Colegio de Postgraduados

Salinity and microbiological risk assessment in surface runoff and main tributaries to La Vega Dam in Teuchitlán, Jalisco, Mexico

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ABSTRACT

Objective: This research aimed to evaluate the water quality of the main tributaries to the La Vega Dam for irrigation purposes through the physicochemical and microbiological parameters.

Design/methodology/approach: The 10 main tributaries to the La Vega Dam were selected. The variables evaluated were pH, Temperature, Electrical Conductivity, Total Dissolved Solids and Dissolved Oxygen, boron calcium, magnesium, sodium, SAR, and RSC.

Results: 50% of samples presented low sodicity risk, 10% medium risk, 20% and 20% very high risk. In the RSC results, only one site (10%) presented a low risk, and the remaining four tributaries (40%) of this area presented a medium risk. Five sites (50%) located east of the dam presented a high risk. Also, high boron concentration was observed, corresponding to El Salado River. Fecal pollution was detected in 100% of sites, limiting their use as irrigation water.

Limitations on study/implications: Continuous water quality monitoring of the main tributaries to and into La Vega Dam should be followed up.

Findings/conclusions: The most significant contribution of contamination to the dam was observed in the eastern part, with the entrance of El Salado River. High concentrations of boron were also observed. A high concentration of total and fecal coliforms was also found, in addition to the presence of *Pseudomonas* spp., which indicates fecal contamination. The effluent at the east of La Vega Dam is unsuitable for irrigation.

Keywords: biological hazard, dam, monitoring, sustainability, water bodies.

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INTRODUCTION

La Vega Dam is the largest water body in the Valles Region, located in the Central West of Jalisco State, in the municipality of Teuchitlán. Its main tributaries are the El Salado River, Teuchitlán River, Arroyo Chapulimita (stream), and Arroyo Grande (stream). El Rincón springs and four springs are north of the dam, converging the reservoir as a single tributary (CEA, 2011). Additionally, surface runoff typically originates during the rainy season and can contribute to chemical and biological contamination in the reservoir (Czemiel, 2010; Vialle *et al.*, 2011). La Vega Dam is of socio-economic importance in the region as it captures and distributes water for the irrigation district users of Ameca, Jalisco (CEA, 2011). The main activity in the communities surrounding the reservoir is agriculture, especially the cultivation of sugar cane, corn, and wheat.

On the other hand, water quality standards provide the basis for controlling polluting activities and guide identifying and developing quality criteria (Malakar *et al.*, 2019; Qadir *et al.*, 2021). This endures that water use and management of its watershed can be appropriately designated (Heiskary & Wilson, 2005; Park *et al.*, 2018). In the case of water for irrigation use, the content and type of salts are crucial to determine its quality; depending on these factors, irrigation water can favor or correct alkaline or saline soils (Gurjinder *et al.*, 2017; Amer, 2010). A high concentration of salts present in irrigation water reduces water availability for crops. Thus, the plant will have to work harder to absorb water, even suffering physiological stress due to dehydration, which affects its growth (Safdar *et al.*, 2019; Kiremit & Arslan, 2016). Determining the type of salts in irrigation water is essential since they also alter the soil and modify its structure, reducing infiltration (Cuellar *et al.*, 2015; Can *et al.*, 2008). The parameters that must be evaluated to determine the water quality for irrigation use are the following: electrical conductivity, pH, total amount of dissolved salts; calcium, magnesium, sodium, potassium, nitrates, carbonates, bicarbonates, chlorides, boron, the Sodium Absorption Ratio (SAR) and Residual Sodium Carbonate (RSC) levels (Marín *et al.*, 2002). Sodicity causes impairment of water mobility in different soil layers, and as a result the growing plant's roots may not have adequate water.

The most common method for measuring water and soil sodicity is calculating the sodium absorption ratio (SAR). The SAR defines sodicity in terms of the relative concentration of sodium (Na) compared to the sum of calcium (Ca) and magnesium (Mg) ions. The SAR assesses the potential infiltration problems due to sodium imbalance in water. For the SAR calculation, the Na, Ca, and Mg ions concentration is estimated in milli-equivalents per liter (Meq L^{-1}) (Tanji, 1990). According to the international criteria established for irrigation water (Ayers & Westcot, 1994), a scale determines the sodium risk in water.

Conversely, considering the broad exposure to different factors that can alter the water quality of the tributaries to a water body, the vital liquid can become a transmitter of various diseases (Tarqui *et al.*, 2016). In this way, microbiological analysis is another critical examination for determining water quality. Total Coliform bacteria are a collection of microorganisms that live in large numbers in the intestines of humans and warm-blooded animals. A specific subgroup of this collection is the fecal Coliform bacteria (Erdal *et al.*, 2003). The Ecological Criteria for Water Quality CE-CCA-001/89 mentions maximum permissible limits (MPL) for fecal Coliforms of 1000 with the Most Probable Number (MPN/100 ml) technique in the case of irrigation water. According to the literature, fecal coliforms in aquatic environments indicate that the water has been contaminated with fecal matter from humans or animals. Consequently, the water source is contaminated by pathogens, bacteria, or viruses that cause diseases that can also exist in fecal matter (De

La Mora *et al.*, 2013). The objective of this research was to evaluate the quality of water for use in irrigation in the main tributaries of La Vega Dam through physicochemical and microbiological parameters.

MATERIALS AND METHODS

Area of study location

Within the hydrological regions in the Jalisco State, there is the Ameca region, within which La Vega-Cocula Dam, the Ameca-Atenguillo River, and the Ameca-Ixtapa River are located. La Vega Dam is in the municipality of Teuchitlán, and its reservoir is 9.5 km south of Teuchitlán town. The reservoir has several tributaries: from the north, it receives the contribution of the Teuchitlán River, which is permanent. However, it is also a reservoir for the municipal discharges of Teuchitlán that eventually flow into the reservoir. In the north, a series of El Rincón springs flow into the reservoir in addition to the Teuchitlán River. In the west, La Vega Dam is fed by the contributions of the Grande or La Mora streams and the Chapulimita stream. However, the most significant contribution is in the southeast, corresponding to El Salado River, the reservoir's most important permanent recharge (CEA, 2011).

Selection of sampling sites

The 10 main tributaries to La Vega Dam were selected; the coordinates of the sites are shown in Table 1 and Figure 1. A land vehicle was used to collect samples, and the sites were located using a GPS (Etrex Garmin® brand).

Collection and transfer of samples

The collection of water samples was carried out following the technical guidelines established in the Mexican Official Norm NOM-AA-14-1980 "Receiving bodies, sampling," published in the Federation Official Gazette on Friday, August 27, 1980. The sampling was carried out by trained personnel from the National Institute of Forestry,

Table 1. Selection of sampling site coordinates.

Sampling site		Geographic coordinates	
Number	Name	N	W
1	El Tajo (Stream)	20° 40' 14.54585"	−103° 52' 23.13664"
2	Hacienda Labor de Rivera (Stream)	20° 40' 34.74973"	−103° 52' 43.36434"
3	Chapulimita (Stream)	20° 38' 29.49457"	−103° 52' 30.78224"
4	Cuisillos 1 (Stream)	20° 38' 21.74096"	−103° 47' 29.63054"
5	Cuisillos 2 (Stream)	20° 36' 31.04939"	−103° 48' 33.20593"
6	Acacias 1 (Stream)	20° 36' 21.19111"	−103° 49' 25.98805"
7	El Refugio (Stream)	20° 39' 49.59324"	−103° 44' 10.7637"
8	Teuchitlán River	20° 40' 50.02752"	−103° 50' 45.90186"
9	Teuchitlán (municipality discharge)	20° 40' 52.74163"	−103° 50' 40.197998"
10	Acacias 2 (Stream)	20° 36' 21.239557"	−103° 49' 26.06363"

Figure 1. Sampling site locations.

Agricultural, and Livestock Research INIFAP and Technological Institute José Mario Molina Pasquel y Henríquez, Academic Unit Arandas. They used sampling materials with the specific conditions and volume required for each evaluation parameter and the specifications for preservation and transfer to the laboratory. One-liter glass jars were adequately identified and labeled for handling with the site number and the name of the tributary. Sampling was conducted in August and December 2018. The data collected *in situ* were recorded on a format designed for this purpose.

The samples were stored in a cooler at a temperature of approximately 4 °C for their conservation and later transferred to the Microbiology Laboratory of the Technological Institute José Mario Molina Pasquel y Henríquez, Academic Unit Arandas, for analysis. It is essential to mention that, for the microbiological analysis, the samples were processed and analyzed within 24 hours of collection. For calcium, magnesium, sodium, carbonate, bicarbonate, and boron, the analysis was conducted at the Soil Fertility Laboratory in the Santiago Ixcuintla Experimental Field in Nayarit, which is part of the the National Institute of Forestry, Agricultural and Livestock Research (INIFAP). The analyzed parameters are shown in Table 2.

Sample analysis

The samples were analyzed according to the Mexican Official Norm, NOM-092-SSA1-1994, method for accountability of aerobic bacteria on plates; the Mexican Norm NMX-AA-42-1987, Water Quality-Determination of the Most Probable Number (MPN) of total coliforms, fecal coliforms (thermotolerant), *Escherichia coli* and Presumptive; and in the case of *Pseudomonas* spp. Calcium, sodium, lead, boron, and magnesium were analyzed using atomic absorption equipment.

Table 2. Analyzed parameters in the 10 main tributaries to La Vega Dam in Teuchitlán, Jalisco.

Parameters in water	Symbol	Units	Range(for irrigation) Ayers y Westcot (1994)
Salinity			
Electrical Conductivity	EC_w	dS m^{-1}	0-3
Total Dissolved Solids	TDS	mg L^{-1}	0-2000
Cations and anions			
Calcium	Ca^{++}	Meq L^{-1}	0-20
Magnesium	Mg^{++}	Meq L^{-1}	0-5
Sodium	Na^{+}	Meq L^{-1}	0-40
Carbonate	CO_3^{--}	Meq L^{-1}	0-.1
Bicarbonate	HCO_3^{-}	Meq L^{-1}	0-10
Boron	B	Mg L^{-1}	0-2
pH	pH	1-14	6.0-8.5
Microbiológical			
Total and fecal coliforms		100 mL	1000-2000
Escherichia coli		UFC	1000-2000
Pseudomonas spp.		UFC	0

Information Analysis

Descriptive statistics were performed on the results of the parameters evaluated *in situ*: pH, Temperature, Electrical Conductivity, Total Dissolved Solids, and Dissolved Oxygen. Once the calcium, magnesium, sodium, carbonate, and bicarbonate concentration were obtained, calculations were performed to determine the Sodium adsorption ratio (SAR) and residual sodium carbonate (RSC).

Sodium Adsorption Ratio (SAR) determination

For result analysis, the calculation of sodium absorption ratio (SAR) was used. The following equation calculates SAR:

$$SAR = \frac{\mathrm{Na}}{\sqrt{\frac{\mathrm{Ca} + \mathrm{Mg}}{2}}}$$

Where sodium, calcium, and magnesium are required in Meq L^{-1} from results in water analysis.

Residual Sodium Carbonate (RSC) determination

Residual Sodium Carbonate (RSC), to predict tendencies of calcium and magnesium soil precipitation and is calculated with the following equation:

$$RSC = \left(\mathrm{CO}_3^{2-} + \mathrm{HCO}_3^{1}\right) - \left(\mathrm{Ca}^{2+} + \mathrm{Mg}^{2+}\right)$$

Microbiological analysis

For the determination of Coliform bacteria (Most probable number technique), a) Presumptive test, b) Confirmatory test for Total Coliforms, and c) Confirmatory test for Fecal Coliforms *Pseudomonas* spp.: If there is microbial growth: Positive/g, if there is no microbial growth: Negative/g.

RESULTS AND DISCUSSION

For the parameters measured *in situ*, the following results were obtained: For pH, the values determined during the first sampling varied from 7.56 to 6.08, belonging to sampling sites number 1 "El Tajo" and number 8 "El Refugio," respectively, with an average of 6.8. Regarding the second sampling, the values were from 6.2 to 8.1, corresponding to sites number 4, "Cuisillos 1," and number 1, "El Tajo," with an average of 7.

Low pH can make toxic elements and compounds more mobile and available for uptake by aquatic organisms and plants. This can produce toxic conditions for aquatic life, particularly sensitive species (Yan *et al.*, 2007). According to CE-CCA-001/89, the pH values found in this research do not represent a risk for the protection of aquatic life, aquaculture, and irrigation water since they fall within the MPLs of 6-8.5 for irrigation water and 5-9 for drinking water.

The temperature recorded during the first sampling showed variability from 29.2 °C to 25.0 °C, values corresponding to sampling sites number 9, "Río Teuchitlán Descarga," and site number 3, "Arroyo Chapulimita," respectively, with an average of 26.3 °C. In the second sampling, the values obtained showed a variability ranging from 17.8 °C corresponding to sampling site number 1, "El Tajo," to 7.8 °C corresponding to site number 5, "Cuisillos 2", with an average of 12.9 °C. CE-CCA-001/89 does not mention LMP for temperature. Generally, the temperature obtained on the sampling dates does not represent a risk to aquatic life in La Vega Dam (Yan *et al.*, 2007; Custodio & Pantoja, 2012).

Electrical conductivity values ranged from 0.870 dS m^{-1} to 199 dS m^{-1}, results that were obtained at sampling sites number 7, "El Refugio," and site 9, "Río Teuchitlán (municipal discharge)," respectively, with an average of 0.410 dS m^{-1}. In the second sampling the values ranged from 0.900 dS m^{-1} to 0.200 dS m^{-1}, corresponding to sites number 4, "Cuisillos 1", and site number 8, "Río Teuchitlán," giving an average of 0.407 dS m^{-1}.

Electrical Conductivity (EC) is a key quality parameter that significantly influences crop productivity as the risk of salinity, measured as EC. The first effect that high electrical conductivity values have on crops is the inability of plants to compete for ions present in water and soil (physiological drought). EC CCA 001/89 mentions EC as Maximum Permissible Limit (MPL) of 0.1 dS m^{-1} for irrigation water; most of the sites where water samples were collected in this research presented values less than 0.1 dS m^{-1}.

Regarding Dissolved Oxygen, the range obtained in the first sampling was 5.02 mg L^{-1} to 1.48 mg L^{-1} values corresponding to sites number 3, "Arroyo Chapulimita," and site number 9, "Río Teuchitlán (municipal discharge)," with an average of 3.4 mg L^{-1}. During the second sampling, the observed range was 7.6 mg L^{-1} to 0.9 mg L^{-1}, corresponding to sites number 2, "Hacienda Labor de Rivera," and site number 4, "Cuisillos 1", respectively, with an average of 5.5 mg L^{-1}. EC-CCA-001/89 does not mention DO MPL for irrigation water. However, Gebremariam and Beutel (2008) say that low DO concentrations (less than 5 mg L^{-1}) can have critical consequences as they cause oxygen deficiency in plant roots, which can result in agronomic problems (Gebremariam and Beutel, 2008). According to the DO levels required by the crops mentioned in the literature, the DO determined in the various sampled sites, some of the sampled sites presented values that pose a risk to the crops (Gebremariam and Beutel, 2008).

Regarding Total Dissolved Solids, the range observed in the first sampling was from 480 mg L^{-1} belonging to site 10, "Acacias 2", to 105 mg L^{-1} corresponding to site 9, "Teuchitlán River (municipal discharge)" with an average of 251.4 mg L^{-1}. In the second sampling, a range was obtained from 450 mg L^{-1} corresponding to site 4, "Cuisillos 1", to 100 mg/L value obtained in sites 8 and 9 "Teuchitlán River" and "Teuchitlán River (municipal discharge),"respectively, with an average of 201 mg L^{-1}. CE-CCA--001/89 establish the MPLs for the concentration of TDS for the various water uses. For irrigation water, the MPLs mention 500 mg L^{-1}; therefore, most of the sampled sites are within these limits. Particles not ingested by aquatic organisms eventually settle, accumulating contaminants in the surface layers of the dam (Miller *et al.*, 2002; Bindler *et al.*, 2011).

Sodium Adsorption Ratio (SAR)

The average SAR for the two samplings is presented in Table 3. The sodicity risk in percentage was observed in that 50% of the sampled sites presented a low risk, 10% medium risk, 20% corresponded to high risk, and 20% presented a very high risk. The low sodicity risk corresponded to the 5 tributaries to La Vega Dam located in the north and west. Only one site presented medium risk (Cuisillos 2), while two sites presented high risk (Acacias 1 and 2), and two sites presented very high risk (Cuisillos 1 and El Refugio). It should be noted that the two sites that presented the highest SAR value correspond to the entrance of the El Salado River, which has been previously identified as having high salt content (De La Mora *et al.*, 2013). It is concluded that these salts have a geological origin since El Salado River originates in the Primavera forest, which has a volcanic origins.

The average SAR value was 12.43, with a standard deviation of 10.14. Sodium risk causes infiltration and permeability problems (Cuellar *et al.*, 2015; Can *et al.*, 2008). Although plant growth is initially limited by salinity levels (EC) present in irrigation water, the use of water with these characteristics (without sodium balance) under certain soil texture conditions can reduce production yield (Gasca *et al.*, 2011; Tartabull & Betancourt, 2016). The study area includes clay soils, which tend to salinize easily, according to GAT

Table 3. Results of sodicity risk in the tributaries to La Vega Dam.

Sodicity Risk (SAR) results		
SAR range	**Risk**	**Number of samples**
0-10	Low	5
11-17	Medium	1
18-26	High	2
Above 26	Very High	2

(2012). Also, a reduction in water infiltration can occur with large amounts of sodium with respect to calcium and magnesium (Dongli *et al.*, 2015).

Residual Sodium Carbonate (RSC)

RSC results showed that only 1 site (10%) presented a low risk, corresponding to a tributary in the northern part of the dam. The remaining 4 tributaries (40%) in this area offered a RSC value of less than 2, which indicates medium risk. However, the remaining 5 sites (50%) located in the eastern part of the dam presented a high risk (Table 4).

The RSC calculation results showed the highest value, 4.9, which corresponded to El Salado River. In contrast, the lowest value was 0.45, corresponding to a tributary in the northern part of the dam. The average RSC value found was 2.4, and the standard deviation was 1.33.

It is essential to mention that the sodium content in irrigation water negatively affects the soil's physical characteristics. When the sodium content is high compared to the content of other cations, there is a risk of soil deflocculation and loss of its physical characteristics such as granular structure, permeability, density, total porosity, consistency, water retention capacity (Zuñiga *et al.*, 2011. Therefore, determining SAR and RSC in irrigation water is crucial. The results indicated that 50% of the sampled sites showed a high risk of calcium and magnesium precipitation in soils irrigated with water from the tributaries to La Vega Dam.

Boron concentration obtained in both samplings

It was observed that the average in both samplings, in the 5 tributaries selected in the northern and western part of the dam, presented boron concentrations less than 1 mg L^{-1}. This level does not represent a risk for vegetation or aquatic life. However, the five sites presented concentrations between 4.5 and 11.2 mg L^{-1}. of boron, sites located east of the dam that correspond to El Salado River. These findings are consistent with those reported by Eisler (1990) in Eastern Europe, where high concentrations of boron found in surface waters are related to water with abundant minerals, indicating the natural origin of boron.

The maximum permissible limits (MPL) for boron (B) in irrigation water, as established by CE-CCA-001/89, specify that for sensitive crops such as peas, onions and avocados (Ayers and Wescot, 1994), among others, the water must contain a maximum of 0.75 mg L^{-1}, except for other crops such as corn, squash and oats (Ayers and Wescot, 1994) among others where concentrations of up to 3 mg L^{-1} can be accepted. The average B value found in this investigation was 4.02 mg L^{-1}. It was observed that this value exceeds 5 times the MPL. The average of the highest values determined in 5 sampling sites exceeds 2.5

Table 4. Results of the Residual Sodium Carbonate (RSC) risk in the tributaries to La Vega Dam.

RSC (Me L^{-1})	Risk	Number of samples
<1.25	Low	1
1.25-2.5	Medium	4
Above 2.5	High	5

times the concentration applicable to tolerant crops. The standard deviation of the data corresponded to a value of 4.18.

Microbiological analysis showed contamination at all sampling sites. In this regard, it is essential to mention the activities carried out in the area influencing the analyzed tributaries. For example, in the northern part, where the Teuchitlán River is one of the main tributaries to the dam, two samples were collected in this river, one before receiving the domestic discharges from the city of Teuchitlán and the other after receiving the discharges. Fecal contamination was expected at the site after the discharge but not at the sampling site before the discharge, where contamination was likely to be present but not at the level found.

Also, in the northern part of the dam, the site that corresponds to el Tajo, this river is formed from springs in the area and surface runoff from agricultural lands during the rainy season. Given the origin of the river, minimal microbiological contamination was expected to be found; however, the results showed countless fecal contaminations and positive for *Pseudomonas* spp. It is important to mention that the population closest to these springs, where the river originates, is approximately five kilometers from it, and physically, no contamination from discharges or characteristic odor of wastewater discharges were detected. Therefore, the origin of the fecal contamination is unknown.

Another tributary in the eastern part of the dam is the Chapulimita Stream, where a characteristic odor and color of wastewater were detected. This stream originates in the upper part of the basin, where some communities are located, such as Ahualulco del Mercado. It is unknown whether domestic wastewater is discharged directly. However, according to the results obtained, it is evident that there are discharges before entering La Vega Dam.

Another runoff originates in the Hacienda Rivera northeast of the dam (positive in the two analyses carried out in this work) and presents color and odor. There is no information on domestic discharges; however, the runoff is located a few meters from a hotel, which may be a fixed source of fecal contamination.

In the southeastern part, samples were collected from sites identified as Acacias 1 and Acacias 2. The selected sites correspond to a sample before a residential center identified with the same name (Acacias) and another after. The results were positive for both total and fecal coliforms and *Pseudomonas* spp. cases.

Also, in the southeast, the sites identified as Cuisillos 1 and Cuisillos 2 tested positive for the studies. In this area, there is a community with the same name, Cuisillos, so it is believed that sewage is also discharged into this river. Finally, the sampling site identified as El Refugio in the eastern part of La Vega Dam also tested positive for fecal and total coliforms and for *Pseudomonas* spp. It is important to mention that the results were expected since a few kilometers from this site is the city of Tala, Jalisco, and it is known that domestic discharges are released into the river. It is also known that the discharges from the sugar mill in Tala, Jalisco, also pour their waste into this river, in addition to the runoff typical of the rainy season, making this river (El Salado) one of the primary sources of pollution for La Vega Dam, not only from fecal contamination but from other types of contaminants reported in the literature.

CONCLUSIONS

According to the MPL mentioned in the Ecological Criteria for Water Quality CE-CCA-001/89, parameters such as pH, EC, and TDS are within the MPL for use in aquaculture, irrigation, domestic and recreational use. In the case of DO, some values fall below the MPL, which is 5 mg L^{-1}. The most significant contamination contribution to La Vega Dam was detected in the eastern part of the dam, with the entrance of El Salado River and other minor tributaries. Among the parameters analyzed, sodium presented high concentrations, contributing to a high value of both the SAR and the RSC. High concentrations of boron were also observed, which can negatively affect crops in the area according to their sensitivity. In addition to *Pseudomonas*, a high concentration of total and fecal coliforms was also found, which indicates fecal contamination. On the other hand, the northern and western parts of the dam presented a low risk in the SAR and RSC values. However, the total and fecal coliforms are outside the maximum permissible limits of the Mexican Official Norm cited, and the presence of *Pseudomonas* spp. Limiting its use for irrigation water. Based on the above, the water quality of the main tributaries to La Vega Dam on the east side is unsuitable for irrigation use. Constant monitoring of the tributaries to La Vega dam and within the reservoir is recommended. Additionally, wastewater treatment plants in various municipalities around La Vega Dam, which can reduce pollution, are recommended.

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