Journal of Environment and Earth Science www.iiste.org
ISSN 2224-3216 (Paper) ISSN 2225-0948 (Online)
Vol.8, No.8, 2018

Influence of Dry and Rainy Seasons on Physicochemical Parameters and Water Quality Index, Zahuapan River, Mexico

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Abstract
Rivers pollution is an environmental problem in Mexico. Zahuapan River shows an important level of contamination due to raw wastewater discharges and runoff. The goal of this study was to evaluate the influence of dry and rainy seasons on physicochemical parameters and water quality index in the Zahuapan River. The physicochemical parameters were registered in situ using a portable multiparametric device. The data analysis was taking into account the dry and rainy seasons. Physicochemical parameters among seasons were compared by the Mann-Whitney and *t* tests. The analysis of physicochemical, temperature and rainfall relationships were carried out through the multiple regression and correlation matrix. Zahuapan River water quality index was estimated by CCME WQI method. Mann-Whitney and *t* tests evidenced that the physicochemical parameters were significantly different ($p<0.05$) in dry and rainy seasons. Coefficients of determination indicated that the multiple regression model was a good descriptor of variables. The pH was the best response variable in the rainy season and the EC was the best response variable in dry season. More correlated pair variables were present in the rainy season than in the dry season. Water quality index got slightly better in the rainy season but due to the given condition of the river, it remained ranked in poorly quality category. The results revealed that the contamination has affected the Zahuapan River sensitivity, that no longer it responds to seasonal changes. The methodology used in this study may be useful in the evaluation of Zahuapan River restoration, and others rivers as well.
Keywords: River pollution, river sensitivity, lineal multiple regression, correlation

1. INTRODUCTION

Mexico is organized in 37 hydrological regions, where the 51 of the main rivers originate; being the Balsas River among of them. In these rivers flows 87% of the surface runoff and their catchment areas cover 65% of national territory (CONAGUA 2016a). The Balsas River Basin (BRB) protrudes in Mexico, due to its catchment area and population growth. In the BRB are living approximately 12 million people and important metropolitan areas like Puebla-Tlaxcala and Cuernavaca are settled, as well as industrial parks. The Zahuapan River (ZR) is located in the upper part of BRB.

River´s pollution is aggravated in Mexico, and it is a sign of the environmental deterioration. Human activities have harmed the river system through deforestation, urbanization, agriculture, land drainage, pollutants discharges, and flow regulation (Bellos y Sawidis 2005). Although, in Tlaxcala State there are wastewater treatment plants, the ZR is one of the most polluted in Mexico (CONAGUA 2016a). Besides this, it is classified in the polluted category by biochemical oxygen demand (CONAGUA 2016b). The ZR pollution is the result for cities and towns discharges directly to the river stream or indirectly to tributary channels, of raw or partially treated wastewater (onsite observations made by the authors). The wastewater treatment plants dysfunction happens, mainly, due to economics causes. This situation is common in Mexico, so that 73% of aquatic systems show some kind of contamination (Mendoza et al., 2014); for this reason, the study of polluted rivers is motivated. Some studies have reported investigations of Mexicans rivers, for instance, the contamination of Texcoco River (Guzmán et al., 2007, Rivera et al., 2007), and the Lerma River (López et al., 2007). Regarding water quality index, the investigations focused on San Juan River (Saldaña-Fabela et al., 2011), the Seco River (Torres et al., 2013), Duero River (Silva et al., 2016), and the Grijalva River (Musalem-Castillejos et al., 2018), to name a few.

In the ZR basin, particularly, have been reported investigations on environmental degradation (Alvarado et al., 2008), water quality (Castilla-Hernández et al., 2014), seasonal dynamics of physicochemical parameters (Martínez-Tavera et al., 2017), ecological conditions evaluation and water quality in the ZR (Mena et al., 2017). Based on that, studies with different approaches have been conducted in the ZR that contributed with valuable information in the river sanitation. As mentioned by Singh et al., (2013), different environmental factors influence the seasonal distribution pattern of river physicochemical parameters. Also, the climatic change can be added, which is the modification of temperature and rainfall tendencies, and affects the biogeochemistry, ecologic, and water quality processes of rivers (EEA 2010). Hence, temperature and rainfall play an important role and have an influence on physicochemical parameters that must be taken into account. For this reason, the objective of this study was to evaluate the influence of dry and rainy seasons on physicochemical parameters and water quality index in the Zahuapan River.

2. MATERIALS AND METHODS

2.1 Zahuapan River Basin

ZR crosses Tlaxcala State from north to south. Atlangatepec dam divides the ZR into two segments 1 y 2. The segment 1 has 28 km and the segment 2 has 78 km. The ZR basin area is of 1632 km^2 (40.9% of the Tlaxcala State area), and there are 49 municipalities inside it. According to the official website of Mexico National Institute of Statistics and Geography, in 2015 there were living approximately 1.103 million inhabitants in these municipalities. The ZR population density ranges over 676-1000 hab/km^2. From La Malinche volcano, Tlaxco mountain range, and Tlaxcala-block mountains comes the runoff in the ZR stream during the rainy season; on the other hand, the wastewater discharges from the cities and towns do it mainly in the dry season.

2.2 Data collection

***Physicochemical parameters measurements*:** The physicochemical parameters measurements were made on a monitoring site located approximately in the middle basin of ZR (19^0 20' 22'' north y 98^0 20' 34'' west). The catchment area delineation for monitoring site was made using the Whitebox software (Lindsay et al 2008, http://www.uoguelph.ca/~hydrogeo/
Whitebox/download.shtml) (Figure 1). According to SIATL software (http://antares.inegi.org.mx/analisis/red_hidro/siatl/#), in the catchment area are living 284 982 inhabitants, 75.5% of the soil is used in agriculture, 14.6% is forested, 8% is induced vegetation,1.8% water bodies, and 0.1% human settling.

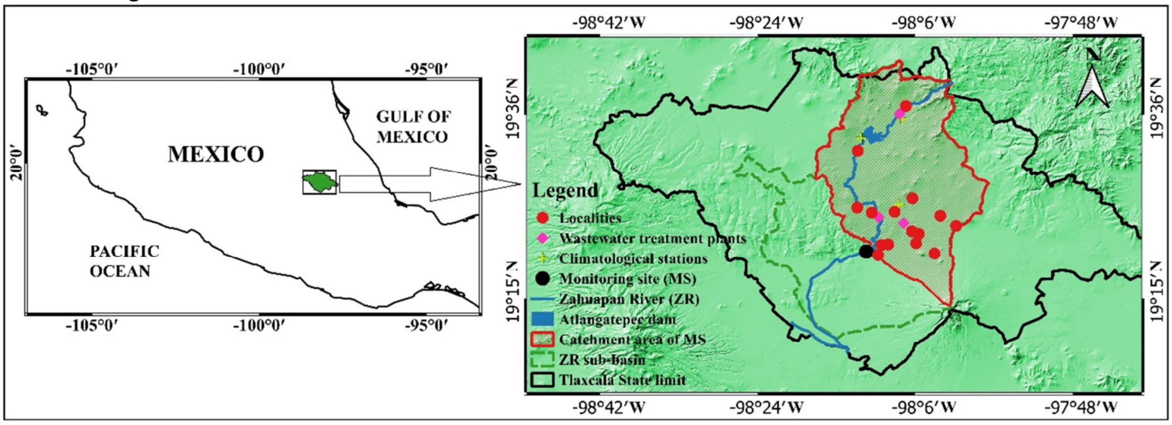

Figure 1. Study area map illustrating monitoring site localization from Zahuapan River.

The physicochemical parameters measurements were done from February 24th to December 24th 2016. This period covered the dry and rainy seasons. The physicochemical parameters considered in this study were: stream temperature (Ts) (^{0}C), proton activity (pH) (no units), oxidation-reduction potential (ORP) (mV), electrical conductivity (EC) (μS/cm), total dissolved solids (TDS) (ppm), salinity (Sal) (PSU), dissolved oxygen (DO) (mg/L), and turbidity (Turb) (FNU). To register the parameters was used a Hanna Instrument multiparameter model 9829. The multiparameter sensors were calibrated according to the user manual, and they remained submerged in the stream river during data recording. The registers started at 9:00 AM and ended at 10:00 AM, being data stored every five minutes. Data collected in the last 30 minutes of registering was analyzed in this study.

Rainfall and air temperature: The rainfall data was obtained from four climatological stations (Apizaco, Atlangatepec, Tocatlan, and Tlaxco), located in the catchment area of the monitoring site. The air temperature (Ta) data was provided by the climatological station located at 5 km downstream of the monitoring site. These climatological stations are operated by Mexico´s National Water Commission Office in Tlaxcala State.

2.3 Data Analysis

In order to evaluate the influence of dry and rainy seasons on physicochemical parameters, the data was grouped based on the rainy season. According to Bravo et al., (2014), the rainy season was defined from the Julian day 131 (May 10th) (standardized accumulated rainfall<0.15) to the day 279 (October 5th) (standardized accumulated rainfall<0.94). The days outside of this interval time were considered as dry season. For physicochemical parameters, rainfall, and air temperature grouped seasonally, were calculated the means, coefficient of variation (CV) and skewness coefficient (SC). The physicochemical parameters between dry and rainy seasons were compared by the *t* and Mann-Whitney tests (McBean and Rovers, 1998).

The relationship between variables was evaluated by multiple regression model and correlation matrix. The sum of rainfall (Rsum) registered in the four climatological stations, Ts, pH, DO, ORP, EC, and Turb were used for the multiple regression model. Due to TDS and Sal are calculated of EC in the multiparameter, these were not considered in the analysis. The multiple regression model (Schuenemeyer and Drew, 2011) is formulated as

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \beta_6 X_6 + \varepsilon \quad \text{Eq. 1}$$

where Y is response variable, $\beta_0 \ldots \beta_6$ are the model coefficients, $X_1, \ldots X_6$ are explanatory variabl ; random error. The model was evaluated for each physicochemical parameter as the response variable, whereas the other parameters were taken as explanatory variables. Moreover, the model was tested using the raw data and their respective logarithms base 10 (Log_{10}) (Malamud and Turcotte 2013), excepting for pH, because of pH=-$Log_{10}\{H^+\}$, and ORP due to negative and positive values. For each season data, a correlation matrix was obtained, a significant correlation among pair variables was defined when $p<0.05$.

2.4 Water quality index

The influence of dry and rainy seasons on ZR water quality was evaluated using the CCME (Canadian Council of Ministers of the Environment) water quality index (CCME 2001). The calculation of index values involved the next variables pH, Ta, Ts, DO, ORP, EC, TDS, Sal, y Turb. The desirable state of the river (water quality objectives) was established as: Ts<Ta+1.5 (°C), TDS<500 mg/l and DO>5 mg/l (SEDUE 1989); 6.5<pH<8.5 (CCME 2001, eCFR 2018); ORP>300 mV and EC<100 µS/cm (Sanders 1998); Sal<1 PSU (Hart et al., 1990) and Turb<50 FNU (eCFR 2018).

3. RESULTS AND DISCUSSION

3.1 Rainfall and air temperature

Table 1 shows basic statistics of rainfall, air temperature, and river physicochemical parameters. The number of rainfall events, registered in Tocatlan (RTo) and Tlaxco (RTl) climatological stations, were comparable to 107 events reported by Mercado-Mancera et al., (2104). Apizaco (RAp) and Atlangatepec (RAt) climatological stations registered more events than in Tocatlan and Tlaxco stations. The total annual rainfall registered in the four climatological stations was greater than the normal rainfall of 740 mm (CONAGUA 2016a) in the 1981-2010 periods.

Table 1. Basic statistic of physicochemical parameters, temperature and rainfall.

	Dry					Rainy				
	N	Sum	Avera	CV	SC	n	Sum	Avera	CV	SC
RAp	36	203.00		133.23	2.19	96	743.50		91.22	1.71
RAt	30	205.50		86.77	1.16	86	763.50		70.86	0.64
RTl	29	175.40		83.60	1.46	73	595.92		102.10	1.62
RTo	26	142.50		128.15	3.34	77	778.00		99.09	1.21
Ta	23		18.17	18.90	-0.53	23		19.28	8.71	-0.19
Ts	23		15.85	10.46	0.219	27		17.27	5.44	0.85
pH	23		8.02	2.56	1.37	27		7.98	1.55	-0.40
ORP	23		-47.71	-74.93	0.45	27		1.76	1443.61	-0.86
EC	23		905.92	25.55	1.42	27		673.68	38.99	0.38
TDS	23		452.95	25.56	1.43	27		336.79	39.00	0.38
Sal	23		0.45	26.66	1.46	27		0.33	40.19	0.41
DO	22		1.97	67.10	0.99	27		5.17	35.42	0.26
Turb	23		29.22	79.28	4.02	27		257.77	116.26	1.47

Avera= Average, CV= Coefficient of variation, SC= Skewness coefficient.

RAp, RAt, RTl and RTo: Rainfall (mm) registered in Apizaco, Atlangatepec, Tlaxco and Tocatlan climatological stations, respectively. Ta: air temperature (°C); Ts: stream temperature (°C); pH: proton activity (no units); ORP: oxidation-reduction potential (mV); EC: electrical conductivity (µS/cm); TDS: total dissolved solids (ppm); Sal: salinity (PSU); DO: dissolved oxygen (mg/L); Turb: turbidity (FNU).

The maximum rainfalls registered in the four stations ranged 24-40 mm. In Atlangatepec station, the rainfalls were more homogeneous (CV equal to 74.7%) than the others three stations (CV>100%). The SC was also less in Atlangatepec station, with a value of 0.74, the other three stations ranged from 1.5 to 1.76, which were greater than reported by Chowdhury and Beecham (2013). SC values from 0.5 to 1 are considered moderately skewed to the right (McBean and Rovers, 1998). Regarding monthly distribution, the data showed that between May and September rained 75-80% of total annual and August was the rainiest month (22-25%). During January, February, March, April, October, November, and December, it rained 19-24% of the total annual. In general, monthly rainfall distribution is comparable to reported by Mexico´s National Water Commission (CONAGUA 2015). In the dry season were registered from 26 to 36 rainfall events, whereas in rainy season were from 73 to 96 events. The rainfall depth ranged 142.5-205.5mm and 595.9-778.0mm in dry and rainy seasons, respectively. The rain in dry season represented 26% of the rainy season and 20% of total annual. As it was expected, the CV and SC of rainfall were greater in the dry season than in the rainy season.

3.2 Physicochemical parameters

50 measurements of physicochemical parameters were made, approximately one per week, 23 of them in the dry season and 27 in the rainy season (Table 1). The average, interval, and CV of Ta were greater than those of Ts, this was predictable because water has a greater heat capacity than air (Manahan 2017). The averages of Ts (16.6 ^{0}C), EC (780.5 µS/cm), TDS (390.2 mg/l), and Turb (152.6 FNU) were less than the reported in the literature for Mexican rivers (Guzmán et al., 2007; López et al., 2007; Rivera et al., 2007; Saldaña-Fabela et al., 2011; Torres et al., 2013; Silva et al., 2016; Mena et al., 2017; Musalem-Castillejos et al., 2018). The pH annual average (8.0) was the highest reported among Mexican rivers (Saldaña-Fabela et al., 2011; Torres et al., 2013; Mena et al., 2017). Similar ORP annual average (-21.0 mV) obtained in this study was reported by Martínez-Tavera et al., (2017). Regarding salinity, the average (0.38 psu=380 mg/L) was greater than reported by Mena et al., (2017). Conversely, the DO average (3.73 mg/l) was among the lowest values of Mexican rivers reported in the literature (Rivera et al., 2007; Castilla-Hernández et al., 2014; Mena et al., 2017). Related to the CV statistical, Ts and pH had lower values than the Zahuapan River reported by Castilla-Hernández et al., (2014). On the other hand, the ORP and Turb showed higher variation. The DO had greater variation in the rainy season than in the dry season. The CV values of EC, TDS, and Turb were comparable to the ones reported by Flores and Návar (2002). Regarding SC statistical, Ta, Ts, and ORP showed negative values, which indicate that the data distribution is skewed to the left and higher values prevailing (McBean and Rovers, 1998). As mentioned in the rainfall analysis, the SC of EC, TDS, Sal, DO, pH, and Turb had positive values, this indicates that the data distribution is skewed to the right. The Turb had the higher SC value than the others parameters considered here, opposite as reported by Flores and Návar (2002), who reported a value of 4.02 in turbidity.

Similarly, as reported by Balakrishnan et al., (2017) and Martínez-Tavera et al., (2017), the physicochemical parameters showed seasonal variation. The rainy season and summer coincide in the ZR basin, which affected the parameters in dissimilar proportion. As shown the *t* and Mann-Whitney tests, the physicochemical parameters were significantly different ($p<0.05$) between the dry and rainy seasons. However, the pH was not influenced by the seasonal fluctuations of rainfall and temperature. The pattern of physicochemical variation, due to seasonal changes, is not generalized, but depends on geographic location, geology, vegetation, and particular condition of the river, to name a few. For instance, the increment of pH and EC on the ZR during the dry season is comparable to the one reported by Etesin et al., (2013), but the Ts and DO are incomparable because they reported diminishes of these parameters in the rainy season, whereas in this study the Ts and DO incremented.

3.3 Physicochemical parameters relationship

The best multiple regression models obtained in this study were considering pH and EC as response variables, in rainy and dry seasons respectively. Moreover, the multiple regression models had higher correlation coefficient using the Log_{10} data than using the raw data. The models were formulated as

$$\widehat{pH} = \beta_0 + \beta_1 logTs + \beta_2 logRsum + \beta_3 logDO + \beta_4 logORP + \beta_5 logEC + \beta_6 logTurb \quad \text{Eq. 2}$$

$$log\widehat{EC} = \gamma_0 + \gamma_1 logTs + \gamma_2 logRsum + \gamma_3 logDO + \gamma_4 logORP + \gamma_5 logpH + \gamma_6 logTurb \quad \text{Eq. 3}$$

where $\widehat{pH}$ and log$\widehat{EC}$ are the calculated pH and EC in dry and rainy season models, respectively. The β_i and γ_i coefficients values are in Table 2, which shows the multiple regression analysis. For the two models, the adjusted coefficients of determination (r^2_{adj}) were significant ($p<0.05$). The coefficient of determination (r^2) is adjusted because it may increase even when an added variable is not significant (Schuenemeyer and Drew, 2011). The ANOVA (Table 2a) for the dry season provides information on the goodness of fit of the model. A measure of model significance is given by the F-statistics. Since $p<0.05$, the model, Ts, and DO are significant, this means that the Rsum, ORP, EC, and Turb do not explain any statistically significant component of pH. The percentages of sum of squares (SS) partition ((SSvariable/SSmodel)*100) of model variability accounted for the explanatory variables are: Ts 37.58%, Rsum 8.79%, DO 50.45%, ORP 0.00%, EC 0.30%, and Turb 2.88%. The multiple regression model ANOVA in the rainy season (Table 2b) shows that the model, Ts, Rsum, DO, pH, and Turb are significant ($p<0.05$), and these parameters explain statistically the EC. The percentages accounted by the explanatory variables are Ts 52.31%, Rsum 6.08%, DO 17.46%, ORP 0.66%, pH 17.9%, and Turb 5.59%. In the dry season, the pH had two explanatory variables, and in the rainy season EC had five explanatory variables. The Ts and DO were explanatory variables that accounted with 87% and 69% of SS in dry and rainy season, respectively. In the dry season, the association among pH, DO and Ts is comparable with the fact that the DO influences on oxidation-reduction reactions which generate proton transference (pH) (Stumm y Morgan 1996, Manahan 2017), and the DO is influenced by temperature (Riđanović et al., 2010). In the rainy season, the association between parameters included Rsum and Turb. It was possibly because the rainfalls affect the DO of water body (Barceló-Quintal et al., 2011), and rainwater runoff impacts organic matter, silt, and finer sand particles (Issaka and Ashraf, 2017), transporting them to the river and affecting the turbidity.

Table 2. Coefficients and ANOVA of multiple regression

a) Dry season

r=0.8518	r^2=0.7256	r^2_{adj}=0.6159				
Terms	Coeff.	SS	df	MS	F-value	p-value
Intercept.	$\beta_0 =$ 4.8099					
Model		0.660	6	0.110	6.60	0.0014
LogTs	$\beta_1 =$ 2.3855	0.248	1	0.248	14.88	0.0015
LogRsum	$\beta_2 =$ 0.2461	0.058	1	0.058	3.48	0.0821
LogDO	$\beta_3 =$ -0.3494	0.333	1	0.333	19.98	0.0004
LogORP	$\beta_4 =$ 0.0184	0.000	1	0.000	0.00	0.9487
LogEC	$\beta_5 =$ 0.0019	0.002	1	0.002	0.12	0.7486
LogTurb	$\beta_6 =$ 0.2578	0.019	1	0.019	1.14	0.3056
Residual		0.250	15	0.017		
Total		0.910				

b) Rainy season

r=0.9335	r^2=0.8715	r^2_{adj}=0.8261				
Terms	Coeff.	SS	df	MS	F-value	p-value
Intercept.	$\gamma_0 =$ 0.6617					
Model		0.6219	6	0.1036	19.21	0.000001
LogTs	$\gamma_1 =$ 2.1990	0.3253	1	0.3253	60.31	0.000001
LogRsum	$\gamma_2 =$-0.0103	0.0378	1	0.0378	7.01	0.016943
LogDO	$\gamma_3 =$-0.5425	0.1086	1	0.1086	20.13	0.000324
LogORP	$\gamma_4 =$-0.0230	0.0041	1	0.0041	0.76	0.393186
pH	$\gamma_5 =$ 0.0009	0.1113	1	0.1113	20.63	0.000296
LogTurb	$\gamma_6 =$-0.0965	0.0348	1	0.0347	6.45	0.021370
Residual		0.0917	17	0.0054		
Total		0.7136	23			

Coeff.= model coefficients, SS=sum of squares, df= degrees of freedom, MS= mean square, Log= logarithm. Ts: stream temperature (^{0}C); Rsum: sum of rainfall registered in the four climatological stations; DO: dissolved oxygen (mg/L); ORP: oxidation-reduction potential (mV); pH: proton activity (no units); EC: electrical conductivity (µS/cm); Turb: turbidity (FNU).

The association between paired parameters are shown in Table 3. In the rainy season resulted 12 paired parameter correlated significantly ($p<0.05$) (Table 3a), whereas in the dry season resulted eight paired parameters (Table 3b). The paired parameters as Ts-pH, ORP-DO, DO-Turb did not change their sign in rain and dry correlation analysis, and Ts-DO, Ts-Turb, pH-EC changed it. Although, the parameter monitoring in this study was longitudinal, some significant correlations resulted comparable to others studies, for example, EC-Rsum (Petersen et al., 2017); Ts-pH, pH-EC, DO-Turb and Ts-Turb (Triphati et al., 2017); and Ts-DO (Posada et al., 2013), which used different method of data collection. Comparing multiple regression model and correlation matrix, in the rainy season showed similar associated parameters, but in the dry season the associated parameters between the two methods were dissimilar.

3.4 Water quality index

Using the CCME QWI method for annual, dry and rainy scales, it resulted that the ZR water quality, in its middle basin, was ranked in the "poorly" category, which stablishes that water quality is frequently threatened or impaired. These conditions often depart from natural or desirable levels (CCME 2001). The water quality index values were 36.22, 36.92, and 41.14 for annual, dry, and rainy scales, respectively (Figure 2). The water quality index of annual and dry season had a difference of 0.7 units, and the difference between dry and rainy seasons was of 4.2 units. Although, the index is based on a combination of factors scope (F_1), frequency (F_2), and amplitude (F_3) (CCME 2001), it was noted that the index difference of rainy and dry season obtained in this study was due to F_3, which represents the amount of failed test values that did not meet their objectives. ORP, EC, DO, and Turb were the parameters that unmet their objectives with greater intensity. The ZR water quality index obtained in this study is comparable to the one reported for the same river by Mena et al., (2017), and with other rivers reports that used the same method, for example, Awash River Ethiopia (Keraga et al., 2017), Karum River Iran (Ranjbar et al., 2016), and Surma River Bangladesh (Munna et al., 2013). The results indicated that the rain events affected the levels of the physicochemical parameters ($p<0.05$), but they did not improve the water quality river. This may be an indicator of the river loss sensitivity to seasonal variations due to its high levels of pollution.

Table 3. Correlation matrix of physicochemical parameters and rainfall. Correlation coefficients in bold are significant ($p<0.05$).

a) Dry season

	Ts	pH	ORP	EC	DO	Turb	Rsum
Ts	1						
pH	**0.53**	1					
ORP	0.41	-0.08	1				
EC	0.20	**-0.44**	0.17	1			
DO	**0.48**	-0.09	**0.43**	-0.05	1		
Turb	**0.46**	-0.01	**0.44**	0.14	**0.53**	1	
Rsum	0.32	0.18	0.25	0.13	**0.48**	-0.02	1

b) Rainy season

	Ts	pH	ORP	EC	DO	Turb	Rsum
Ts	1						
pH	**0.47**	1					
ORP	**-0.45**	-0.03	1				
EC	**0.71**	**0.54**	-0.36	1			
DO	**-0.65**	-0.34	**0.49**	**-0.75**	1		
Turb	**-0.47**	**-0.52**	0.33	**-0.70**	**0.50**	1	
Rsum	-0.11	-0.39	-0.06	**-0.48**	0.38	**0.52**	1

Ts: stream temperature (^{0}C); pH: proton activity (no units); ORP: oxidation-reduction potential (mV); EC: electrical conductivity (µS/cm); DO: dissolved oxygen (mg/L); Turb: turbidity (FNU); Rsum: sum of rainfall registered in the four climatological stations.

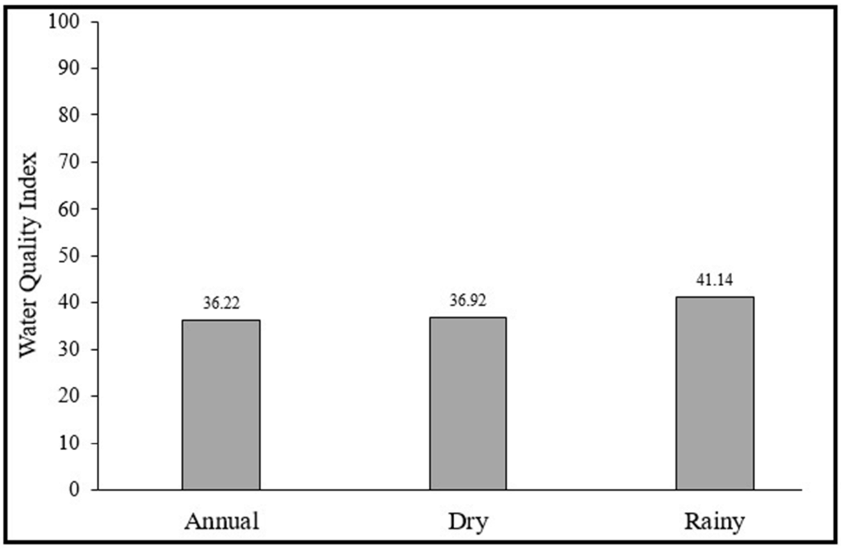

Figure 2. Water quality index of Zahuapan River for the monitoring site.

4. CONCLUSION

In the year of study, the annual rainfall was a rainy year compared to the 1981-2010 normal rainfalls. According to skewness coefficient, the low depth rain events prevailed. From May to September rained 75-80% of the total annual, this period was used to define clearly the rainy and dry seasons and then evaluated their influence on physicochemical parameters and water quality of Zahuapan River. Ts, EC, TDS showed less average than other Mexican rivers, but pH annual average was among the highest. In contrast, the DO had the lowest value and ORP was comparable to Mexican rivers. The rainy and dry season effect on Zahuapan River physicochemical parameters, excepting the pH, was demonstrated with *t* and Mann-Whitney tests ($p<0.05$). However, the physicochemical variation between the two seasons was dissimilar to that reported in the literature.

The multiple regression models described acceptably the relationship among river physicochemical parameters, air temperature, and rainfall. The pH and EC resulted as response variables for dry and rainy seasons, respectively. The coefficients of determination were greater with Log_{10} data than with raw data. In the dry season, pH had two explanatory variables (Ts and DO), and in the rainy season EC had five explanatory variables (Ts, DO, Rsum, pH, and Turb). Correlation matrix of association between paired parameters showed in the rainy season resulted in 12 paired parameter correlated significantly ($p<0.05$), whereas in the dry season only resulted eight. The signs of correlations coefficient of Ts-DO, Ts-Turb, pH-EC changed between the rainy season and dry seasons.

The water quality index calculated in this study ranked the Zahuapan River in the "poorly" category, that is the lowest of the scale. The rainfall affected positively the river water quality and increased slightly the index respect to dry season. However, given the severe pollution of the river, the rainfalls did not improve the water quality of the river substantially, which may be an indicative of its loss of sensitivity to respond to seasonal changes, then the Zahuapan River restoration might be more complex than it seems. The monitoring on the diurnal and nocturnal scale and considering others sites strengthen the knowledge of season influence on physicochemical parameters and water quality of Zahuapan River. Likewise, the inclusion of more parameters (for example nitrate, phosphate, sulfate, chemical oxygen demand, among others) helps to understand the relations between agriculture areas, population, and the river.

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