbiological quality of the main bodies of surface water, such as dams and rivers, of the 20 municipalities that make up The Highlands region in the state of Jalisco, to detect their degree of contamination at short-term and medium term.

Table 1. Agricultural, livestock and fishing production by geographic area (Source: Adapted from SIAP/CONAPESCA, 2018. NA=Not Applicable)

State	Production (Tons)	Percentage Regional	National Classification
San Luis Potosí	10,785,429	3.8	12°
Jalisco	**40,207,280**	**14.1**	**1°**
Michoacán	12,086,578	4.2	2°
Regional	84,155,954	29.4	NA
Nacional	286,019,272	100.0	NA

Table 2. Breeding cattle (unit) by geographic area (Source: Adapted from the National Livestock Register –SIAP-, 2019).

State	Bovine	Ovine	Goat	Porcine
Querétaro	131,723	5,560	38,614	116,714
Guanajuato	453,151	12,555	110,425	353,758
Jalisco	**1,957,404**	**81,045**	**647,756**	**245,046**
Regional	4,357,382	203,021	1,401,406	1,322,206
National	23,173,839	1,169,781	5,731,020	5,562,040

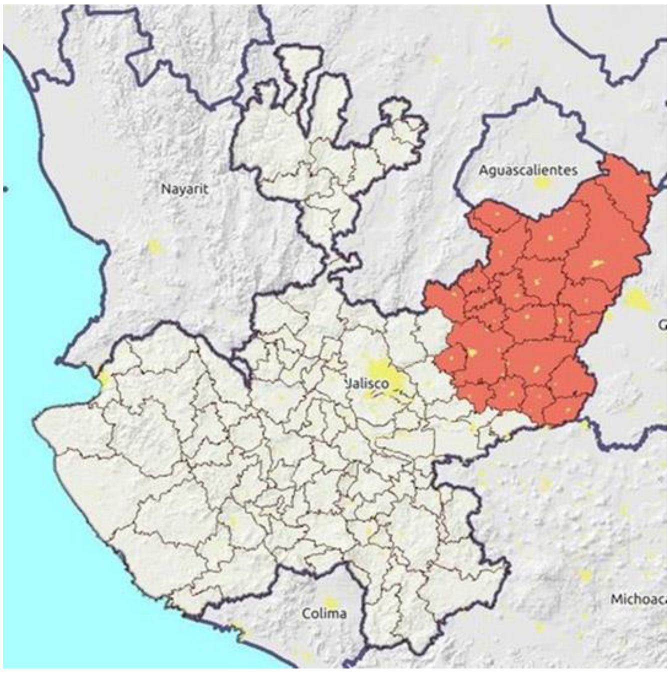


Figure 1. Location of The Highlands region in the state of Jalisco, Mexico (Source: UASEJ, 2021).

Table 3. Total area by municipality of The Highlands region of Jalisco, in reference to the state total (Source: Jalisco 2030 Regional Development Plan. Second edition).

Municipality	Surface (Km^2)	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
Jalostotitlan	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
Tepatitlán 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
Total Regional	**15,153.77**	**18.44**

Table 4. Distribution of the population in The Highlands of Jalisco (Source: INEGI, 2020).

Municipality	Population	Municipality	Population
Arandas	80,609	San Julian	16,792
Acatic	23,175	San Miguel el Alto	31,965
Encarnacion de Diaz	53,039	Teocaltiche	39,839
Jalostotitlan	32,678	Tepatitlan de Morelos	150,190
Jesús María	18,982	Union de San Antonio	19,069
Lagos de Moreno	172,403	Valle de Guadalupe	6,627
Mexticacan	5,307	Villa Hidalgo	20,088
Ojuelos de Jalisco	33,588	Cañadas de Obregon	4,388
San Diego de Alejandria	7,609	Yahualica de González Gallo	22,394
San Juan de los Lagos	72,230	San Ignacio Cerro Gordo	18,341
Total			**829,313**

Table 5. Main livestock products in The Highlands of Jalisco, according to their volumes of production, compared to State and National production, 2013 cycle (Source: AEDRJ, 2020).

Product	Units	Regional volume	State volume	State %	National volume	National %
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
Wax	Tons	66	541	12.3	2,010	3.4

2. MATERIALS AND METHODS

Through field recognition and geographic information, such as the hydrological features of each of the municipalities that make up The Highlands of Jalisco region, 55 monitoring and sampling points were established, distributed according to the importance of each body of water. The geographical location and a brief description of these sampling points, distributed in the 20 municipalities of the study area, are found in Table 7.

Both the collection of samples and the analytical determinations were carried out between November 2020 and March 2021, that is, during the dry season (low water).

The main parameters that were quantified were the following:

a) Chemical Oxygen Demand (COD): it is the amount of oxygen, measured in milligrams per liter (mg/L) that is consumed in the oxidation of organic matter and oxidizable inorganic matter, under test conditions; it is an indicator the degree of water pollution (NMX-AA-030-SCFI-2001).

b) Dissolved Oxygen (DO): it is a quantification of the volume of oxygen present in the water and available for respiration, this amount depends, among other factors, on the consumption of aerobic organisms (bacteria and fish), on the consumption of plants (algae), as well as temperature and depth. It is a basic parameter for classifying the degree of contamination in surface waters when comparing its values at the same temperature conditions, with water saturated with oxygen in solution.

c) Specific Conductivity (SC): in general, terms it consists of the ability of water to conduct electric current, it depends on the amount of dissolved solid matter: Indirectly it provides the volume of ions in solution (nitrate, sulfate, phosphate, sodium, magnesium and calcium). In general, untreated wastewater discharges to bodies of water tend to increase their conductivity, since they increase the amount of dissolved matter, which infers on its quality, the SC is measured in milisiemens per centimeter (mS/cm).

d) Total Nitrogen (TN): This represents ammoniacal nitrogen plus organic nitrogen, which is made up of nitrates, nitrites and ammonia. N is a pollutant present in wastewater that causes a decrease in DO in surface waters and is toxic to aquatic ecosystems.

e) Total Phosphorus (TP): Phosphorus is generally found in natural, sewage and treated wastewater in the form of phosphates. These are classified as orthophosphates, condensed phosphates, and organophosphate compounds. Phosphorus is an essential element in the growth of plants and animals, together with N they are responsible for the excessive growth of algae and other organisms, this process is known as eutrophication and is the main responsible for the contamination of water in lakes, dams rivers and reservoirs.

f) Total Coliform Organism (TCO): They are all those facultative aerobic or anaerobic organisms capable of growing at 35 ºC in a lactose liquid medium, producing acid and gas in a period of 48 hours. The samples for this microbiological indicator were collected in sterile glass bottles with a 500 ml screw cap, following the procedure established in NOM-230-SSA1-2002. To perform the presumptive test, the Most Probable Number method was used in 100 ml of sample (MPN/100 ml) in multiple tubes according to NOM-112-SSA1-1994; the incubation was carried out at 44.5 ° C ± 0.2 ° C for 24 to 48 hours in a water bath with a recirculation system looking for gas formation (NOM-210-SSA1-2014, NOM-112-SSA1-1994).

Likewise, the samples were taken in accordance with the corresponding norms and standards (NOM-230-SSA1-2002. APHA, 2012).

The main laboratory equipment used for quantitative determinations were DRB200 digital reactor, DR 2800 spectrophotometer (HACH, 2019).

The field equipment used were DR900 portable colorimeter and Sension + model portable meters applications: OD6 (OD) and EC5 (CE) (HACH, 2019).

Table 6. Production volume (tons) of live cattle and poultry 2014 (Source: SAGARPA, 2015. NA=Not available).

Municipality	Bovine	Porcine	Ovine	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	NA	NA	NA	NA	NA
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	**112,985**	**184,205**	**1,443**	**840**	**242,858**
State	**378,569**	**313,347**	**6,341**	**2,773**	**411,455**
State %	**29.84**	**58.79**	**22.76**	**30.29**	**59.02**

Table 7. Geographical location of the sampling points in The Highlands of Jalisco, 2021 (Source: Own elaboration).

Sample identification key	**Location of the sampling point**			**Type**	**Description**
	N	**W**	**Altitude (m)**		
L1	21°21.071’	101°55.741’	1870	River	In the center of Lagos
L2	21°20.660’	101°56.288’	1867	River	At the exit of Lagos

L3	21°22.880’	101°56.646’	1871	Dam	Orilla del Agua, north of Lagos
L4	21°22.101’	101°55.183’	1872	River	At the entrance of Lagos
SJL1	21°14.851’	102°20.329’	1713	River	In the center of San Juan
SJL2	21°22.319’	101°56.638’	1718	Dam	Alcala by highway to Lagos
SJL3	21°15.366’	102°20.733’	1706	River	At the exit of San Juan
SJL4	21°13.733’	102°18.917’	1708	River	At the entrance of San Juan
E1	21°31.454’	102°14.461’	1806	River	In the center of Encarnacion
E2	21°31.389’	102°13.559’	1845	Dam	East of Encarnacion
U1	21°08.467’	102°00.690’	1904	Dam	At the entrance of Unión de San Antonio
VH1	21°40.440’	102°35.610’	1918	River	In the center of Villa Hidalgo
VH2	21°41.888’	102°36.507’	1941	Dam	Guadalupe, west of Villa Hidalgo
VH3	21°41.921’	102°32.605’	1875	Dam	Juiquinaqui, northeast of Villa Hidalgo
TE1	21°25.581’	102°34.449’	1717	River	In the center of Teocaltiche
TE2	21°24.683’	102°34.250’	1710	River	At the entrance of Teocaltiche
O1	21°31.203’	101°43.349’	1982	Dam	Cuarenta, by road to Lagos
O2	21°52.038’	101°35.325’	2216	Dam	In the center of Ojuelos
O3	21°44.967’	101°49.917’	2073	Dam	Duquesa, in municipality of Ojuelos
SDA1	20°59.981’	102°01.586’	1960	Dam	Amapola, west of San Diego de Alejandria
SDA2	20°59.306’	101°59.975’	1943	Dam	The Park, in San Diego de Alejandría.
T1	20°51.295’	102°42.873’	1904	Dam	Jihuite in Tepatitlán
T2	20°51.308’	102°48.089’	1888	Dam	Carretas in Tepatitlan
T3	20°48.257’	102°45.765’	1767	River	In the center of Tepatitlan
T4	20°47.258’	102°48.893’	1742	River	At the exit of the municipality of Tepatitlan
T5	20°49.135’	102°35.003’	2052	Dam	In Capilla de Guadalupe
T6	20°46.707’	102°48.202’	1744	Stream	Tributary of the Tepatitlan river
AC1	20°03.078’	102°49.365’	1738	Dam	Red in the municipality of Acatic
AC2	20°01.435’	102°57.675’	1620	Dam	Calderon In the municipality of Acatic
AC3	20°45.675’	102°52.653’	1697	Dam	Lagunillas at Acatic
AC4	20°45.873’	102°54.002’	1688	River	At the entrance to Acatic
AC5	20°47.009’	102°56.932’	1670	River	At the exit of Acatic
AC6	20°45.873’	102°54.356’	1689	Stream	Tributary of the river in Acatic
AR1	20°44.123’	102°25.564’	2014	Dam	Tule in Arandas
AR2	20°44.478’	102°20.341’	2059	River	In the center of Arandas
AR3	20°41.214’	102°19.893’	2026	River	At the exit of Arandas
Y1	21°10.947’	102°54.149’	1817	Dam	Estribon in Yahualica
Y2	21°00.421’	102°49.961’	1473	River	Verde before Yahualica
SMA1	20°59.574’	102°24.312’	1835	Dam	San Miguel in San Miguel el Alto
SMA2	21°01.649’	102°23.503’	1843	River	In the center of San Miguel
CO1	21°11.702’	102°42.010’	1612	River	Verde in Temacapulin
SI1	20°46.068’	102°32.092’	2069	Dam	Mezquite in San Isidro CG
J1	21°09.384’	102°27.482’	1749	Dam	In Jalostotitlan
J2	21°09.703’	102°28.005’	1738	River	In the center of Jalostotitlan
SJ1	20°58.204’	102°10.956’	2088	Dam	San Isidro in San Julian
SJ2	21°00.007’	102°10.405’	2052	River	At the exit of San Julian
SJ3	21°00.508’	102°09.004’	2048	Dam	In San Julian
SJ4	21°00.581’	102°10.204’	2057	River	At the entrance of San Julian
M1	21°16.587’	102°46.704’	1756	Dam	Paloma in Mexticacan
M2	21°15.937’	102°46.392’	1733	River	In the center of Mexticacan
M3	21°16.201’	102°46.596’	1741	River	At the entrance to Mexticacan
JM1	20°43.308’	102°09.002’	2207	Dam	In Ojo Zarco, Jesús María
JM2	20°39.004’	102°08.045’	2171	Dam	La Luz in the municipality of Jesus Maria
VG1	21°01.746’	102°42.002’	1812	Dam	El salto in Valle de Guadalupe
VG2	21°00.604’	102°37.167’	1820	River	In the center of Valle de Guadalupe

Table 8. Coverage of piped water, drainage and sanitation services by municipality (Source: CEA.Jal, 2019).

Municipality	Coverage of water piped (%)	Coverage of Drainage connected to the public network (%)	Coverage of Sanitation (%)
Encarnacion de Diaz	86.78	81.09	0
Lagos de Moreno	88.49	77.39	66.23

Ojuelos de Jalisco	86.21	55.15	6.63
San Diego de Alejandria	89.72	75.83	77.48
San Juan de Los Lagos	79.64	79.29	75.31
Teocaltiche	90.73	70.49	71.41
Union 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	**84.52**	**78.23**	**48.38**

Table 9. Reference standards to evaluate the physicochemical and microbiological quality of the water bodies of Highlands of Jalisco (Source: Own elaboration with official information).

Parameter Unit	**COD mg/L**	**TN mg/L**	**TP mg/L**	**SC mS/cm**	**DO mg/L**	**TCO NMP/100 ml**
NMX-029-SCFI-2001			0.2-0.3			
NOM-001-SEMARNAT-1996	60-400	15-60				
NOM-003-SEMARNAT-1997	40-60					240-1000
NOM-127-SSA1-1994		10.55				2
NOM-069-ECOL-1994	120			250		
WHO (human consumption)		2.5	0.2		8.4 (20°C)	

3. RESULTS AND DISCUSSION

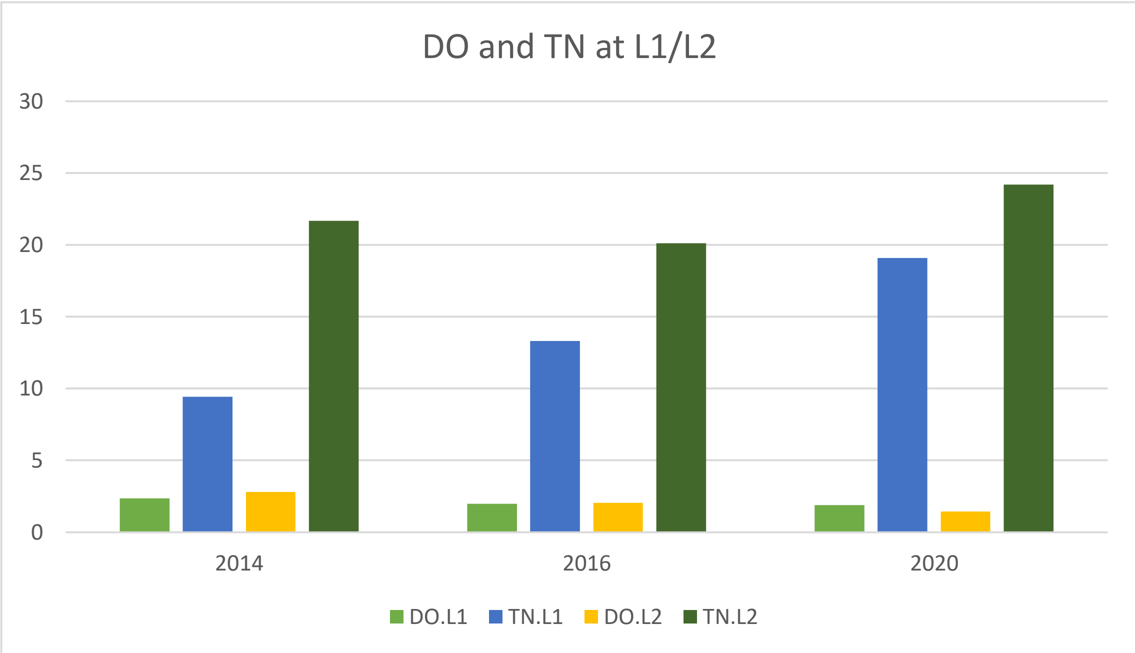
All Drinking water coverage in The Highlands region (Jalisco), reaches an average 84.52%, as for the drainage system the coverage is 78.23% and for the sanitation of domestic wastewater is 48.38%. In summary, the municipalities that show the greatest lags in the coverage of the aforementioned services are: Encarnacion de Diaz, Union de San Antonio, Ojuelos de Jalisco, Villa Hidalgo, Cañadas de Obregon, Arandas, Jesus Maria and San Miguel el Alto (Table 8) (CEA-Jal., 2019).

In order to establish the physicochemical-microbiological quality of the surface waters of the main water bodies (rivers and dams) of the Altos de Jalisco region, in the present study the reference for the microbiological content was taken as referenced in the NOM- 127-SSA1-1994, likewise for the physicochemical parameters both the official regulations in force in our country for wastewater and wastewater treated for reuse were considered (NOM-001-Semarnat-1996, NOM-002-Semarnat-1996, NOM-003-Semarnat-1996, NOM-201-SSA1-2015, NOM-110-SSA1-1994), as well as those suggested by the World Health Organization (WHO, 2020), whose reference values appear in the Table 9.

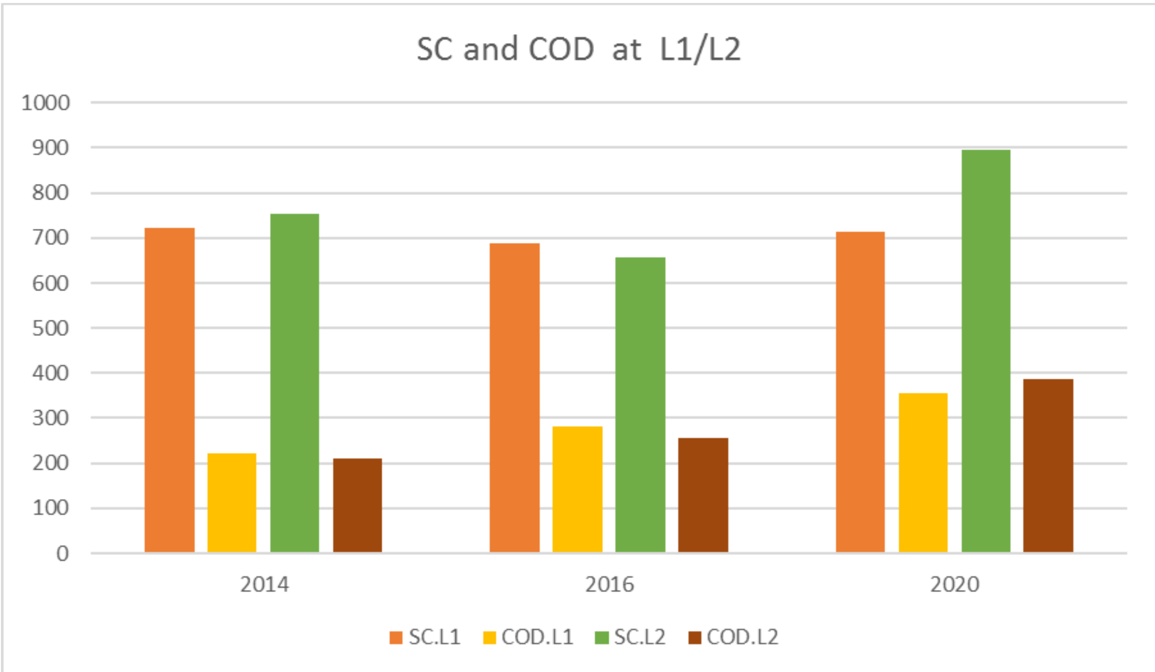
The results are presented in Table 10, where different levels of quality can be seen in the bodies of water in the study area.

In the present analysis it is highlighted that in practically all sampling points in the study area, there is a certain degree of contamination, the municipalities that present lower physical-chemical and microbiological quality in their surface bodies of water are: Lagos de Moreno, San Juan de los Lagos, Encarnacion de Diaz, Union de San Antonio, Villa Hidalgo, San Diego de Alejandria, Tepatitlan, Acatic, Arandas and San Julian, likewise the municipalities that present less contamination and therefore better quality in their surface waters are: Teocaltiche, Mexticacan, Cañadas de Obregon, San Miguel el Alto and Jesus Maria.

The results of physicochemical studies of some of the sampling points carried out in 2016 and 2014 are presented below, in order to make a comparison of the behavior of water bodies in more critical contamination conditions (Table 11) (Castañeda et al., 2018).



Graph 1. DO (mg/L) and TN (mg/L) at the Lagos River (Source: Own elaboration).



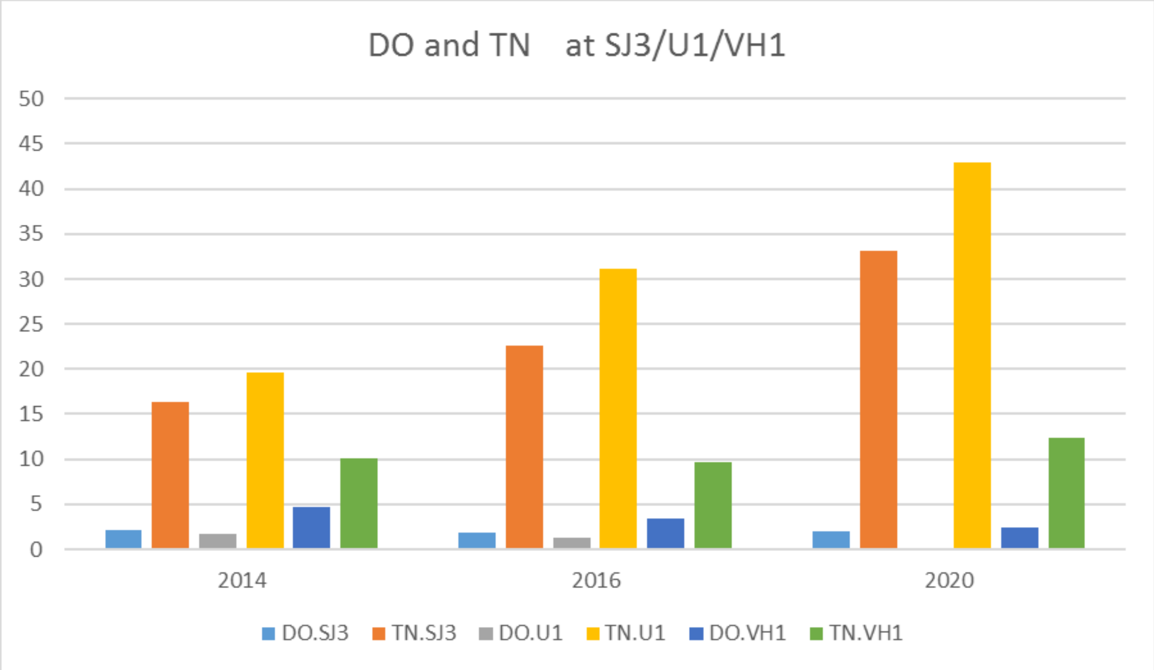
Graph 2. SC (mS/cm) and COD (mg/L) at the Lagos River (Source: Own elaboration).

In graphs 1 and 2, it was possible to observe the behavior of the waters of the Lagos River in the center of the city (L1), as well as at the exit (L2), in reference to the physicochemical quality in the years 2014, 2106 and 2020 denoting a constant and gradual decrease in its physicochemical quality.

In reference to the waters of the San Juan River at the exit of San Juan (SJL3), the dam at the entrance of Union de San Antonio (U1) and the river in Villa Hidalgo (VH1), in a similar way, a decrease in DO is observed and an increase in TN, SC and COD reflecting a decrease in quality (graph 3 and 4).

For the waters of the Tepatitlan river at the exit of the municipality (T4), in Acatic (AC5) and the waters of the Arandas river at the exit of Arandas (AR3), the decrease in DO is evident as well as the increase in TN, SC and

COD, denoting the progressive decrease in the quality of the waters of these sampling points (Castañeda, 2020) (graphs 5 and 6).



Graph 3. DO and TN at SJL3, U1 and VH1 (Source: Own elaboration).

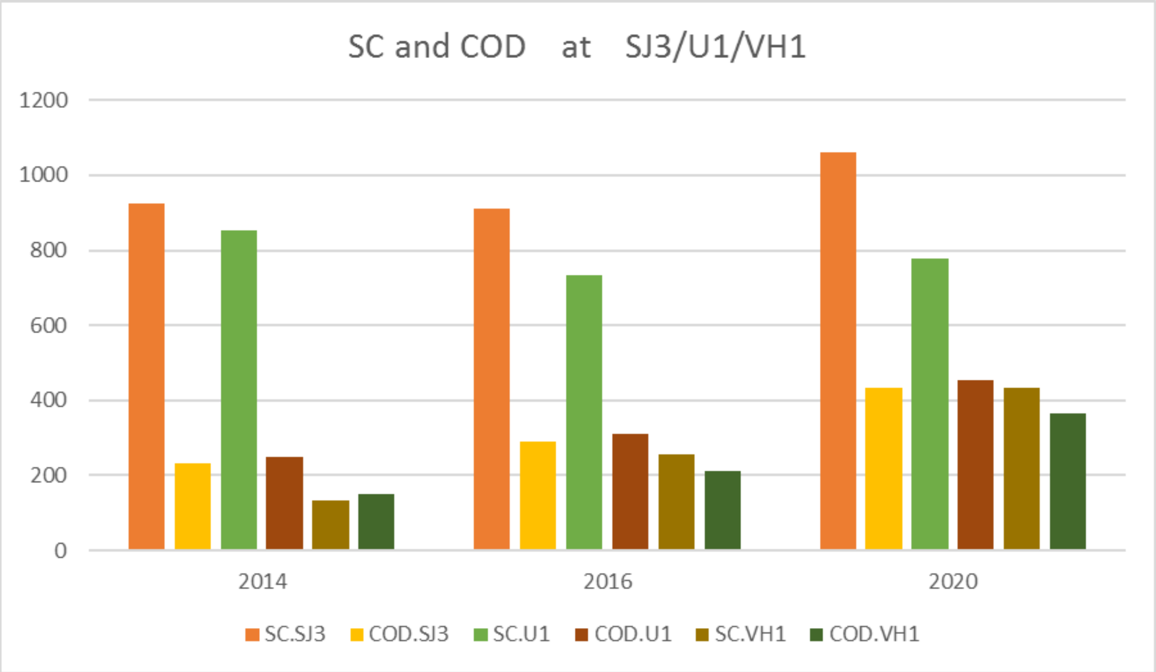
Table 10. Results of the Physicochemical and bacteriological analyzes of surface waters in Highlands of Jalisco, 2020 (Source: Own elaboration).

Key	COD mg/L	TN mg/L	TP mg/L	SC mS/cm	DO mg/L	TCO MPN/100 ml
L1	356	19.1	8.1	712.7	1.89	1,500,000
L2	388	24.2	12.5	896.8	1.45	2,900,000
L3	188	14.2	3.4	372.8	2.45	28,000
L4	192	4.3	2.3	223.0	4.65	21,000
SJL1	267	31.1	13.2	874.4	2.56	24,000
SJL2	168	11.7	8.7	137.9	4.56	700
SJL3	432	33.1	16.1	1060	2.03	2,100,000
SJL4	179	26.3	4.8	935.4	4.51	1,700
E1	412	4.9	3.6	601.3	3.78	720,000
E2	163	3.1	1.3	189.2	5.87	70
U1	455	43	13.6	776.8	0.02	9,200,000
VH1	365	12.4	4.2	434.8	2.44	4,000
VH2	171	2.6	1.8	94.4	4.73	46
VH3	87	2.1	1.2	72.1	8.15	7.8
TE1	289	6.8	3.9	493.7	2.45	4,000
TE2	117	3.8	2.1	88.4	6.12	1,600
O1	155	6.5	1.5	83.5	8.54	9,200
O2	325	13.4	3.6	372.7	2.34	1,400
O3	178	2.6	1.7	73.9	7.11	220
SDA1	160	7.5	3.8	125.9	6.56	2,800
SDA2	322	9.3	4.9	393.8	2.73	17,000
T1	193	12.3	2.2	223.6	152	170
T2	122	6.2	1.2	134.3	122	<1.8
T3	398	31.2	5.7	452.9	2.54	42,000
T4	867	36.4	17.3	978.8	0.34	9,200,000
T5	204	9.2	2.7	273.0	3.45	2,100
T6	420	18.1	3.8	634.4	2.12	135,000
AC1	94	15.3	1.3	301.2	7.18	540
AC2	88	12.5	1.5	137.9	7.23	330
AC3	125	15.9	7.1	452.9	3.12	22,000
AC4	125	13.4	8.4	367.4	2.67	46,000
AC5	385	19.6	11.96	874.7	1.78	1,700,000

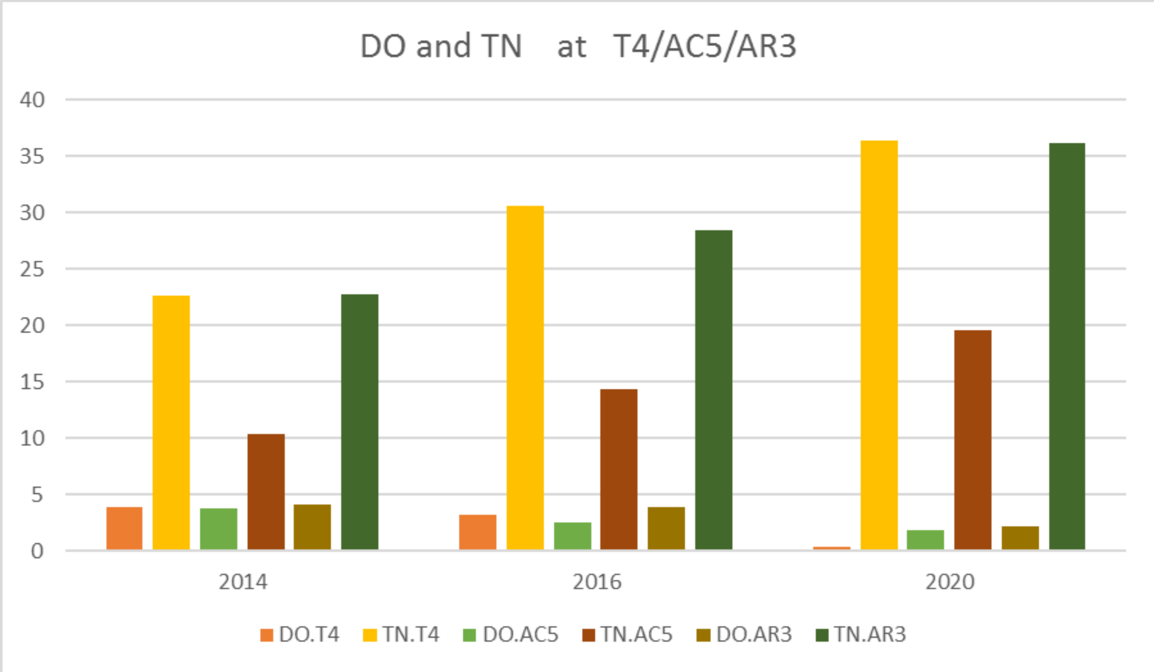
AC6	178	6.3	4.1	137.9	5.33	4,900
AR1	90	3.4	1.5	172.3	5.54	28
AR2	183	2.5	2.2	292.3	3.45	4,300,000
AR3	378	36.2	10.1	605.4	2.11	22,000,000
Y1	106	3.36	2.7	163.7	4.23	33
Y2	143	2.8	2.3	277.3	5.32	130
SMA1	135	5.9	2.1	185.8	5.66	110
SMA2	150	7.5	5.7	339.4	4.04	280
CO1	82	7.3	3.1	96.3	6.67	94
SI1	105	3.8	0.7	132.6	8.13	350
J1	151	5.8	1.8	145.6	6.43	920
J2	132	7.3	2.1	98.6	7.34	250
SJ1	175	18.6	5.8	134.6	4.56	2,800
SJ2	123	28.4	9.4	298.3	3.23	24,000
SJ3	69	3.8	0.8	88.7	6.83	170
SJ4	108	17.6	3.9	203.5	5.78	1,700
M1	98	8.8	3.1	432.6	3.23	1,600
M2	68	7.1	2.8	278.1	6.45	79
M3	58	5.7	1.4	104.7	7.88	22
JM1	114	5.9	1.8	177.7	6.89	170
JM2	71	4.8	1.3	155.1	7.43	70
VG1	79	3.8	1.3	232.6	7.23	12
VG2	142	11.9	2.2	453.5	3.56	350

Table 11. Summary of surface water analysis results at The Highlands of Jalisco 2016/2014 (Source: Castañeda et al., 2018).

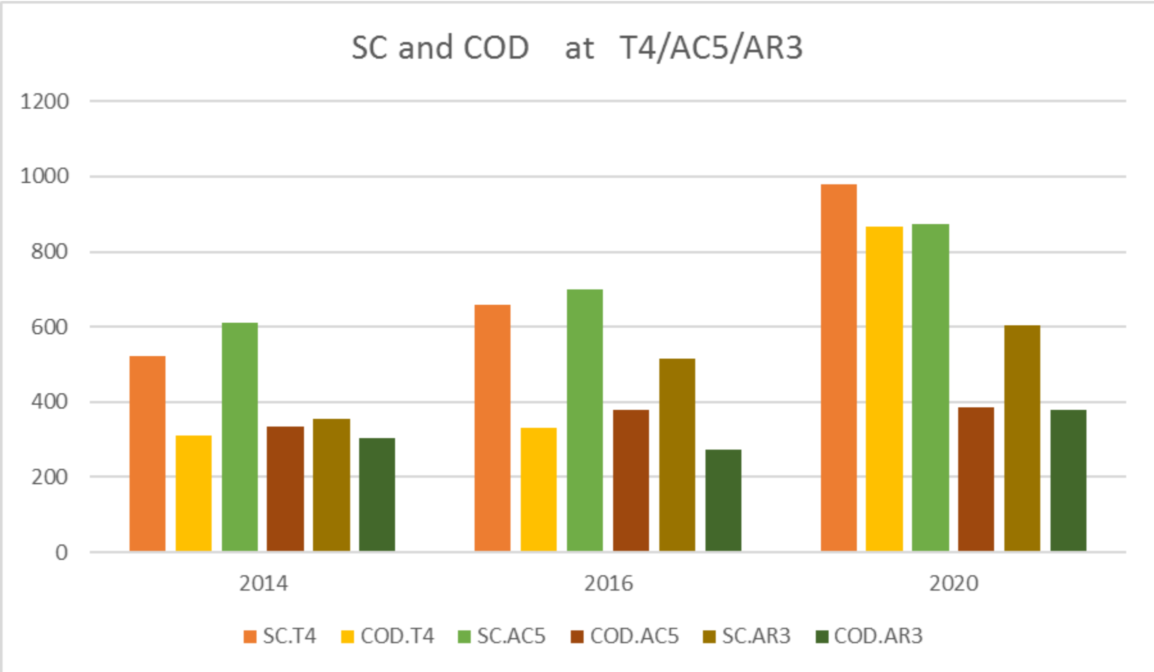
Key	DO (mg/L)		TN (mg/L)		SC (mS/cm)		COD (mg/l)	
	2016	**2014**	**2016**	**2014**	**2016**	**2014**	**2016**	**2014**
L.2	2.05	2.80	20.11	21.69	657.6	753.3	255	210
L.1	1.98	2.36	13.32	9.43	689.7	723.8	281	222
SJL.3	1.83	2.15	22.64	16.40	911.4	925.2	291	232
U.1	1.27	1.66	31.12	19.64	734.0	852.6	312	250
VH.1	3.45	4.66	9.67	10.15	254.8	133.5	210	149
T.4	3.23	3.89	30.56	22.61	658.2	521.3	330	312
AC.5	2.46	3.78	14.33	10.36	701.3	611.3	378	333
AR.3	3.90	4.12	28.41	22.73	515.2	356.2	273	302



Graph 4. SC and COD at SJL3, U1 and VH1 (Source: Own elaboration).



Graph 5. DO and TN at T4, AC5 and AR3 (Source: Own elaboration).



Graph 6. SC and COD at T4, AC5 and AR3 (Source: Own elaboration)

4. CONCLUSION

The results of this study indicate that the majority of surface water bodies in the study area present varying degrees of both physicochemical and microbiological contamination, among the water bodies that chronologically have shown a constant decrease in their quality are those of: Lagos de Moreno, Tepatitlan, San Juan de los Lagos, Union de San Antonio, Acatic and Arandas, on the other hand, the municipalities that present an acceptable level in the quality of their surface waters are: Teocaltiche, San Ignacio Cerro Gordo, Jesus Maria , Encarnacion de Diaz and Cañadas de Obregon. Likewise, it was evident that one of the main factors for the contamination of these bodies of water is related to the discharge of domestic, livestock and industrial wastewater, with insufficient or no treatment to rivers, streams and dams in the region. Noting the lack of adequate infrastructure for the treatment of the entire volume of wastewater generated a situation that puts the sustainable development of this strategic part of the country at risk. It is necessary to implement programs for the permanent evaluation of water quality in the main bodies of water to quantify both the impact of the economic activities of each municipality, and to measure the effectiveness of actions and policies for environmental control and improvement.

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Conflict of Interest: authors declare that there is no conflict of interest.

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