Desalination and Water Treatment
www.deswater.com

doi: 10.5004/dwt.2023.29994

311 (2023) 26–33
November

Assessment of water quality indices for human consumption and their comparison

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Received 11 April 2023; Accepted 19 September 2023

ABSTRACT

The water quality was determined from water quality parameters and Brown, Dinius, Dinius Second and Said indices were applied to evaluate the drinking water from the municipality of Villa Guerrero, México. Water samples were collected in both raining and dry seasons from nine sampling stations during 2022 and 18 parameters were analyzed: biochemical oxygen demand, total dissolved solids, the concentration of hydrogen ions, dissolved oxygen, turbidity, phosphates, nitrate nitrogen, ammoniacal nitrogen, chlorides, total hardness, specific conductivity, total acidity, total alkalinity, total coliform, fecal coliform, color, temperature and total solids. The indices indicated in general that the water of this region is suitable for human consumption, although its quality depended on the index used in the determination, because each index considers different parameters and weightages assigned to each one. The results show the importance of monitoring the water quality and the comparison of the results obtained from different indices indicated the effects of external factors that may alter its quality and help the authorities to take the right decisions to improve it.

Keywords: Water quality; Brown index; Dinius indices; Said index

1. Introduction

The surface water quality represents an important environmental concern, its exploitation depends on the natural processes and anthropogenic activities [1], such as, the weathering of the rocks, precipitation, soil erosion, as well as agricultural, urban and industrial activities, together with the overexploitation of water resources, which have an impact on the economy of each region [2]. In that sense, the sources of water supply for human consumption have been seriously affected by the continuous deposition of solid waste and pollutants in lakes and rivers generating a global health problem [3]. Pollutants can be of organic and inorganic nature, they settle and in winter they can increase, decreasing the quality of the water, and therefore they are an ecological risk to the aquatic systems [4,5]. Two important sources of water for human consumption are surface and underground water, the first consists of canals, streams,

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lakes and wetlands, while the second is in the spaces of the pores inside the rocks and the alluvium, in the cracks and in openings and aquifers.

Some features are notable from surface water for example, it could be easily contaminated with organisms and chemicals that cause waterborne contamination and intestinal infections, the turbidity frequently changes with the amount of rain, consequently, an increase in turbidity increases the treatment and operational costs and the temperature of surface water changes with the temperature of the environments. Groundwater shows great benefits because it is not effectively contaminated or polluted as surface water, the nature of groundwater is consistently steady and groundwater sources are mostly lower in bacteria than surface water sources; however, it is susceptible to hydrochemical imbalance of cations and anions [6,7]. Recently, some changes have been detected in the physicochemical parameters of water in the aquifer of Toluca Valley probably due to its overexploitation coupled with the increase of urban, agricultural and industrial activities. Also a change on the chemical parameters of groundwater has been observed and an increase on the presence of certain contaminants, such as nitrates and heavy metals associated with changes in salinity and sulfate concentrations due to the use of fertilizers in agricultural areas and/or discharge of wastewater [8]. A study of mathematical modeling in 18 communities of the municipality of Villa Guerrero, State of México, indicated that part of the aquifer in this area is significantly exposed to pesticide contamination because these substances are applied with high frequency and quantity [9]. One study reported that the Amacuzac River in its channel through the State of Morelos is moderately contaminated, and the main pollutants found were nitrates, biochemical oxygen demand and fecal coliforms with high levels at the beginning of the raining season [10].

In México, the quality of surface waters is monitored by The National Water Commission considering basically 4 parameters: the 5-day biochemical oxygen demand (BOD_5), the chemical oxygen demand, fecal coliforms and the total suspended solids (TSS) [11]. Spatial and temporal variations in hydrochemistry require regular monitoring for a reliable estimation of their quality [12].

The water quality index (WQI) is a simple method utilized as a part of surveying the general water quality by using a group of parameters which reduce the large amounts of information to a single number, usually dimensionless [13,14].

Various WQI have been developed worldwide to evaluate the water quality for direct human consumption and other uses; as well as helping to assess the environmental impact caused by pollution [15,16], they allow the comparison of water qualities from diverse sources, suggesting an appropriate use according to the type of water resource, these studies allow authorities to make decisions on the development of more objective policies, identify any contamination conditions before implementing a new policy or regulatory law and also provides a general picture of the general water quality to non-technical personnel [15,17]. A WQI is applied when it is known that there is a specific contamination problem, a specific monitoring is carried out, considering selected variables or indicators for the aquatic system under study [18]. Among the most outstanding WQI's are: Brown [19], Dinius, Dinius Second and Said, among others. Calculation of WQI's are based on a number of physicochemical and microbiological parameters.

There are 4 classes of water qualities within this WQI, namely class 1 for drinking water sources, class 2 for water recreation, class 3 for fisheries and animal husbandry and class 4 for agriculture. Excellent (0–25), good (26–50), poor (51–75), very poor (76–100), unsuitable for drinking (>100) [13].

Brown's WQI (1970) represents general water quality, it does not incorporate or recognize functions of specific water uses, such as the use for human consumption, uses in agriculture or industry, etc. This index is calculated as the weighted arithmetic average of the individual weights assigned to each quality parameter. This WQI is made up of nine water quality parameters: dissolved oxygen, fecal coliforms, pH, BOD, nitrates, phosphates, temperature, turbidity and TSS [19,20].

Dinius One' WQI (1972) was developed to describe different levels of polluting parameters and through its use the planning, measurement of costs and impacts of pollution were evaluated and was a precursor in decision making. The water quality index is of mathematical character and the water is classified according to five different uses; one of them is for industrial and agricultural purposes. This index is based on the analysis of 11 water quality parameters (dissolved oxygen, 5-day BOD, total coliforms, fecal coliforms, specific conductivity, chlorides, hardness, alkalinity, pH, temperature and color) [21,22].

Dinius' Second WQI (1987) includes the above parameters and the nitrate analysis, classifies water in six water uses as public water supply, recreation, fish, shellfish, agriculture and industry. This index is based on multiplicative aggregation, with values expressed as a percentage of good water quality corresponding to 100% [21].

Said et al. WQI ([14]) was based on only 5 parameters and can be used to compare the status of different sites, the variables are dissolved oxygen, total phosphates, fecal coliform, turbidity and specific conductivity. The index has been designed to range from 0 to 3.

The purpose of this work was to analyzed surface water in both raining and dry seasons and to assess whether the physicochemical and microbiological quality of surface water is suitable for human consumption or general purposes by means of long-term Brown, Dinius, Dinius Second and Said water quality indices (dry and raining seasons) and to compare the data obtained by means of each index.

2. Experimental set-up

2.1. Sampling area

Villa Guerrero township lies at 18° 57'N; 99° 38'W; 1,420–3,900 m.a.s.l. (Fig. 1), located in the central region of México, occupies 1.0% of the surface of the state and has 69,086 inhabitants [23]. In the municipality of Villa Guerrero, State of México, the floricultural activity is characterized by an abundant use of water and pesticides, both in open and closed environments (greenhouses). In addition, the geographical disposition of the town, surrounded

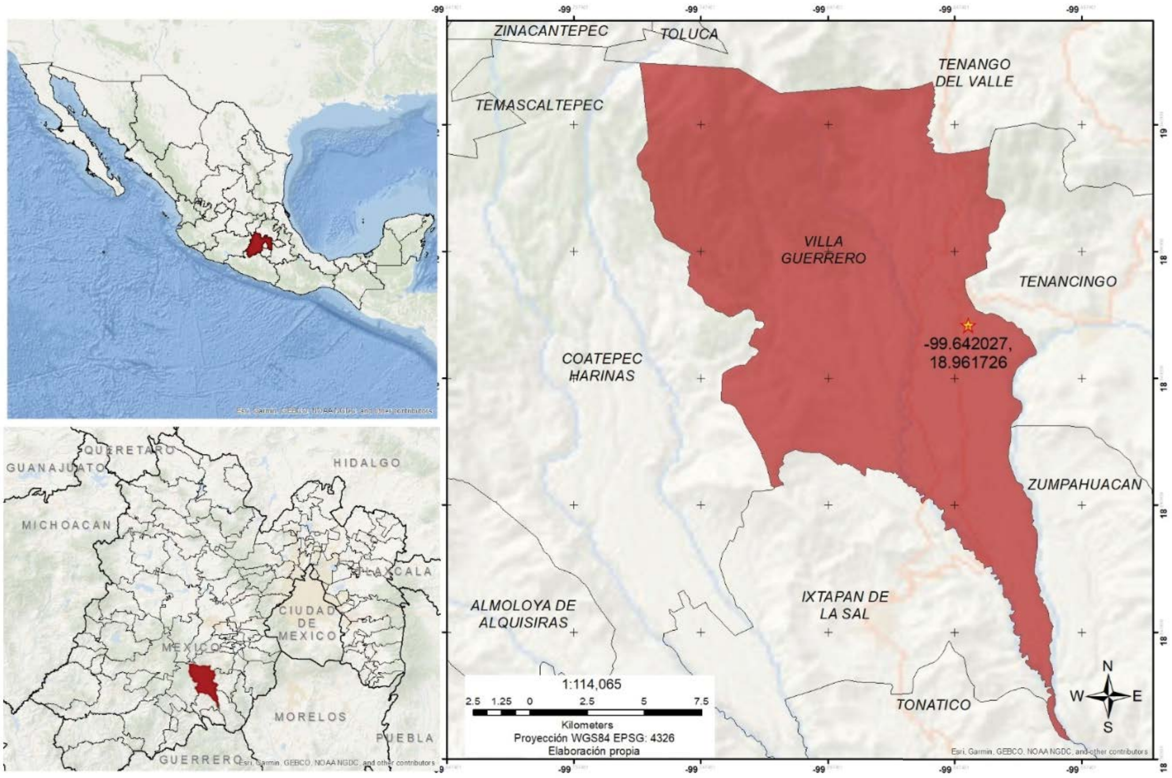

Fig. 1. Map of Villa Guerrero, México.

by a mountainous system [24] generates geographical conditions that contribute substantially to the permanence of these pesticides in the area. In Villa Guerrero, the summers are short and hot, the winters are short and cool, and it is dry and partly cloudy around the year. Over the course of the year, the temperature varies from 4°C to 30.5°C and is rarely below 0°C or above 33°C.

2.2. Water samples

9 monitoring stations were selected from the 36 drinking water supply tanks of the municipality of Villa Guerrero México (Fig. 1), covering urban areas and areas for floricultural crops in greenhouses. Site 1 (Buenavista), site 2 (La Joya), site 3 (Coponial), site 4 (Los Fresnos), site 5 (San Francisco I), site 6 (San Francisco II), site 7 (San Francisco III), site 8 (Zacango I) and site 9 (Zacango II). The geographical coordinates of the sampling sites are shown in Table 1 [25].

Sampling was carried out in accordance with the Guidelines Standard [26,27]. Samples were taken before the disinfection process in duplicate and the analysis of each sample was done twice. These datasets were collected during May (dry season) and October 2022 (raining season).

Water samples were collected for the physico-chemical analyzes in polyethylene bottles of 1 L with hermetic screw caps, pre-washed with a 1% solution of non-ionic detergent (Extran) and abundant water, treated with a 5% HCl solution and then rinsed with deionized water, while water samples for microbiological analysis were taken in glass bottles of 300 mL previously sterilized.

Table 1
Geographic coordinates of the sampling sites

	Sampling sites	Coordinates UTM	
1	Buenavista	14 Q 430509 m E	2096660 m N
2	Coponial	14 Q 432130 m E	2097450 m N
3	Estrella - La Joya	14 Q 431088 m E	2098567 m N
4	Los Fresnos/Cabecera Municipal	14 Q 432130 m E	2097450 m N
5	San Francisco I	14 Q 431465 m E	2096959 m N
6	San Francisco II	14 Q 431312 m E	2096456 m N
7	San Francisco III	14 Q 431686 m E	2095352 m N
8	Zacango I	14 Q 424095 m E	2101377 m N
9	Zacango II	14 Q 424145 m E	2101377 m N

The samples were stored in ice and transported to the laboratory where the physicochemical and microbiological analyzes were processed, all chemical reagents used in the analysis were analytical grade. The analysis were performed twice.

The parameters pH, electrical conductivity, dissolved oxygen (DO) were analyzed at the sampling site by using the instrument model edge, Hanna Instruments (México).

2.3. Water quality indices

The WQI were determined from the average values of the 18 parameters of the water quality. The equations of the models used are the following:

2.3.1. Brown' WQI [28]

$$\text{WQI} = \frac{\sum_{i=1}^{n} C_i P_i}{\sum_{i=1}^{n} P_i} \quad (1)$$

2.3.2. Dinius' One WQI [21]

$$\text{WQI} = \frac{1}{21}\sum_{i=1}^{n=11} W_i I_i \quad (2)$$

2.3.3. Dinius' Second Index WQI [20]

$$\text{WQI} = \prod_{i=1}^{n} I_i^{W_i} \quad (3)$$

2.3.4. Said' WQI [29]

$$\text{WQI} = \log\left[\frac{(\text{DO})^{1.5}}{3.8^{\text{TP}}\,\text{Tur}^{0.15}\,(15)^{F-\text{Coli}} / 10000 + 0.14(\text{SC})^{0.5}}\right] \quad (4)$$

where n is the total number of the parameters included in the study, C_i is the normalized value of parameter i, and P_i is the weight of parameter i used in Brown index. I_i is the sub-index function of the pollutant parameter, W_i is the unit weight of the pollutant parameter whose value ranges from, 0–1 in Dinius' One index [30].

Weightages assigned to the quality parameters utilized in Dinius' Second index methodology were: 0.241, 0.169, 0.174, 0.215, and 0.200 for DO, pH, specific conductivity (SC), BOD_5 and NO_3–N, respectively [20].

3. Results and discussion

3.1. Parameter selection

The parameters of drinking water should be selected considering the substances that are known to be important to health and are present in significant concentrations in the water source [26].

In this research 18 parameters and four indices were selected to determine the quality of water (Table 2). The parameters that characterize water quality are classified in different ways, one of them considers physical, chemical, and microbiological properties. The importance of each parameter is critical [18].

Table 2 shows the average of each parameter in both dry and raining seasons, as it can be observed most parameters are below the maximum values recommended by World Health Organization (WHO). Shah and Joshi [31] have reported the importance of each parameter in the water quality, therefore only a brief description of them is given.

3.1.1. pH

The pH has an important effect on the body chemistry, health and disease because human body has from 50% to 60% water. The pH level of our body fluids should be in the 7–7.2 range. If pH is less than 5.3, assimilation of vitamins or minerals is not possible. If pH is higher than 8.5, causes a bitter taste or soda-like taste. The pH in the samples was sometimes up to 8.4 and the recommended value by WHO is between 7.0 and 8.0.

Table 2
Descriptive statistics of monitored parameters from analyzed water

Parameter	Abbreviation	Unit	Dry season		Raining season		WHO Standard
			Max.	Min.	Max.	Min.	
Temperature	T	°C	13.5	8	26	9	–
Hydrogen ion concentration	pH		8.1	7.4	8.4	7.3	7.0–8.0
Total hardness	TH	mg/L	186.1	37.2	100.0	20.0	500 mg/L
Specific conductivity	SC	mS/cm	166.3	75.9	160.3	72.8	–
Turbidity	Turb	NTU	1.55	0.08	0.2	0.02	1 NTU
Total acidity as $CaCO_3$	Acid	mg/L	59.8	16.1	22.1	3.5	–
Total alkalinity as $CaCO_3$	Alkal	mg/L	70.7	30.0	73.5	39.2	–
Chlorides	Cl^-	mg/L	27.4	13.0	20.2	5.0	250 mg/L
Dissolved oxygen	DO	mg/L	8.0	6.7	6.2	3.8	–
5-Day biochemical oxygen demand	BOD_5	mg/L	19.4	1.5	2.9	0.6	–
Total coliform	T-coli	(counts/100 mL)	920	2	0	0	–
Fecal coliforms	F-coli	(counts/100 mL)	49	1	0	0	Not detectable
Color	Color	TCU	6	1	4	1	15 TCU
Ammoniacal nitrogen	NH_3–N	mg/L	3.92	1.5	0.5	0.03	50 mg/L
Nitrate nitrogen	NH_3–N	mg/L	5.8	0.6	4	0.4	–
Total phosphates	$(PO_3)^{-4}$	mg/L	2.0	0.001	2.2	0.6	–
Total suspended solids	TSS	mg/L	64	8	72	16	–
Total dissolved solids	TDS	mg/L	212	100	156	18	1,000 mg/L

3.1.2. Dissolved oxygen

The concentration of DO in waters depends on water temperature, turbulence, salinity, and altitude. This parameter determines whether biological changes are brought by aerobic or anaerobic organisms. Low concentrations of DO indicates a high organic pollution in the river. The optimum value for good water quality is from 4 to 6 mg/L. The values found in the water samples were from 6.7 to 8.0 mg/L in the dry season and from 3.8 to 6.2 mg/L in the raining season, these values may indicate some organic pollution in the water.

3.1.3. Biochemical oxygen demand

This parameter determines the oxygen required to stabilize domestic and industrial wastes. Minimum 2–7 mg/L of DO is required for the degradation of oxidizable organic matter. The values found in the samples were higher in the dry season than raining season, in the first one some values were near 20 mg/L which indicate water pollution.

3.1.4. Specific conductivity/total dissolved solids

This is the amount of dissolved solids in the water. The specific conductivity depends on the total dissolved solids. The content of dissolved solids is important because it affects the quality of the water used for drinking and irrigation. Dissolved ions affect the pH of water, which is important to the health of aquatic species. The conductivity values obtained were similar in both seasons and these values corresponded to those of freshwater streams which have a conductivity between 150 to 500 μS/cm to support diverse aquatic life.

3.1.5. Nitrate nitrogen

This parameter is responsible of eutrophication of waters due to growth of aquatic plants and algae. Excess of nitrate nitrogen in water can cause serious health hazards. Bacteria in the digestive system transform nitrate to nitrite, then the nitrite reacts with iron in the hemoglobin of red blood cells to form methemoglobin, which lacks the oxygen carrying ability of hemoglobin. A nitrate level up to 3 mg/g in well water is safe for drinking. The U.S. Environmental Protection Agency [32] has set the primary drinking water standard (from public water supplies) for nitrate of 10 mg/L. The values determined in the samples were from 0.4 to 5.8 mg/L.

3.1.6. Total and fecal coliform

Coliforms should be absent according to WHO. In this study coliforms were present in the samples taken in the dry season and were absent in the raining season. This behavior could be due to the fact that water samples were taken before the chlorination process in some sites and in other sites the chlorination system was out of order.

3.1.7. Turbidity

This is a measurement of the ability of light to pass through water, turbidity may depend on the type of the soil that make up the base of the wells. High turbidity values indicated a possible presence of microorganisms and other suspended solids that may affect the quality of water. Consumption of high turbid water can consequently cause serious health risks. Points with high turbidity values above the recommended limits should be disinfected before use. The turbidities in the water samples were similar and low in both dry and raining seasons.

3.1.8. Chloride

This chemical species enters into ground system from various sources such as raining water, agricultural activities and leaching from waste disposal. The concentration found in the samples was much lower than the permissible limit of WHO [26].

3.1.9. Color

Color in water is the result of soluble chemical substances that may come from different sources like metal ions, humic and fulvic acids, lignin, tannin, algae, peaty matters, etc. The color of samples was lower than the permissible limit of WHO.

Table 3
Water quality indices of the sampling sites

WQI	Brown progression arithmetic		Brown progression geometric		Dinius One		Dinius Second		Said	
	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry
Buenavista	80.8	73.0	77.9	63.4	80.6	51.2	100.4	72.1	2.1	2.5
La Joya	80.2	79.5	77.4	75.9	78.3	69.4	93.8	84.9	2.3	2.4
Coponial	79.7	75.1	76.6	68.0	77.5	62.8	88.0	74.0	2.3	2.4
Los Fresnos	79.1	71.9	75.03	64.7	79.6	58.4	88.3	71.5	2.0	1.8
San Francisco I	88.3	82.0	87.3	77.8	85.5	65.7	98.3	83.9	2.3	2.3
San Francisco II	78.9	69.6	73.5	61.6	82.5	56.0	94.8	73.4	1.7	1.6
San Francisco III	82.8	78.7	80.4	72.2	84.2	63.4	92.1	76.4	2.2	2.4
Zacango I	79.1	80.3	76.1	73.1	79.9	72.5	95.3	85.1	2.2	2.5
Zacango II	79.4	72.4	75.2	69.7	85.7	54.7	101.7	77.9	2.0	2.4

Phosphorus defines the type of plants that will prevail, as well as the eutrophication of aquatic ecosystems because it is usually the limiting nutrient. The natural levels of phosphate usually range from 0.005 to 0.05 mg/L, the concentration of phosphate in the water samples was higher than this range.

3.1.10. Water quality indices

Data of Table 2 were treated with Brown's (1970), Dinius (1972), Dinius' Second (1987) and Said (2004) [21]. Each index considers different parameters as described. The parameters have different importance and a value is assigned to each one according to its relative effect on the water quality and these values depend on the permissible limit regulations for drinking water set by national and international agencies.

Table 3 shows the water quality indices determined from the analysis of the parameters and the models, Table 4 shows the classification of water according to the water quality indices.

Fig. 2 shows the quality of water from each sampling site. The results show that the quality of water depends on the index used to treat the data, since each index considers different water parameters. Although most parameters are lower than the maximum limits settled by the regulations,

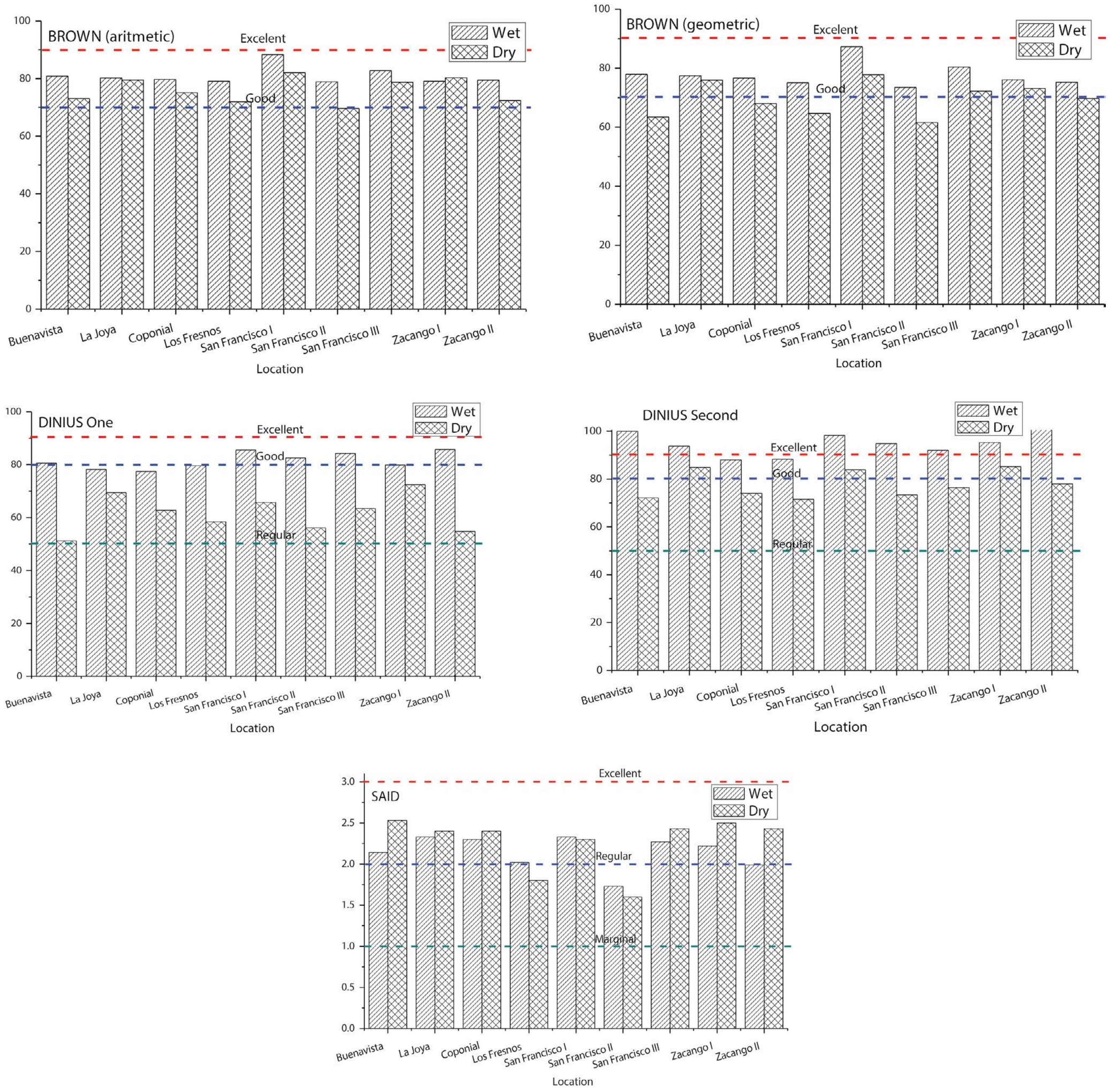

Fig. 2. Brown, Dinius One, Dinius Second and Said WQI's in different sampling sites during dry and wet season.

Table 4
Classification of water for human consumption according to the water quality indices

Brown		Dinius		Said	
Excellent	100–90	Excellent	100–91	Very good	3.0
Good	90–70	Good	90–81	Acceptable	3.0–2.0
Medium	70–50	Regular	80–51	Marginal	2.0
Bad	50–25	Bad	50–41	Poor	1.0–0
Very bad	25–0	Very bad	40–0		

in some cases the water quality is marginal. The results from the Brown and Dinius indices show that the quality of water is better in the raining season than in the dry seasons, this is reasonable because the pollutants are diluted, although the Said WQI shows the opposite, these results indicate that the parameters considered in each index are very important to determine its quality. The quality of water from the Brown (arithmetic) index shows that water is good in all cases and for the Brown (geometric) index in some cases is not good in the dry season. The index that considers most parameters is the Dinius One, in most cases the results show regular quality mainly in the dry season, similar behavior was observed for Dinius Second index although the water quality improved, in most cases, the water quality was excellent in the raining season. The Said index considers less parameters than the other and showed the lowest water quality, in most cases was regular and marginal. These results show that it is important to consider the value of each parameter to select the index, for example in this study, the specific conductivity seems to play an important role on the Said index and therefore the results show that the water quality is lower than using the other indices. Ewaid and Abed [13] found that poor quality of water was mainly due to the turbidity, SC, and total dissolved solids and the decisive factors responsible for water quality are only five: turbidity, SC, chemical oxygen demand, total hardness, and pH. The water quality parameters determined in this study showed acceptable values of water for human consumption. In general, the water quality indices calculated show that the water of this region is adequate for human consumption (municipality of Villa Guerrero), the water comes from the slopes of the Nevado de Toluca volcano [33]; however, there are anthropological factors, such as agricultural activities that generate uncontrolled consumption of pesticides and fertilizers in the region that may affect its quality, which have not yet been studied in detail and it is recommended to analyze their impact in future work. It is advisable to establish sanitation practices for water intakes for human consumption in some places (Buenavista, Coponial, Los Fresnos, San Francisco II and San Francisco III) because the water quality index of Dinius Second showed regular water quality, which is based on the largest number of water quality parameters. In addition, it is advisable to carry out adequate water resource management and greater ecological awareness to avoid the deterioration of local water supplies [7]. It is also recommended to determine the WQI in the following years to ensure that water quality is maintained.

4. Conclusions

Biochemical oxygen demand, total dissolved solids, the concentration of hydrogen ions, dissolved oxygen, turbidity, phosphates, nitrate nitrogen, ammoniacal nitrogen, chlorides, total hardness, specific conductivity, total acidity, total alkalinity, total coliform, fecal coliform, color, temperature and total solids were determined in drinking water of nine wells from the municipality of Villa Guerrero, México. The quality water indices were determined by using these water quality parameters and Brown, Dinius, Dinius Second and Said indices, in general the results indicate that water is adequate for human consumption. The results showed that the indices depends on the parameters used in each one.

Acknowledgements

The authors are grateful to UAEMex for the financial support of this research, project 4601/2018ESP, J.A. López-Martínez for their valuable contribution (Thesis) and CONACYT scholarship grant for J.A. López-Martínez.

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