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Research Paper

Evaluation of phosphate content in surface water bodies in the Southern Highlands region of Jalisco, Mexico

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ABSTRACT: *Excess phosphates promote phytoplankton growth, deteriorating surface water quality. This study evaluates phosphate concentrations in surface waters in the Southern Highlands region of the state of Jalisco (Mexico), highlighting that the municipalities with the highest concentrations are those with the highest population density and economic dynamism. Some of the factors detected that contribute to the contamination of water bodies in the region are: limited infrastructure for wastewater treatment, mainly in municipal capitals, and diffuse and point source discharges of waste from livestock farms and processing and manufacturing companies.*

KEYWORDS: *Highlands of Jalisco; Phosphate eutrophication; Surface water; Water pollution*

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I. INTRODUCTION

In many regions of the planet, such as Mexico, the overexploitation of natural resources such as water tables and aquifers is causing a decrease in the supply and contamination of water used for both domestic and industrial purposes. This contamination is not only caused by natural minerals, but also by other harmful chemical compounds such as heavy metals, among others. It is therefore of great importance to implement adequate water resource management, ensuring proper control and distribution of water of adequate quality, as well as the active participation of authorities, researchers, and society to contribute to the sustainability of this vital resource [1].

In general terms, phosphorus refers to the chemical element, while phosphates refer to molecules containing the phosphate ion, which consists of a polyatomic anion formed by a phosphorus atom (P) bonded to four oxygen atoms (O), with a net charge of -3 (PO_4^{3-}). The difference is important for several reasons, including the calculation of chemical and metabolic equilibrium and reactivity; phosphorus is highly reactive with oxygen and does not exist as such in the human body. Some essential processes that require phosphates in human development are:

1) Growth of strong bones and teeth; most phosphate is found in bones, where it combines with the mineral calcium.

2) Energy generation and storage (adenosine triphosphate -ATP-); contributes to the proper functioning of nerves and muscles.

3) Muscle contraction; aids flexibility and proper muscle contraction.

4) Repair and preservation of tissues and cells; ensures the proper functioning of cell membranes, DNA and RNA.

5) Participates in the regulation of essential enzymatic reactions [2].

Phosphate and phosphorus are interchangeable, with the difference that one measure is the compound, while the other is elemental. To quantify phosphates, they can be divided into three categories: orthophosphates, condensed phosphates, and organic phosphates. In short, phosphorus is an essential nutrient for plants and animals. However, an excess of nutrients such as this in water can cause a process called eutrophication, which consists of the uncontrolled growth of algae and aquatic plants. This phenomenon negatively affects water quality as it consumes dissolved oxygen (hypoxia) and generating large amounts of organic matter, causing alterations in biodiversity (damage to various forms of aquatic life). On the other hand, phosphates are chemical compounds essential for life, widely used in fertilizers, detergents, and industrial processes. However, their accumulation in aquatic environments, resulting from wastewater runoff and/or agricultural activities, represents a significant environmental problem. Likewise, with animal excrement and waste and dead plant remains, detriticolous organisms or return to the soil can absorb phosphates. Phosphate compounds can also be transported in runoff to rivers, lakes, and oceans, where aquatic organisms absorb them [3]. Therefore, phosphate pollution affects both surface and groundwater. In surface water, excess phosphates promote phytoplankton growth, deteriorating water quality. In groundwater, although less common, the presence of phosphates may be linked to leaks from polluting sources. The natural phosphate content in surface water bodies is less than 1 mg/l (0.005 to 0.05 mg/l); higher amounts promote eutrophication (Figure 1).

Figure 1. Surface water body with excess algae (eutrophication). **Source**: [4].

Some public water supply systems often add phosphates to drinking water to prevent the release of metals. Orthophosphate is most commonly used to control lead and copper. Polyphosphates sequester iron and manganese to prevent water discoloration, but they are not effective in controlling lead and copper.

In general, sources of phosphates can be natural, such as waterfowl waste, atmospheric deposition, erosion of geological phosphate material, and plant decomposition; or they can be manufactured, such as fertilizers, animal waste, agricultural and urban runoff, industrial and domestic wastewater, or faulty or overloaded septic systems. Extremely high levels of phosphate in drinking water can cause digestive problems, leading to hyperphosphatemia.

Remember that Total Phosphorus (TP) represents the sum of all forms of phosphorus present in water, generally expressed as milligrams of phosphorus per liter (mg P/l). It includes both dissolved and particulate forms:

a) Dissolved phosphorus: Orthophosphates (PO_4^{3-}): the inorganic form directly available to aquatic organisms (e.g., monopotassium phosphate or sodium phosphate), Polyphosphates: chains of linked orthophosphates (e.g., pyrophosphates or tripolyphosphates) and Dissolved organic phosphorus: from soluble organic matter (phospholipids, nucleotides, etc.).

b) Particulate phosphorus: particulate inorganic phosphorus, mineral phosphates adsorbed to sediments, and particulate organic phosphorus: associated with phytoplankton remains, bacteria, or organic detritus.

In the determination of TP, all these forms are converted to orthophosphate (PO_4^{3-}) by acid and oxidizing digestion (e.g., with persulfate), and then measured colorimetrically (usually with the molybdenum blue method). Therefore, TP includes both free phosphates and those released from organic and inorganic compounds after digestion [5].

For federal water policy purposes, Mexico has 37 main basins (Figure 2), grouped into 13 Hydrological Regions (HR), with 43 large rivers registered, 18 of them on the western slope, one of which is the Verde River. In these HRs, two in particular have a deficit operation: HR-13 "Valle de Mexico" and HR-12 "Lerma-Santiago" [6].

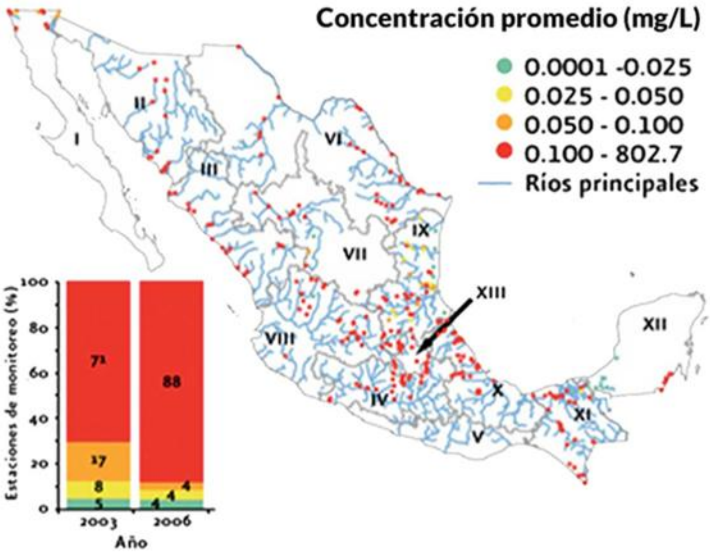

Figure 2. Concentration of phosphates at surface waters in Mexico (2006).
Source: [7].

The state of Jalisco comprises part of HR-7: Lerma-Santiago, Huicicila, Ameca, Costa de Jalisco, Armeria-Coahuayana, upper part of the Balsas River, and El Salado, of which the most important is Lerma-Santiago. Hydrologically, the Southern Highlands are located in RH-12 "Lerma-Santiago," within the basins of the Verde River (the predominant one), the Lerma-Salamanca (Southern part), the Salado River (a small portion), the Lerma-Salamanca River, the Lerma-Chapala River, the Santiago Guadalajara River, and a small part of the municipality of Yahualica in the Juchipila River basin [8].

In the region, the Verde River basin is the most ecologically affected in terms of its natural flow system. It is located between the geographical coordinates 20° 42´ and 22° 43´ north latitude, 101° 15´ and 103° 17´ west longitude, It covers a catchment area of approximately 20,502 square kilometers (Km²), distributed across the states of Guanajuato, Zacatecas, Aguascalientes, and Jalisco, with the latter accounting for 13,925 Km². The general slope of the collector (Verde River) is 0.37%. Its main tributaries are the Encarnacion, Teocaltiche, Lagos, Jalostotitlan, and Valle rivers. The Verde River is one of the most important tributaries of the Santiago River due to its length and considerable average annual runoff, contributing an average annual flow of 28 cubic meters per second (m³/s). It originates 20 Km south of Zacatecas city, initially flowing southward and known in this area as the San Pedro River. It passes through the city of Aguascalientes and, 17 Km downstream; its runoff is stored in the Niagara Dam. Continuing in the same direction, it enters the state of Jalisco and changes its name to Río Verde at the confluence with El Rincon stream, approximately 3 Km upstream from the town of San Jose de Ajojucar. At the town of Belen del Refugio, it changes direction, now flowing southwest, which it maintains until its confluence with the Santiago River. Among its main tributaries within the state of Jalisco are the following rivers, listed from upstream to downstream according to their confluence with the Verde River: Encarnacion, Teocaltiche, San Juan de los Lagos, Jalostotitlan, Ipalco, El Salto, and Tepatitlan. All secondary tributaries to the Verde River are intermittent, that is, they only carry water during the rainy season, with the exception of streams that discharge wastewater into them. Within the Verde River basin, there are several dams, among which the following stand out: Plutarco Elias Calles, Abelardo L. Rodriguez, Niagara, Cuarenta, Mexticacan, Estribon, San Miguel, Pabellon, and Ajojucar [9]. On the other hand, in the middle and lower reaches of the Lerma River (traditionally impacted by agricultural and industrial activities), the presence of phosphates has reached levels between 1.73 and 5.26 mg/l, which shows that natural concentrations may be exceeded in areas with high anthropogenic influence. This important watercourse originates in the Almoloya lagoon in the State of Mexico and flows into Lake Chapala in Jalisco. In many areas along its course, its waters are used for crop irrigation, making it essential to estimate the toxicological risk of these practices. In a study conducted in 2019, the average phosphate concentration was 4.027 mg/l, with a coefficient of variation indicating high heterogeneity in the ionic concentration of the water, attributed to domestic and industrial wastewater discharges and agricultural drainage. As a result, this watershed has different degrees of restriction on its use with regard to the toxicity risk posed by specific ions [10].

Based on the update provided by the Mexico National Water Commission –CONAGUA- (2020) [11] on the average annual availability of groundwater, of the 59 aquifers located in the state of Jalisco, 34 are overexploited. The Southern Highlands region is located above 11 different aquifers, of which nine are overexploited and the remaining two have an average annual availability of 2.82 Million cubic meters (Mm^3) and a deficit of -101.75 Mm^3. The aquifers in the region have an annual extraction volume of 642.62 Mm^3 and an average annual recharge volume of 620.2 Mm^3. It has thus been determined that the Altos -Sur region is overexploiting its groundwater resources [12].

The region has a defined aquifer in the Acatic-Tepatitlan-Arandas area, covering an approximate surface area of 6,000 Km^2, which, due to its geohydrological characteristics, is widely exploited, especially in the municipalities of Tepatitlan and Arandas, with the depths of the wells in the area ranging between 200 and 300 meters (m) on average. In the municipalities of Acatic, San Julián, and San Miguel el Alto, there are isolated aquifers, which are accessed through deep wells with flows of 20 to 50 liters per second (l/s) at depths greater than 350 m. These flows decrease as they move away from the aquifers. On the other hand, the municipalities of Mexticacan and Yahulica are part of the "Teocaltiche-Encarnacion" aquifer in the Northern Highlands region, with regular supply prospects. The municipalities of Jalostotitlan, Valle de Guadalupe, and Cañadas de Obregon are part of the Lagos de Moreno aquifer, with Jalostotitlan having the most regular hydrogeological conditions. Water resources the municipality's water resources consist of groundwater, rivers, and lakes.

The Southern Highlands is physiographically located in province X "Neovolcanic Axis," subprovince 48 "Altos de Jalisco," and a small part of the municipality of Yahualica in province III "Sierra Madre Occidental," subprovince 17 "Sierras y Valles Zacatecanos" [13]. They have a total area of 6,614.01 Km^2, which corresponds to 8.36 % of the total area of the state (Table 1).

Municipality	**Surface (Km^2)**	**Percentage of the regional total**	**Percentage of the state total**
Acatic	331.04	5.01	0.42
Arandas	984.06	14.88	1.24
Cañadas de Obregon	249.40	3.77	0.32
Jalostotitlan	527.48	7.98	0.67
Jesus Maria	684.08	10.34	0.86
Mexticacan	278.57	4.21	0.35
San Julian	250.23	3.78	0.32
San Miguel el Alto	864.99	13.08	1.09
Tepatitlan de Morelos	1,252.43	18.94	1.58
Valle de Guadalupe	375.50	5.68	0.47
Yahualica de Gonzalez Gallo	588.11	8.89	0.74
San Ignacio Cerro Gordo	228.02	3.45	0.29
Region Altos-Sur total	**6,614.01**	**100**	**8.36**
State total	**79,094.06**	**18.44**	**100**

Table 1: Total area by municipality in the Southern Highlands region of Jalisco and the state total.
Source: [14].

The 12 municipalities that make up this region are Acatic, Arandas, Cañadas de Obregon, Jalostotitlan, Jesus Maria, Mexticacan, San Julian, San Miguel el Alto, Tepatitlan de Morelos, Valle de Guadalupe, Yahualica de Gonzalez Gallo, and San Ignacio Cerro Gordo.

It is important to note that there is a close relationship between rainfall indices in the region and the generation of various climatic chains whose formation is favored by the hydro-morphology of the Verde River basin. Through this runoff, it is possible to appreciate climatic variations that have favored the operation of different economic activities in Southern Highlands. Total annual precipitation varies from less than 500 to 700 millimeters (mm), which represents significant precipitation volumes for a semi-arid region. The months with the highest precipitation are August and September, with a range of 160 to 170 mm, and the driest is February, with precipitation of less than 5 mm.

The main factors involved in climate variation in the region are the altitude gradient and the local and regional physiography. The climate types are warm and semi-warm, located in the lower altitude areas, and semi-dry, normally found in the higher regions. The former are located in the region that receives temporary moisture from the Pacific, unlike the latter, which extend into the transition region between the Neovolcanic Axis and the Sierra Madre Occidental. The mountainous regions prevent the passage of moisture generated in the Pacific Ocean, resulting in a drier, steppe-like climate. It is important to note that there is a close relationship between the region's rainfall indices and the generation of various climatic chains whose formation is favored by the hydromorphology of the Verde River basin. Thus, along this runoff, it is possible to appreciate climatic variations that have favored the operation of different economic activities" [15].

Warm subhumid climates with rainfall in summer, temperatures ranging between 7°C and 14°C with the hottest month of the year before June, and deep canyons are conducive to this type of climate, which enters from the Santiago Canyon and occupies regions with the same physiographic characteristics. Semi-warm climates occur upstream and are characterized by an annual temperature above 18°C, with an average temperature in the coldest month between 5°C and 10°C. This climate is considered more attractive for human settlements, with a higher incidence of anthropogenic activities and corresponding environmental modifications.

The climate is semi-warm temperate, with rainfall in summer, an average annual temperature between 18ºC and 20ºC, and winter rainfall between 5 and 10.2 %. The average temperature of the hottest month is above 22ºC, temperatures range between 7ºC and 14ºC, and the warmest month is before June.

According to data from the 2020 Population and Housing Census, the region had 411,448 inhabitants, representing 4.93 % of the state total [16]. In Southern Highlands, the territorial distribution pattern of the population in the region is dominated by a notable dispersion of the population in hundreds of small towns. However, it is an area with high agro-industrial activity, where activities such as tequila production and intensive corn and agave cultivation predominate. The value of livestock production in the region has shown an upward trend during the period 2015-2021, with 2021 being the year in which the highest level in the region was recorded. In 2021, the value of livestock production represented 36.98 % of the state total, reaching approximate value of 40,200 million pesos for that year. Among the livestock products that stand out (2021) for their share are, in first place, eggs, which account for 45.79 % of the total value of production in the region, followed by pork with 20.99 % and, in third place, cow's milk, which accounts for 18.81 % of the total value of production in the region.

The following are the main economic activities in each municipality: in Acatic there are tile and brick factories, a mushroom packing plant, feed (balanced feed) and dairy product factories, tequila industries, shoe, sock, and clothing factories; in Jalostotitlan there is a textile industry, factories producing tubular furniture, gloves, chrome-plated furniture, and milk coolers; in Jesus Maria there are factories producing footwear, furniture, surgical clothing, huaraches, and tequila. In San Julián, spheres, ceramics, and handicrafts are manufactured. In San Miguel el Alto, there are clothing factories, hosiery factories, and feed industries. Tepatitlan has developed the poultry industry, cold meat packing, and the industrialization of milk, eggs, agave, and other agricultural products. In Yahualica, there are chick incubators, hot sauce factories, and water purification plants. Corn, wheat, agave, and alfalfa are also grown there.

These practices use phosphate-rich fertilizers, increasing the nutrient load in water bodies. In addition, the region faces challenges related to inadequate wastewater management and overexploitation of aquifers. Furthermore, scientific information on the distribution and concentration of phosphates in surface and groundwater in this region is limited, which hinders the implementation of sustainable management strategies. It is therefore essential to understand the dynamics of these compounds in both surface water bodies and groundwater aquifers in this region in order to assess their environmental impact and propose corrective actions. Studies such as this one contribute to knowledge about water quality in the region, facilitating informed decision-making for its proper management, conservation, and protection.

The main objective of this approach is to evaluate the concentration of phosphates in surface waters in the Southern Highlands region of the state of Jalisco, determining their possible sources of contamination. Likewise, it aims to analyze the spatial distribution of phosphates in relation to human activities in the region, compare the concentrations found with the limits established by environmental standards, and identify key factors that influence the presence of phosphates in surface water.

II. MATERIALS AND METHODS

The study area for this work comprised the 12 municipalities that make up the Southern Highlands region of the state of Jalisco (Figure 3), which covers 6,612.82 Km² and is the sixth largest region in the state. This area is located in the northeast of the state of Jalisco, between latitudes of approximately 20° N to 21° 01′ 30″ N and longitudes of 102° 33′ 10″ W to 102° 56′ 30″ W. ° 35′ N to 21° 01′ 30″ N and longitudes of 102° 33′ 10″ W to 102° 56′ 15″ W. Its three strategic nodes are Tepatitlan, Arandas, and San Miguel el Alto.

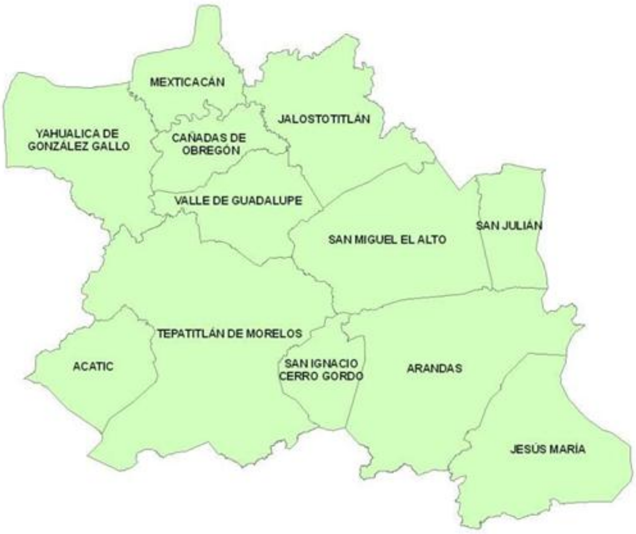

Figure 3: Location of the municipalities at Southern Highlands region of Jalisco. **Source**: [17].

Representative points were selected from the main surface water bodies in each municipality, such as rivers, dams, and reservoirs in areas with high population density and agricultural and agro-industrial activity.

The regional territory has elevations between 1,162 and 2,670 meters above sea level and a predominantly gentle slope of less than 5°, characteristic of flat terrain. Most of the territory has a temperate sub-humid climate. The average annual temperature is 17.8°C, and the average minimum and maximum temperatures range between 5.4°C and 30.4°C. The average annual precipitation is 817 mm.

The predominant land cover in the region is agricultural, accounting for 66.78 % of its surface area, followed by secondary vegetation with 23.27 %. Human settlements occupy only 1.19 % of the total territory. The smallest area of land cover is bare soil, accounting for 0.03 %. The regional tree cover represents 4.12 %, of which 3.42 % corresponds to primary tree vegetation, which has not been altered from its natural state, and 0.7 % to secondary tree vegetation, which has been modified due to disturbances and shows a process of plant succession. The municipality with the highest percentage of tree cover in the region is Yahualica de Gonzalez Gallo with 8.54 %, most of which is primary. In contrast, the municipality with no tree cover is Valle de Guadalupe [14].

The regional territory lies within the Santiago 1 and 2, Verde River 1 and 2, Lerma 6 and 7, San Miguel, Turbio, Zula, del Valle, Lagos, and Juchipila 2 river basins; of which 66.70 % have availability and 33.30 % have a deficit of surface water availability, such that the types of water resources in the region consist of groundwater, rivers, and lakes. Based on the update carried out by CONAGUA on the average annual availability of groundwater (September 17, 2020), of the 59 aquifers located in the state of Jalisco, 34 are overexploited [11].

The Southern Highlands region is located above 11 different aquifers, of which nine are overexploited and the remaining two have an average annual availability of 2.82 Mm³ and a deficit of -101.75 Mm³. The aquifers in the region have an annual extraction volume of 642.62 Mm³ and an average annual recharge volume of 620.2 Mm³. In terms of regional surface area, 86.45 % has no availability and 13.55 % has groundwater availability [12]. Likewise, according to data from the 2020 Population and Housing Census, the study region had 411,448 inhabitants, representing 4.93 % of the state total [18].

Through field surveys and geographic information, such as the hydrological features of each of the 12 municipalities in the Southern Highlands region of Jalisco, 37 monitoring and sampling points were established [19], whose location and description are included in Table 2.

Municipality	ID		Location of sampling points			Type	Reference
			North	**West**	**Altitude (m)**		
Jalostotilan	J	1	21°09’20.75”	102°27’26.84”	1749	Jalostotitlan Dam	Curtain
		2	21°09’47.23”	102°28’02.85”	1738	Jalostotitlan River	Jalostotitlan downtown
		3	21° 12′ 17″	102° 36′ 59″	1731	Jalostotitlan River	At the exit of Jalostotitlan
Jesus Maria	JM	1	20°3’17.75”	102°09’00.33	2207	Ojo Zarco Dam	Curtain
		2	20°39’01.39”	102°08’49.26	2171	Luz Dam	Curtain
Tepatitlan	T	1	20°51’19.63”	102°42’51.35”	1904	Jihuite Dam	Curtain
		2	20°51’21.51”	102°48’11.33”	1888	Caretas Dam	Center
		3	20°49’11.64”	102°45’19.29”	1777	Tepatitlan River	Northeast of Tepatitlan
		4	20°48’15.35”	102°45’47.40”	1767	Tepatitlan River	Tepatitlan downtown
		5	20°47’20.67”	102°48’54.23”	1742	Tepatitlan River	At the exit of Municipality
		6	20°49’22.08”	102°35’01.10”	2052	Arboledas Dam	Capilla de Guadalupe
Acatic	AC	1	20°43’12.82”	102°49’19.35”	1738	Red Dam	Curtain
		2	20°41’25.15”	102°57’42.59”	1620	Calderon Dam	Center
		3	20°45’41.79”	102°52’46.43”	1697	Lagunillas Dam	Acatic
		4	20°45’40.25”	102°54’43.16”	1688	Tepatitlan River	At the entrance of Acatic
		5	20°47’08.03”	102°56’56.58”	1670	Tepatitlan River	At the exit of Acatic
Arandas	AR	1	20°44’05.39”	102°25’34.39”	2014	Tule Dam	Curtain
		2	20°43’15.64”	102°19’58.81”	2085	Arandas River	North bypass
		3	20°44’05.39”	102°20’23.93”	2059	Arandas River	Arandas downtown
		4	20°41’13.42”	102°19’55.75”	2026	Arandas	South bypass

						River	
Yahualica	Y	1	21°10’59.03”	102°54’08.54”	1817	Estribon Dam	Center
		2	21°13’47.52”	102°51’02.21”	1671	Rio Verde	Yahualica to Mexticacan Highway
		3	21°00’25.62”	102°49’05.39”	1473	Verde River	Yahualica to Tepatitlan Highway
Cañadas de Obregon	CO	1	21°11’33.81”	102°41’26.52”	1620	Verde River	At Highway to Mexticacan
		2	21°11’35.32”	102°42’04.12”	1612	Verde River	At Temacapulin
Mexicacan	M	1	21° 16’34.83”	102°46’41.91”	1758	Paloma Dam	Curtain
		2	21°15’57.88”	102°46’26.30”	1756	Rio Mexticacan River	Mexticacan downtown
		3	21°16’27.23”	102°46’34.21”	1759	Rio Mexticacan River	At the exit of Mexticacan
San Ignacio Cerro Gordo	SI	1	20° 46’05.10”	102°32’07.73”	2069	Mezquite Dam	Curtain
San Julian	SJ	1	20° 58’13.18”	102°10’54.57”	2093	San Isidro Dam	Curtain
		2	21° 00’46.57”	102°11’18.89”	2057	San Julian River	At the entrance of San Julián
		3	21° 00’ 33”	102°09’02”2099	2099	San Julian Dam	Curtain
		4	21°00’36.89”	102°10’12.43”	2052	San Julian River	At the exit of San Julian
San Miguel el Alto	SM	1	20° 59’33.01”	102°24’23.81”	1835	San Miguel Dam	Curtain
		2	21° 01’40.58”	102°23’59.43”	1843	San Miguel River	San Miguel downtown
Valle de Guadalupe	VG	1	21°01’48.16”	102°42’01.04”	1812	Salto Dam	Curtain
		2	21°00’39.02”	102°37’09.21”	1820	Valle de Guadalupe River	Valle de Guadalupe downtown

Table 2. Location of sampling points for the determination of phosphates. **Source:** Own elaboration

The phosphate content was determined using the molybdate-blue spectrophotometric method, which allows the quantification of reactive phosphate concentrations. This analysis was carried out in a certified laboratory, following the guidelines established by NOM-014-SSA1-1993.

The data obtained were analyzed using statistical tools and GIS (Geographic Information Systems) to identify spatial patterns. In addition, the concentrations obtained were compared with the limits established by national and international standards (World Health Organization -WHO-).

Several sampling campaigns were carried out at selected points during the low-flow period (February to May) of 2024, both for the collection, preservation, and storage of specific samples, as well as for the quantitative determination of phosphate concentrations in surface waters in the study area. The corresponding official Mexican regulations (mainly NOM-003-ECOL-1997, NMX-AA-115-SCFI-2015, NOM-127-SSA1-2021, and NOM-001-SEMARNAT-2021) were taken into consideration, as well as the American Public Health Association Standard [20] and procedure No. 8190 for the HACH DR-2800 digital photometer [21].

The analytical determinations were carried out in the Water Analysis Laboratory of the Centro Universitario de Los Altos (University of Guadalajara), with technical support from the UDG-561 Academic Group "Integrated Water Management" and the economic stimulus program for outstanding students.

To determine the phosphate concentration in surface water samples, procedure number 8190 was used, which employs potassium persulfate and a 1.54 N sodium hydroxide solution, using the following HACH brand equipment: DRB-200 digital reactor for digestion and DR-2800 digital spectrophotometer with program 536P

III. RESULTS

The Southern Highlands region of Jalisco has drinking water coverage of 82.15 % and sewerage coverage of 81.12 %; In general, wastewater sanitation coverage is 48.32 %. The municipalities with the greatest lag in coverage of these services are Cañadas de Obregon, Arandas, Jesus Maria, and San Miguel el Alto.

Surface water sampling was carried out between February and May 2024, monitoring 37 points in the main water bodies (dams, rivers, and streams) of the 12 municipalities that make up the Southern Highlands region of Jalisco.

The arithmetic mean results for phosphate concentration at the sampling points are shown in Table 3.

ID	**(PO_4^{3-}) (mg/l)**
J.1	4.56
J.2	2.22
J.3	2.87
JM.1	1.12
JM.2	1.27
T.1	1.26
T.2	1.21
T.3	2.04
T.4	4.42
T.5	16.03
T.6	1.23
AC.1	3.55
AC.2	3.87
AC.3	4.35
AC.4	9.13
AC.5	14.71
AR.1	1.08
AR.2	6.45
AR.3	12.68
AR.4	2.11
Y.1	2.21
Y.2	4.32
Y.3	12.02
CO.1	4.67
CO.2	5.46
M.1	1.26
M.2	0.72
M.3	0.88

SI.1	0.67
SJ.1	2.34
SJ.2	1.89
SJ.3	0.73
SJ.4	4.89
SM.1	1.45
SM.2	2.78
VG.1	1.54
VG.2	5.78

Table 3. Results of the determination of phosphate content in surface waters. **Source:** Own elaboration

In general, it can be seen from the above results that most sampling points exceed the reference concentration of 1.00 mg/l of phosphates, with T.5, AC.5, AE.3, Y.3, and AC.4 standing out with values greater than 9 mg/l. The sampling points with lower values were SI.1, SJ.3, M.2, M.3, and AR.1.

IV. DISCUSSION

The main source of phosphorus in wastewater may be detergents from human activities that make up domestic and industrial wastewater, as some detergents contain sodium phosphate. Agricultural drainage is another source, due to the washing away of phosphate fertilizers in agricultural areas [22]. In this regard, since the 1980s, Ayers & Westcot have proposed that irrigation water of acceptable quality should generally contain less than 2 mg/l of phosphate (0.652 mg of P/l). On the other hand, Hem (1985) [23] emphasizes that excessive concentrations are a source of nutrients that contribute to the development of algae and aquatic vegetation (eutrophication), causing accumulation and obstructing irrigation systems.

The results of this study indicate that most surface water bodies in the study area show varying degrees of contamination. In this regard, the sampling points that have chronologically shown constant and increasing contamination are located in Tepatitlan, Acatic, and Arandas. The municipalities with acceptable surface water quality are San Ignacio Cerro Gordo, Jesus Maria, and Cañadas de Obregon. It was also evident that one of the main factors contributing to the contamination of water bodies in the region is related to the discharge of domestic, livestock, and industrial wastewater, with insufficient or no treatment, into rivers, streams, and dams[24].

In studies conducted in 2020, 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) showed a drastic decrease in dissolved oxygen as well as high values of nitrogen, chemical oxygen demand, and electrical conductivity, indicating a progressive decline in the quality of these waters [25]. This deterioration in surface water quality is essentially related to the discharge of domestic, livestock, and industrial wastewater with insufficient or no treatment into rivers, streams, and dams. [26].

V. CONCLUSION

High concentrations of nitrate and phosphate can be attributed to excessive fertilizer application [27], which causes leaching and groundwater contamination, as well as inducing eutrophication of water bodies [28]. Similarly, Ayers & Westcot (1987) [29] indicate that water quality problems are related to its use. From an agronomic perspective, the ionic concentration of the solution affects crops due to the type of ions present [30] y [31].

The Southern Highlands region of the state of Jalisco is of great importance at both the state and national levels; however, there is limited quantitative information on the contamination of its surface waters. Studies such as this one show increases in pollutants such as phosphates in various surface water bodies in most of the municipalities in the study area, a situation that threatens both the health of the population and the ecological and productive sustainability of the region. It is necessary to increase strategies for the periodic monitoring of the quality of surface water in the main water bodies, evaluating their impact on the socio-economic activities of each municipality in a timely manner.

In general, the municipalities with the highest concentrations of phosphates in their surface waters are those with the highest population density and economic dynamism: Villa Hidalgo, Tepatitlan, Acatic, and Arandas. Some of the factors detected that contribute to the contamination of water bodies in the region are: limited wastewater treatment infrastructure, mainly in municipal capitals, and diffuse and point source discharges of waste from livestock farms and processing and manufacturing companies. There is a clear need for more frequent studies that also include microbiological analyses to 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 pollution, as well as the dynamics of pollutants and their effects on both the environment and the region's population in the short and medium term.

During the low-flow periods in 2020, 2021, and 2022, microbiological parameters (total and fecal coliforms) were determined in the study area as indicators of organic contamination of fecal origin in surface waters. The results showed that the sampling points in the municipalities of Tepatitlan (T3, T4, T6), Acatic (AC5), Arandas (AR2, AR3), and San Julián (SJ4) had a considerable amount of fecal coliforms. This is directly related to the economic activities carried out in the affected municipalities, as well as the discharge of domestic wastewater without adequate treatment from population centers. [32].

When comparing the results obtained with assessments carried out on surface water bodies in these same municipalities over the last five years, it is possible to observe patterns of constant and gradual deterioration in water quality. Although The Highlands of Jalisco region is of great importance at the state and national levels, there is relatively little quantitative information on the evolution of its surface water quality. The advances presented here highlight the gradual and sustained deterioration of surface water quality in many municipalities in the study area, a situation that jeopardizes not only the well-being and health of its inhabitants but also the sustainable development of this strategic part of the country. It also highlights the need to incorporate strategies for the constant monitoring of water quality in the region's main water bodies, quantifying the impacts of each municipality's economic activities in a timely manner and evaluating the efficiency of public policies on natural resource conservation. With the development of this project, it was possible to observe that the main factors causing the decline in surface water quality in the study area are: the lack of adequate infrastructure to treat all domestic effluents generated, especially in urban centers with higher population concentrations such as municipal capitals, and diffuse and point discharges of waste from livestock farms and processing and manufacturing companies.

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