Water Quality Index of Lake Chapala in Mexico and its potential risk to public health

R. Vallejo-Rodríguez, E. León-Becerril, J.J. Díaz-Torres, L. Hernández-Mena, J. Del Real-Olvera, V. Flores-Payán, L.J. Martínez-Mendoza A. López-López*

Department of Environmental Technology, Centro de Investigación y Asistencia en Tecnología y Diseño del Estado de Jalisco, (CIATEJ); Av. Normalistas 800, Colinas de la Normal, 44270, Guadalajara, México.

Corresponding author: allopez@ciatej.mx; alopez103@yahoo.com

Abstract

The aim of this work was to evaluate the Water Quality Index according to the National Sanitation Foundation (WQI-NSF) and the Mexican guideline NOM-127-SSA1-1994 of Lake Chapala. The importance in determining the WQI lies on the possible impacts and implications in public health for the use and consumption of Lake Chapala water, considering that it is the main source of drinking water in the Metropolitan Zone of Guadalajara, Jalisco. WQI of Lake Chapala indicates an average of 55 points, implying a water of medium quality. Therefore, an effective purification process is recommended prior to the distribution and consumption of water; it is also necessary to avoid discharges of municipal wastewater in this important natural source of supply water; from a preventive point of view to reduce the potential risk to public health.

Introduction

Pollution of water supply sources in Mexico represents a potential public health risk, when these water supplies (surface water and groundwater) are the main source of drinking water. Two main causes of the environmental pollution of water surface bodies in Mexico are the low operation efficiencies of wastewater treatment plants and the wastewater discharges from industries and municipalities without treatment. In order to prevent a potential risk for public health, it is important to assess the water quality.

The surface water of this research is Lake Chapala, which is the largest body of water in Mexico. Lake Chapala presents high pollution levels due to many factors, Lerma River that carries many and different type of contaminants discharges in Lake Chapala. Also, about 300,000 people live in communities and with economic activities as fishery one, around Lake Chapala, which also discharged wastewater without treatment (CEAS 2017); these economic activities have increasing pressure on the whole ecosystem (Trasande et al. 2010). Today, it is necessary and important to assess the health risk generated by industrial and domestic sewage discharges without treatment to Lake Chapala.

Background

Quality of surface water can be evaluated through various methods such as the Water Quality Index according to the National Sanitation Foundation (WQI-NSF), which provides a standardized index for determining the quality of different types of water bodies (Brown et al., 1970; Mitchell and Stapp, 2000). WQI considers nine parameters: dissolved oxygen (OD), fecal coliforms, pH, biochemical oxygen demand (BOD, 5 days), temperature change, total phosphate, nitrate, turbidity and total solids. WQI is ranked in the following categories as 90-100, excellent; 70-90, good; 50-70, medium; 25-50, bad; and 0-25: very bad (Brown et al., 1970).

Water quality level is graphically plotted from zero (worst) to 100 (best) from raw data (e.g. pH values 2-12). The drawn curves are averaged to obtain a weighting curve for each parameter. The results of the nine parameters are compared with the curves and a numerical value (Q) is obtained. In the practice, after obtaining a Q value, it is multiplied by a "weighted factor" based on the importance of the water quality test. The resulting nine values are then added together to get a general WQI. If the nine parameters are not determined, it is possible to estimate an overall WQI by adding the results and adjusting with the number of tests.

The Canadian Water Quality Index (Canadian Council of Ministers of the Environment Water Quality Index, CCME WQI) is another index being used by many countries all over the world and has also been endorsed by the United Nations Environmental Program (UNEP) in 2007 as a model for Global Drinking Water Quality Index (GDWQI) (Lumb et al. 2011). Bascaron et al. (1979) contributed to the WQI considering the parameters after normalization, which has not been used in the NSF (Lumb et al. 2011), and a weight assigned to parameters (an indicator of its relative importance for aquatic life/human water use). On the other hand, the British Columbia water quality index was developed by the Canadian Ministry of Environment in 1995 as an extended index to evaluate water quality. This index is similar to CCME WQI whose water quality parameters are measured and their violation is determined by comparison with a predefined limit (Poonam et al. 2013). The most commonly WQI involved parameters as dissolved oxygen, pH, turbidity, total dissolved solids, nitrates, phosphates, and metals among others. All WQI have one or other limitation and the search for a perfect one is still a challenge (Lumb et al. 2011, Poonam et al. 2013, Zandbergen and Hall 1998). Although, there are a several WQI models, the WQI-NSF is very practical to use and there are software on line that permit to obtain an estimation of WQI values (WRC 2016).

WQI-NSF has been used to determine the quality of groundwater in Maharashtra (India) by Rajankar et al. (2006) during the post monsoon, summer and winter. Dos Santos et al. (2008) evaluated the WQI of the Macuco River with 60 to 82 points and Queixada River 57 to 90 points in Sao Paulo, Brazil. Furthermore, WQI-NSF was used to evaluate the stream water quality in Sapanca Lake Basin (Turkey), obtaining values from 50 to 75 points in different sites of the Lake (Akkoyunlu et al. 2012). Finally, the WQI-NSF was applied to evaluate the water quality in a dam of Aydughmush River in Iran, obtaining a water quality suitable for various purposes (Shokuhi et al. 2012).

Lake Chapala, located in Jalisco, is the largest body of water in Mexico and is the main source of drinking water providing the 62% of water to be distributed to the Metropolitan Zone of Guadalajara (MZG), the third economical city in the country. Lake Chapala is a reservoir that receives discharges from Lerma River that collects the domestic and industrial wastewaters along its route of 708 km from Toluca Valley in the southwest of Mexico City; wastewater without treatment from the villages settled around Lake Chapala; runoff water from agricultural field and discharges from wastewater treatment plants. In consequence, quality and availability of water in Lake Chapala have been significantly affected (Brooks et al., 2003). Thus, the aim of this work is to evaluate the Water Quality Index in accordance with the National Sanitation Foundation (WQI-NSF) and the Mexican guideline NOM-127-SSA1-1994 of Lake Chapala, and the possible impacts and implications in public health for the use and consumption of water.

Methodology

Study site

Lake Chapala is located 1500 m above the sea level in western Mexico (CONAGUA 2015). It has a maximum storage, at the quota 97.80 (equivalent to 1,423.80 above sea level) of 7.897 million cubic meters (Mm^3). At the same height, its dimensions are 79 km from east to west and 28 km from north to south (CEAS 2017). According to data from the climatological stations of Mexico National Water Commission (CONAGUA) with records from 1979 to 2006, the climate is temperate subhumid, with 17.43 ºC average annual temperature, 701.82 mm of precipitation, rainfall regime from June to October and 1448.48 mm of potential evaporation (CONAGUA 2015).

Selection of sampling sites

For the goal of this study, 17 sampling sites in Lake Chapala were selected by using a Georeferenced Information System (GIS); the sites are expected to present a higher level of contamination. The spatial and temporal sampling plan was done considering the water extraction sites of the municipal Drinking Water Treatment Plant (DWTP) and previous studies in sampling techniques (Brooks et al., 2003, Félix-Cañedo et al., 2013). Sampling sites were chosen based on municipalities settled on Lake Chapala with anthropogenic activities and fishing activities or discharges of municipal wastewater. A reference distance to Lake Chapala was set for sampling as level 91 (Batimetry 1981), currently declared by the State Water Commission of Jalisco (CEAS-Jalisco 2017). The distance was approximately 400 to 600 m to the shore of Lake. CEAS-Jalisco recorded a bathymetry of 94.27 m and 94.96 m on May and September, respectively, in 2016. Therefore, the deeper water level was 4 to 5 m. Therefore, samples were collected between 1 and 1.5 m to analyze the physicochemical parameters.

Three additional points were included in order to establish a comparison of this study with the water quality reported by Sistema Intermunicipal de los Servicios de Agua Potable y Alcantarillado (SIAPA) Drinking Water Treatment Plants (DWTP). Direct supply sources to the site 19-DWTP (Table 1) are the sites 0-AQZG and 17-SARB (on the shores of Lake Chapala); and for the site 20-DWTP the direct supply source is the site 0-AQZG. Knowing the water quality of the effluents of 19-DWTP and 20-DWTP, the efficiencies of the DWTP can be estimated, depending on the quality of their supply sources. Table 1 shows the sampling sites, their location and identification keyword.

Water sampling campaign

Two sampling campaigns were established, at dry season, from April to early June, and at rainy season, from July to August, according to the climatological database of CONAGUA. Sampling water was performed in the same day, following two different routes, in order to obtain representative water samples, avoiding bias due to climatological changes. Figure 1 illustrates the sampling sites of the two routes.

Water sampling was performed by triplicate at all sites considering a simple sample of 1 liter to determine physicochemical parameters and metals. In the sites 12-LERR and 18-SARD, composite samples of 8 h (1 L x h for 8 hours) were taken to make a final volume of 8 L, thus representing one day of sampling (modified procedure of NMX-AA-003-1980). Samples were collected in amber glass and stored at 4 °C before processing the next day.

Table 1 Sampling sites of Lake Chapala, location and keyword

Site number	Location	Label
0	Aqueduct to transport water to DWTP of MZG	0-AQZG
1	Influent of WWTP of Chapala City	1-WWTP
2	Effluent of WWTP of Chapala City	2-WWTP
3	100 meter inside of Lake Chapala to WWTP	3-LAKE
4	Ajijic	4-AJIJ
5	Jocotepec	5-JOCO
6	San Pedro Tesistán	6-SANP
7	Middle point, near to San Luis Soyatlán	7-WEST
8	Tuxcueca	8-TUXC
9	Tizapán el Alto	9-TIZA
10	Cojumatlan	10-COJU
11	Middle point, near to Las Palmas	11-MPC2
12	Three km before to Rio Lerma discharge	12-LERR
13	Delta of Lerma River	13-LERD
14	Jamay	14-AMA
15	Mezcala	15-MEZC
16	Middle point, near to San Nicolas Ibarra	16-MPC1
17	Beginning of Santiago River	17-SARB
18	Santiago River,1500 m dowstream	18-SARD
19	Effluent of DWTP-1	19-DWTP
20	Effluent of DWTP-2	20-DWTP

Sites 19DWTP and 20DWTP are no shown in Figure 1.

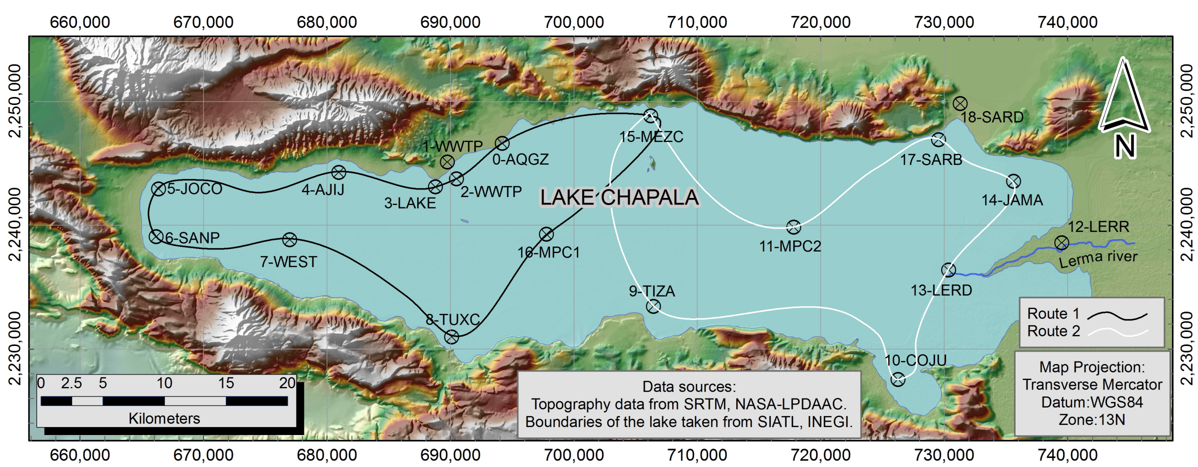


Figure 1. Sampling sites of the two routes on the Lake Chapala.

Physicochemical analyzes

Physicochemical parameters including pH, temperature, Oxidation Reduction Potential (ORP), Dissolved Oxygen (DO), Conductivity, Resistivity, Total Dissolved Solids (TDS), Salinity and Atmospheric Pressure were determined on site (field parameters) by multiparameter probes (HANNA), model HI 98184. Parameters as: fecal coliforms, biochemical oxygen demand (BOD), total phosphate (Total PO_4), nitrate, and total solids (TS) were determined on laboratory using the Standard Methods (Eaton 2005). Metals as Aluminum (Al), Barium (Ba), Cadmium (Cd), Copper (Cu), Chromium (Cr), Iron (Fe), Manganese (Mn), Mercury (Hg), Lead (Pb), Sodium (Na) and Zinc (Zn) were determined using the Method 6010B (USEPA 1996).

Water Quality Index

The WQI was calculated using the online software of the United States Water Research Center (WRC) (WRC 2016), this program is established according to the parameters specified by the NSF. The WQI involved parameters as dissolved oxygen, pH, delta t, biochemical oxygen demand, phosphates, nitrates, fecal coliforms, turbidity and total dissolved solids. The user puts the values of parameters on line and the software gives the value of WQI.

Results

Field parameters

Field parameters were grouped following the two sampling campaigns, as dry and rainy seasons. Average temperature in Lake Chapala was around 25 °C and 23 °C for dry and rainy seasons, respectively; the sites exceeding these values are 1-WWTP, which reached 27 and 28 °C, during rainy season and dry season, respectively, and 12-LERR with 25 °C (Fig. 2a and 3a). pH values, regardless of season and site, are over 7.5 in all sites of Lake (Fig. 2a and 3a). pH and temperatures of Lake Chapala follow the same behavior in both seasons, with a fairly increment in dry season (Fig. 2a and 3a). If temperature increased then the dissolved oxygen diminished, the sites 1-WWTP, 12-LERR and 18-SARD showed this behavior due to the wastewater discharges, in which temperature and anthropogenic activities may be the explanation for the reduction of DO.

Dissolved oxygen concentration throughout the Lake Chapala exceeded 5 mg/L, except for 1-WWTP and 18-SARD were nearly zero mg/L, in the rainy and dry season (Fig. 2b and 3b); also 12-LERR site presents a DO concentration lower than 2.00 mg/L, for both dry and rainy seasons (Fig. 2b and 3b). During the sampling in rainy season, the sites 9-TIZA, 10-COJU and 11-MPC2 near the discharge of the Lerma River had a lower value than the average one of 5.6 mg/L and 4.7 mg/L obtained in dry and rainy seasons, respectively. In the case of the site 11-MPC2, which is just in the center of the eastern part of the Lake, DO value might indicate a high bacterial activity. A lower concentration than 4 mg/L at sampling sites could compromise aquatic life such as fish survival.

Oxidation-reduction potential (ORP) indicates the ability of a matrix (generally aqueous) to be reduced or oxidized. The values indicate that all sites have a ORP+, which means their capacity to be reduced, ranging around 23 mV for 1-WWTP to 146 mV for the center of the Lake of the west side (7-WEST), for the dry season. For the rainy season, ORP goes from 18 mV in the site 1-WWTP to 134 mV for the site 20-DWTP. The presence of oxygen, iron and sulfur, as well as some organic compounds has influence in the determination of ORP. For example, the presence of dissolved oxygen increases the ORP, so it can reach 700 mV. The presence of hydrogen sulfide is usually associated with a strong decrease in ORP (below -100 mV) and evidences bad water conditions. Surface water and groundwater containing dissolved oxygen are usually characterized by ORP values between 100 mV and 500 mV (Chapman, 1996).

It can be observed that the parameters total dissolved solids (TDS), conductivity and salinity follow the same patron (Figures 2b and 3b). TDS are directly related to conductivity and represent 80% of it. In this study, TDS and conductivity show the same behavior and have a direct proportional relationship. TDS concentration ranged from 430 mg/L for the site 13-LERD to 640 mg/L (ppm) for the site 2-WWTP in the dry season (Fig. 2b). For the rainy season, TDS ranged from 160 to 880 mg/L (ppm) for the sites 18-SARD and 8-TIZA, respectively (Fig. 3b). Being a rainy season, there is no apparent explanation for having found a high value in 8-TIZA. Conductivity ranges from 800 to 1300 microS/cm in the dry season campaign, where the highest value corresponds to the 2-WWTP (Fig. 2b). Conductivity values for the rainy season show data with great variability, where the highest value corresponds to the site 9-TIZA. However, it can be observed that this parameter is more uniform in the western part and the eastern west side of the Lake (Fig. 3b). The lowest value corresponds to the Lerma River (12-LERR), whose value is justified by the process of dilution during the rainy season.

Resistivity during the dry season ranged from 800 to 1100 ohm/cm. In the rainy season, data are constant for the western but not for the eastern part of the Lake. Metals have the lowest resistivity, indicating that the presence of non-metallic materials such as quartz, silicates or even human skin residues can increase resistivity. The highest values were found in sites 12-LERR, 14-JAMA, 16-MPC1 and 18-SARD. High resistivity in site 12-LERR may be due to natural processes such as landslides and even anthropogenic activities. Salinity ranged from 0.4 to 0.6 units of salinity (PSU) in the dry season, except in the site 1-WWTP (see Fig. 2b and 3b). However, there are increments and decrements in this parameter during the rainy season for the eastern part of the Lake. The highest values in salinity were obtained in sites located on the shore of Lake Chapala (9-TIZA, 10-COJU, 13-LERD and 15-MEZC). The probable reasons can be the anthropogenic activities that generate a great amount of salts or also the drags of sands through the Lerma River, which are deposited in the Lake.

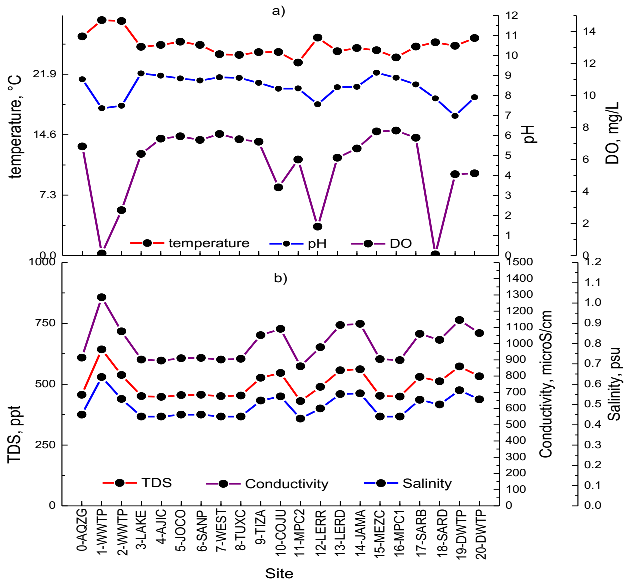


Fig. 2 a, b. Field parameters in dry season campaign.

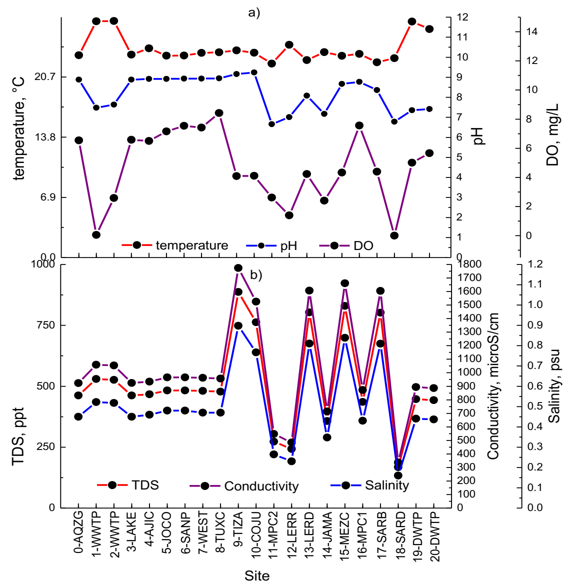


Fig. 3 a, b. Fields parameters in rainy season campaign.

Metals

During the two campaigns, concentrations of all metals are lower than the limit established by NOM-127-SSA1-1994, including heavy metals as Cr, Hg or Pb. The highest concentrations of metals were presented in the sites 1-WWTP, 4-AJIJ, 10-COJU, 14-JAMAY and 15-MEZCA but under the limits established by NOM-127-SSA1-1994.

Water Quality Index

Figures 4a, b, c, d, e, f, g, h and i show the results of WQI parameters in the rainy season. An important parameter in the general state for any lake is the presence of dissolved oxygen; the most sites of Lake Chapala have a concentration nearly to 7 mg/L (Fig. 4a).

pH of Lake Chapala ranged from 7.0 to 8.5 (Fig. 4b); sites 3-LAKE and 15-MEZC have a pH value greater than 9.0, indicating the likely presence of carbonates, generated either by anthropogenic activities or mountain runoffs during the rainy season. These sites are close to slopes of mountains. The lowest pH values were found for the sites 1-WWTP, 2-WWTP, 12-LERR and 1-DWTP with 7.4, 7.5, 7.6 and 7.0, respectively.

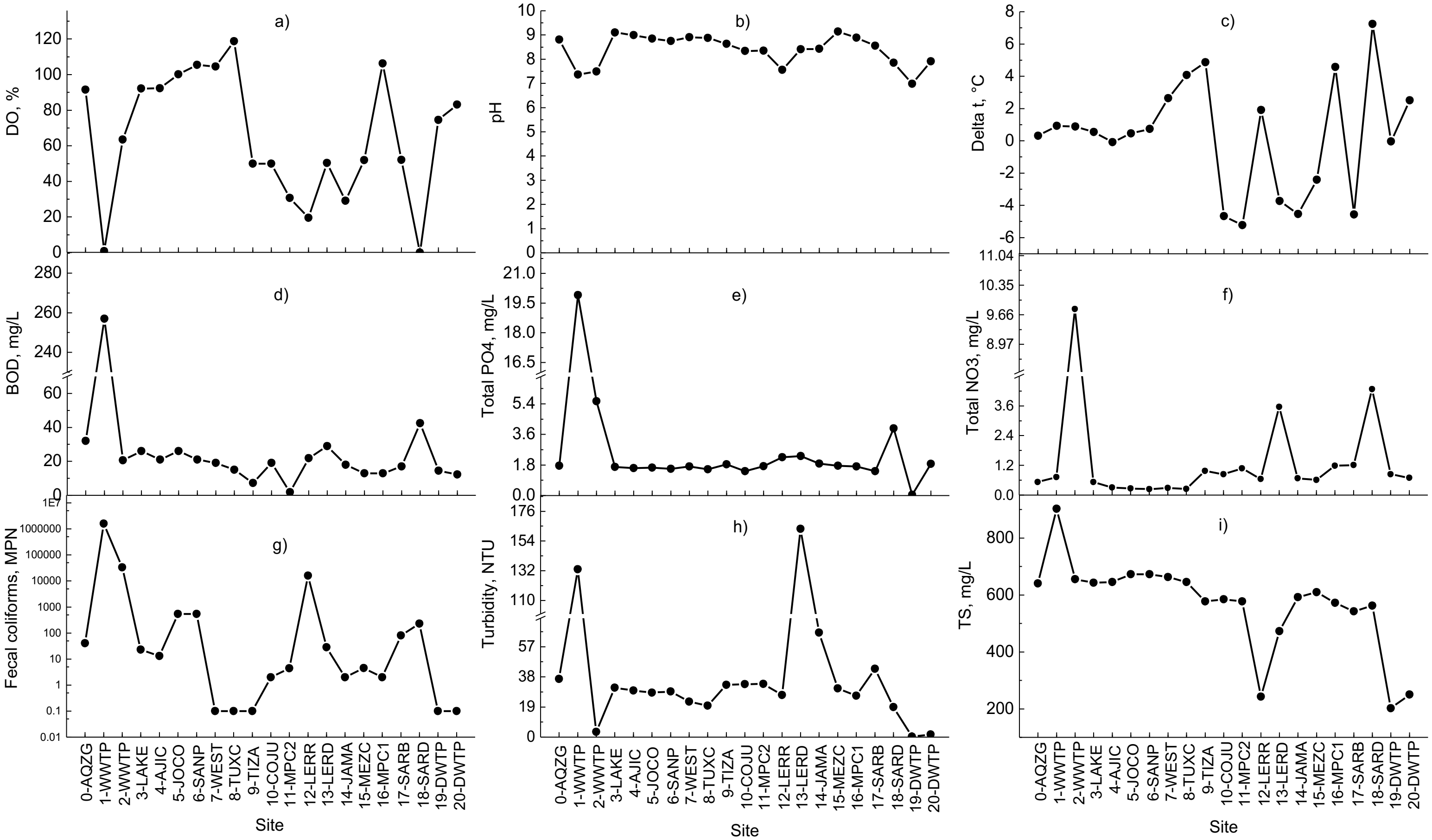
Delta-t is the temperature difference from water temperature (obtained in the sampling campaign) from the atmospheric temperature, delta-T ranged from -6 to + 6 °C, hence Lake Chapala has a high thermal damping capacity (Fig. 4c). Negative values of delta-t were obtained when atmospheric temperatures (taken at different time during the day) were higher than the water ones.

Figure 4d shows the behavior of BOD concentrations, the highest values and BOD were presented for the site 1-WWTP, and the site 18-SARD. It can be observed a significant increment in BOD concentrations in the sites 17-SARB and 18-SARD (1.5 km downstream of the start of Santiago River). In this region, wastewater is discharged directly to the Santiago River, also, there are fishery activities and the wastes are thrown to the stream, as a consequence dissolved oxygen is not present. For the most of sampling sites it can be seen that the BOD concentration ranged around 30 mg/L, which indicates that the Lake water can be useful for filling artificial lakes, irrigation of gardens and ridges or other activities avoiding a direct contact human with water (NOM-003-ECOL-1997).

Levels of nitrate concentration in Lake Chapala are less than 1.5 mg/L (Fig. 4f). In site 1-WWTP, the nitrate concentration exceeds this value due to the presence of nitrifying bacteria from activated sludge processes; also, sites 13-LERD (3.56 mg/L) and 18-SARD (4.28 mg/L) had high levels of nitrates.

The sites with the highest level of fecal coliforms were 1-WWTP, 2-WWTP, 5-JOCOTE, 6-SANP and 12-LERR (Fig. 4g). It can be observed that although the effluent of WWTP of Chapala City (2-WWTP) is subject to disinfection, it is not enough. Sites 5-JOCO and 6-SANP present 540 MPN of fecal coliforms, which indicates the existence of untreated wastewater discharges from municipalities or the low efficiencies of wastewater treatment plants. The site 12-LERR had a high level of coliforms indicating a large number of untreated wastewater discharges along the Lerma upstream. Sites 19-DWTP and 20-DWTP show absence of fecal coliforms, meaning there are an efficient disinfection of their effluents.

Finally, total solids and turbidity are two parameters directly related (Fig. 4i). The highest turbidity value corresponds to the site 13-LERD (163 UTN, nephelometric turbidity units) with a TS concentration of 472 mg/L. Those values contrast with the turbidity in the site 2-WWTP (133 UTN) with a nearly double concentration of TS (900 mg/L). Turbidity of Lake Chapala generally ranged from 20 to 30 UTN and their TS between 500 and 700 mg/L.



Figures 4a, b, c, d, e, f, g, h, i. Results of WQI parameters in the rainy season for Lake Chapala.

WQI-NSF for the sampling campaigns is shown in Table 2. Approximately 66% of the sampling sites have a medium level of WQI, 23% for good and 10% for bad. The lowest WQI was found for the site 1-WWTP (32 points), followed by the 18-SARD (41 points) and 12-LERR (45 points), indicating a bad water quality, in this region water is currently used for crop irrigation that would be a potential risk for population that consumes the products. The only site that barely achieves the medium level of WQI was site 15-MEZC, the municipality in this site has a WWTP in service and operating with low degree of efficiency. On the other hand, sites 19-DWTP and 20-DWTP have 80 and 73 points, respectively, which may indicate that the DWTP operate correctly, considering they treat water whose supply source come from Lake Chapala.

Table 2. WQI-NSF for the sampling campaigns of Lake Chapala

Keyword	WQI	Diagnostic (level)
0-AQZG	59.00	Medium
1-WWTP	32.00	Bad
2-WWTP	47.00	Bad
3-LAKE	59.00	Medium
4-AJIJ	62.00	Medium
5-JOCO	56.00	Medium
6-SANP	56.00	Medium
7-WEST	67.00	Medium
8-TUXC	66.00	Medium
9-TIZA	60.00	Medium
10-COJU	57.00	Medium
11-MPC2	59.00	Medium
12-LERR	45.00	Bad
13-LERD	46.00	Bad
14-JAMA	51.00	Medium
15-MEZC	55.00	Medium
16-MPC1	63.00	Medium
17-SARB	53.00	Medium
18-SARD	41.00	Bad
19-DWTP	80.00	Good
20-DWTP	73.00	Good

Conclusions

The application of the WQI-NSF of Lake Chapala was performed in this study. A WQI average of 56 points in the scale was found and this value is classified as medium quality water. This water is useful for various purposes including the recreations or garden irrigations ones with previous treatment. It is not recommendable the direct drinking use of the water for the sites 12-LERR, 13-LERD, 14-JAMA and 18-SARD under the principle of prevention. WQI-NSF lets to define the use and the final disposal of water of Lake Chapala. This study could contribute for a preventive plan to reduce the potential risk to public health that should include a more strict regulation of municipal and industrial wastewaters, and an adequate drinking water treatment to assure the water quality supplied to the population. The future researches should be oriented to the detection of emerging contaminants.

Acknowledgements

The authors wish to express their gratitude to the financial support from the National Council of Science and Technology (CONACYT) for supported this research through the grant project 248408.

References

Akkoyunlu, A. & Akiner, M. E. (2012) Pollution evaluation in streams using water quality indices: A case study from Turkey's Sapanca Lake Basin. Ecological Indicators, 18, 501-511. Available from: http://dx.doi.org/10.1016/j.ecolind.2011.12.018 [Accessed 29th December 2016]

Bascaron, M. (1979) Establishment of a methodology for the determination of water quality. Bol Inf Medio Ambient, 9, 30–51. CIMA, MOPU, Madrid.

Brooks, B., Hooker, R., Annavarapu, S., Willett, K., Dávalos-Lind, L., Lind, O. (2003) Municipal effluent estrogenicity in the Guadalajara and Lake Chapala region of Mexico. Proceedings in: 24th Annual Meeting in North America, The Society of Environmental Toxicology and Chemistry, 9-13 November 2003, Austin, TX. Available from: http://www.baylor.edu/Research/files/brookslaysummary03.pdf [Accessed 14th July 2016].

Brown, R. M., McClelland, N. I., Deininger, R. A. & Tozer, R. G. (1970) A Water Quality Index – Do we Dare? Water Sewage Works, October, 339–343.

CEAS (2017) Lago de Chapala: Cota. Available from: http://info.ceajalisco.gob.mx/chapala.html [Accessed 20th January 2017].

Chapman, D. (1996) Water Quality Assessments: A guide to the use of biota, sediments and water in environmental monitoring, 2nd. ed. UNESCO-WHO-UNEP, F & FN Spon, London, 609 p. Available from: http://www.who.int/water_sanitation_health/resourcesquality/watqualassess.pdf [Accessed 10th January 2017].

CONAGUA (2015) Actualización de la disponibilidad media anual de agua en el acuífero Chapala (1428). Estado de Jalisco. Diario Oficial de la Federación, México D.F. Available from: http://www.gob.mx/cms/uploads/attachment/file/103755/DR_1428.pdf [Accessed 15th December 2017].

CONAGUA (2016) Información Climatológica: Normales Climatológicas por Estado. Available from: http://smn.cna.gob.mx/index.php?option=com_content&view=article&id=42&Itemid=75 [Accessed 20th January 2017].

Dos Santos Simoes, F., Moreira, A. B., Bisinoti, M. C., Gimenez, S. M. N., & Yabe, M. J. S. (2008) Water quality index as a simple indicator of aquaculture effects on aquatic bodies. Ecological indicators, 8(5), 476-484. Available from: http://dx.doi.org/10.1016/j.ecolind.2007.05.002 [Accessed 7th January 2017].

Eaton, A. D. (2005) 4500-O3 B. Indigo colorimetric method. In: Standard methods for the examination of water and wastewater, 21st ed. APHA, AWWA, WEF, Washington, D.C.

Félix–Cañedo, T. E., Durán–Álvarez, J. C., & Jiménez–Cisneros, B. (2013) The occurrence and distribution of a group of organic micropollutants in Mexico City's water sources. Science of the Total Environment, 454, 109-118. Available from: http://dx.doi.org/10.1016/j.scitotenv.2013.02.088 [Accessed 11th January 2017].

Lumb, A., Sharma, T. C., & Bibeault, J. F. (2011). A review of genesis and evolution of water quality index (WQI) and some future directions. Water Quality, Exposure and Health, 3(1), 11-24. Available from: doi:10.1007/s12403-011-0040-0 [Accessed 12th January 2017].

Mitchell, M. K. & Stapp, W. B. (2000) Field Manual for Water Quality Monitoring: An Environmental Education Program for Schools. 12th edition. Kendall/Hunt Publishing Company. 266 pp.

NMX-AA-003-1980. Residual waters. Sampling. Diario Oficial de la Federación: 25th March 1980.

NOM-003-ECOL-1997, Que establece los límites máximos permisibles de contaminantes para las aguas residuales tratadas que se reusen en servicios al público. Diario Oficial de la Federación: 22th April 1998.

NOM-127-SSA1-1994. Salud ambiental, agua para uso y consumo humano-Límites permisibles de calidad y tratamientos a que debe someterse el agua para su potabilización. Diario Oficial de la Federación: 30th November 1995.

Poonam, T., Tanushree, B., & Sukalyan, C. (2013) Water quality indices—important tools for water quality assessment: a review. International Journal of Advances in Chemistry, 1(1), 15-28. Available from: https://www.researchgate.net/profile/Tanushree_Bhattacharya2/publication/262730848_WATER_QUALITY_INDICES-iMPORTANT_TOOLS_FOR_WATER_QUALITY_ASSESSMENT_A_REVIEW/links/00463538b5584c053a000000.pdf [Accessed 21th December 2016].

Rajankar, P. N., Gulhane, S. R., Tambekar, D. H., Ramteke, D. S., & Wate, S. R. (2009) Water quality assessment of groundwater resources in Nagpur Region (India) based on WQI. Journal of Chemistry, 6(3), 905-908. Available from: http://dx.doi.org/10.1155/2009/971242 [Accessed 20th November 2016].

Shokuhi, R., Hosinzadeh, E., Roshanaei, G., Alipour, M., & Hoseinzadeh, S. (2012) Evaluation of Aydughmush dam reservoir water quality by National Sanitation Foundation Water Quality Index (NSF-WQI) and water quality parameter changes. Iranian Journal of Health and Environment, 4(4), 439-450. Available from: http://ijhe.tums.ac.ir/article-1-50-en.html [Accessed 14th December 2016].

Trasande, L., Cortes, J.E., Landrigan, P.J., Abercrombie, M.I., Bopp, R.F., Cifuentes, E. (2010) Methylmercury exposure in a subsistence fishing community in Lake Chapala, Mexico: an ecological approach. Environ. Heal. 9(1), 1-10. DOI: 10.1186/1476-069X-9-1. Available from: http://www.ehjournal.net/content/9/1/1 [Accessed 17th December 2016].

USEPA (1996) SW-846 reference methodology: Method 6010B. Inductively Coupled Plasma-Atomic Emission Spectrometry. Available from: https://www.epa.gov/sites/production/files/documents/6010b.pdf [Accessed 11th January 2017].

WRC (2016) monitoring the Quality of Surface Waters: Calculating NSF Water Quality Index (WQI), Water Research Center. Access at: http://www.water-research.net/index.php/water-treatment/water-monitoring/monitoring-the-quality-of-surfacewaters.

Zandbergen, P. A., & Hall, K. J. (1998) Analysis of the British Columbia water quality index for watershed managers: A case study of two small watersheds. Water Qual. Res. J. Canada, *33*(4), 519-549. Available at: http://www.paulzandbergen.com/PUBLICATIONS_files/Zandbergen_WQRJC_1998_1.pdf. [Accessed 15th January 2017].