Water quality of the Atoyac river in the Tentzo microbasin Puebla, México

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Abstract

The water quality of the River Atoyac in the Tentzo microbasin in Puebla, Mexico. Was evaluated five sampling stations were selected on the Atoyac River according to the local inhabitants' use of the water: human consumption; agricultural use; and recreation. The physico-chemical parameters (pH, dissolved oxygen, temperature, water flow, electrical conductivity, DBO_5, nitrates, phosphates and ammonium) and microbiological matter (fecal coliforms) were determined over the course of a year, in accordance with the Official Mexican Standards (NOM). The results show that the average values for these parameters across almost all of these months exceeded the Maximum Permissible Limits (MPL) according to the current Mexican legislation (NOM) and indicate a high level of risk for the public health of the local populations.

***Escherichia coli*, water quality of the Atoyac River, Sierra del Tentzo, Atoyatempan and Molcaxac in Puebla**

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Introduction

At a global level, developing countries treat at least 10% of their water, a situation very similar to that in Mexico, where the percentages are closer to 20%.

The majority of the liquid is discharged into rivers, lakes, or the sea without any prior treatment, causing their contamination, and the consequent reduction of available water (SEMARNAT, 2002). Mexico has severe problems with water quality and its water resources are oriented around using the receiving water bodies for pollutant loads. At least 12 million people in Mexico lack drinking water and 23 million do not have a sewage system in their homes, while three out of ten inhabitants of the rural sector do not have access to piped drinking water (FUSDA, 2008).

Hydrological Region (RH-18) of the River Balsas is one of the most important Hydrological Regions in the country, occupying the Central and Southwestern region of the State of Puebla. The River Atoyac belongs to this region and comprises the section of river flowing towards The Southeast and passes through the municipalities of Atoyatempan and Molcaxac in the Sierra del Tentzo State Reserve. (CONABIO, 2011).

From the bibliographical review conducted on the contamination of the River Atoyac basin, there are very limited reports, which have not been updated. With regard to the contamination of the river in the Tentzo microbasin, only the microbiological study by (Rodríguez et al, 2013) was found. It was concluded that Atoyatempan and Molcaxac are at risk from the use of water from the river, with these populations at risk of contracting diseases produced by the bacteria detected: Escherichia coli; Pseudomonas sp .; K. pneumoniae K. oxytoca; And, Morganella sp.

The River Atoyac represents the economic, social and cultural basis for the development of the municipalities of Atoyatempan and Molcaxac.

This study sought to evaluate the quality of the water and the risk to public health of the populations of Atoyatempan and Molcaxac as derived from the various uses of the river water. It is hoped that this information will lead to improved planning for the use of the water resources found in the microbasin. To date, no physical-chemical studies on the water quality of the River Atoyac have been reported in the region.

Methodology

The research was conducted in the period 2012-2014. Five sampling sites were selected in the microbasin according to the water use in each of the municipalities (Figure 1, Table 1). Sixty samples were undertaken in triplicate (Mitchell, *et al*. 1993). This research used the NOM (Table 2).

Transparency was measured *in situ* with a Secchi disk, while the current velocity (m/s), the pH, the concentration of dissolved oxygen (mg O_2 L^{-1}), the temperature (°C), and the electrical conductivity (µS/cm) were taken using the Quanta® Hidrolab probe.

The conservation of the samples was undertaken according to NMX-AA-003-1980. The parameters analyzed in the laboratory were hardness (mg L^{-1} $CaCO_3$), chlorides (mg L^{-1}), and carbon dioxide (mg L^{-1}), with the measurements undertaken using indicators from Hanna Instruments. Sulfates (mg L^{-1}) were measured using the Spectronic 20d spectrophotometer, while the nitrates (mg L^{-1}) were measured with the Hanna Instruments.

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The level of ammonium (mg L^{-1}) was taken with the Hach spectrophotometer and the biochemical oxygen demand (DBO_5 mgL^{-1}) was taken using the BOD Trak™ II-Respirometric BOD Apparatus. Each parameter was measured three times, from which the average value was obtained.

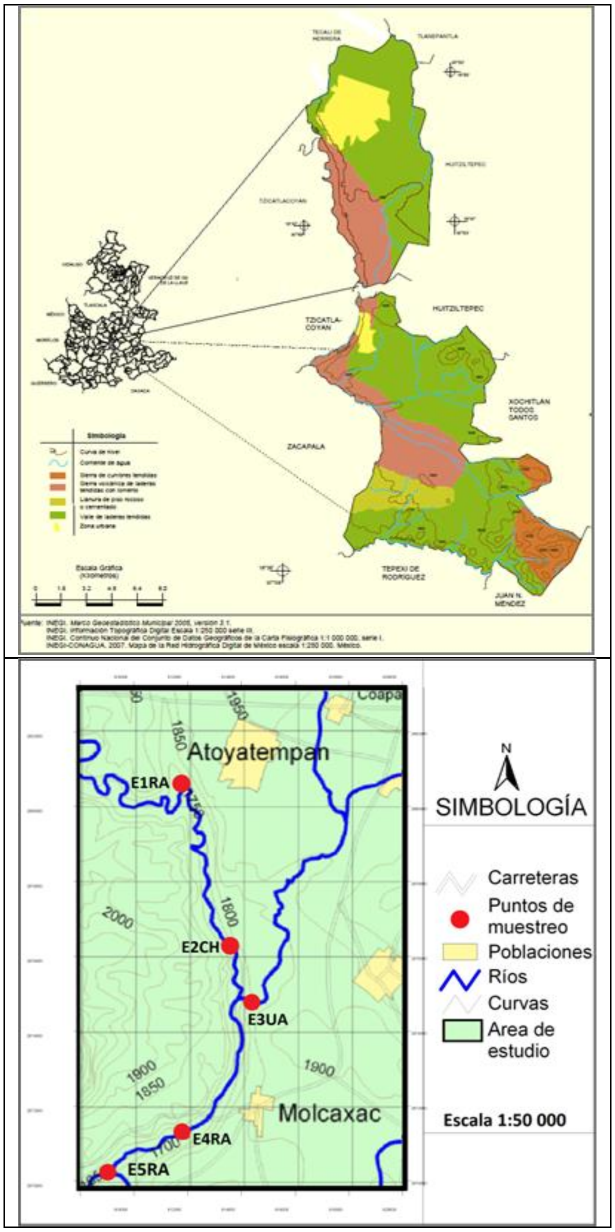

Figure 1 Geographical location of the Municipalities of Atoyatempan and Molcaxac in the State of Puebla and collection sites (INEGI, 2001, 2010)

The Most Probable Number (MPN) and the confidence limit for the bacteria of 95% were determined using the multiple tube technique with three dilutions and three replicas, in accordance with NMX-AA-42-1987, for total coliforms, fecal coliforms (thermo-tolerant), and presumptive *Escherichia coli*.

Sta	Water Use	Coordinates		Observations
		N	W	
E1 ER	Atoyatempan River's beginning	18°48'45.14"	97°55'39.25"	River's shore with tropical deciduous forest vegetation
E2 AP	Water used for human consumption in Atoyatempan	18°46'05.85"	97°55'01.23"	Water coming from springs nearby the Atoyac River, then taken to cisterns
E3 RA	Atoyatempan water used for farming irrigation	18°45'45.04"	97°54'49.38"	There is a large quantity of garbage
E4 RR	Molcaxac, water used for farming and recreation	18°44'05.67"	97°55'30.60"	Puente de Dios, tropical deciduous forest vegetation, geological formations, caves and caverns
E5 RS	Water used for recreation Molcaxac River's end	18°44'00.03"	97°55'41.71"	Cola de Caballo, area visited by tourists

Table 1 Recollection Stations in the micro-basin

The method was based on the inoculation of aliquots from the sample, diluted or undiluted, in a series tubes containing liquid culture medium with lactose. A series of three dilutions (10 mL^{-1}, 1.0 mL^{-2} and 0.1 mL^{-3}) were used and incubated at 35 ± 1°C or 37±1°C for 48 h. The bacterial cultures were examined at 24 and 48 h, with those presenting turbidity and the production of gas and acid were considered positive. The positive tubes were placed in lactoce broth as a confirmatory test in accordance with NOM-127-SSA1-1994.

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NOM	Description
NMX-AA-003-1980	Wastewater. Sampling.
NOM-001-SEMARNAT-1996.	Maximum permissible limits for contaminants in the discharge of wastewater in national waters.
NOM-003-SEMARNAT 1997.	Maximum permissible limits for contaminants in treated wastewater that is reused for public use.
NMX-AA-42-1987	Determination of water quality from the Most Probable Number (MPN) of total coliforms, fecal coliforms (thermotolerant) and presumptive *Escherichia coli*.
NOM-112-SSA1 1994	Goods and services. Determination of coliform bacteria. Most Probable Number technique.
NOM-127-SSA1-1994	Environmental health. Water for human use and consumption – permissible quality limits and treatments to which water must be submitted for its purification.

Table 2 The NOM used in this study

The Student's t-test was applied to the results obtained with a 95% confidence level. The statistical analysis program used was the R commander program. The program Minitab was used to show the behavior of the most significant results in the variables analyzed in both the rainy and dry seasons. In order to identify the relationship between the physico-chemical variables and the concentration of *E. coli* in the sampling sites, for each season of the year, correlation analysis was conducted using the Spearman coefficient (rs) with a significance level of p <α=0.5.

Results and discussion

The River Atoyac in the Sierra del Tentzo watershed presented average temperature values of 17°C - 22 °C. The temperature oscillated between 18°C and 22°C in the rainy season and 17°C and 20°C in the dry season. The average values for transparency oscillated between 0.10 cm and 4.0 m. Station E3RA presented the highest turbidity levels in the rainy season from July to October and reached 0.10 cm in the month of April. This behavior coincided with the increase in water flow, the current velocity and the loading of a large quantity of solid waste in suspension (Figure 2), which constituted a limiting factor in the development of living organisms (Fernández, 2010).

A minimum turbidity of 4.0 m was observed at E2AP station in november and february. The depth of the River Atoyac varied between 2.20 m in the rainy season and 0.60 cm in the dry season.

In physical terms, parameters such as temperature, transparency, and current velocity and depth show that the behavior of the water was homogenous across all the months of the year sampled, and were found to be within the standards applied. The highest average value registered for electrical conductivity was at station E3RA in comparison with the other sampling sites in the rainy season, with values oscillating between 60 and 250 µ S/m, while the lowest registered was at station E2AP, which was from 50 to 140 µ S/m in the dry season.

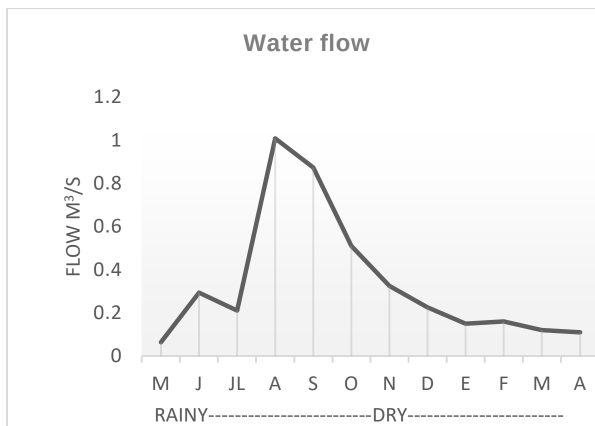

Figure 2 Water flow of the River Atoyac Microbasin in the rainy and dry seasons

It is important to note that during this same period, higher concentrations of *E. coli* were also found, with the highest recorded at station E3RA. The lowest levels found were at station E2AP (Figure 7). These results show that the increase in the concentrations of ions in this season could be due to the increase in the decomposition rates of organic material, coinciding with those reported by (Chalarca, *et al*. 2007; Rodríguez, *et al.* 2013).

NOM-127-SSA1-1994 and NOM-001-SEMARNAT-1996 indicate that the pH values must be between 6.5 and 8.5. Across all the stations in both seasons, the average values vary in a range from 7.3 to 9.0, which is most likely due to the soil composition, in which calcium carbonates predominate, which in turn leads to water with a high level of hardness. In general, values of pH close to 7.0 are expected to be found in an aquifer (Chapelle, F. 1993). The values obtained for calcium carbonate in the rainy season oscillate between 135 and 480 mg L^{-1}, and between 180 and 570 mg L^{-1} in the dry season. In all cases, the values are found to be below the maximum permissible limit.

The highest concentrations were recorded in the months of March 570 mg L^{-1} $CaCO_3$ and April 540 mg L^{-1} $CaCO_3$, exceeding the permissible limit according to NOM-127-SSA1-1994, which stipulates 500 mg L^{-1} $CaCO_3$, and the Federal Law, which establishes 400 mg L^{-1} CaCO3 as a permissible limit. From the results obtained, it can be inferred that the water in the watershed is alkaline. It can also be inferred that the hardness level found in the rainy season can be classified as moderately hard, while the hardness found in the low water season can be classified as very hard, due to the geology of the microbasin (Navarro, *et al*. 2013).

The average chloride values recorded at all the stations, except those recorded at station E3RA, were less than a 100 mg L^{-1} and higher than 50 mg L^{-1} and were found to be within the NOM. The levels recorded at station E3RA during the dry season exceeded NOM-127-SSA1-1994 and reached values of 1050 mg L^{-1}, with the maximum acceptable value being 350 mg L^{-1} (Figure 3).

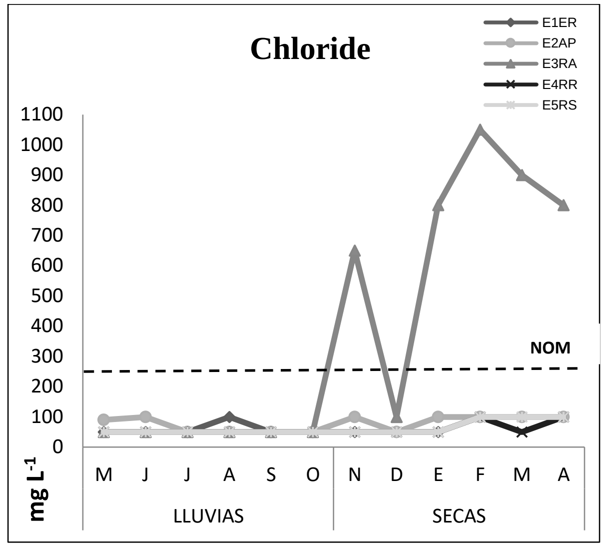

Figure 3 Average values for chlorides obtained at each station.---Permissible limit (NOM-127-SSA1 -1994)

These results may indicate contamination in that waste material of animal origin always has considerable quantities of these salts. These results coincide with the high levels of ammonium, above 10.0 mg L^{-1} (Figure 5), which indicate ammonia contamination, produced by the decomposition of urea by bacteria. Relating these ammonium values to the low or null levels of dissolved oxygen recorded in the dry season (Figure 4) values that coincide with the increase in *Escherichia coli* reported by (Yesenia, *et al*. 2013) (Figure 7) and which is an indicator of fecal contamination could suggest that the high concentrations of chlorides recorded at station E3RA in the dry season show the presence of a higher quantity of organic material compared to the other sampling stations in the watershed. According wing NOM-127-SSA1-1994 (water for human use and consumption) and NOM-001-SEMARNAT-1996, did not indicates permissible levels of oxygen in the water. The literature reviewed here indicates that while dissolved oxygen in water does not have an influence on agriculture, it does constitute a significant indicator of ecosystem health.

The average values for dissolved oxygen are found to be between 4.6 mg L^{-1} and 10 mg L^{-1}, with homogenous behavior at all sampling stations, except for station E3RA. This station presented maximum oxygen levels of 4.0 - 0 mg L^{-1}, which could be due to both rain and sediment from decomposing organic material. From August to September, the value increased to 2.5 mg L^{-1}, and then decreased dramatically in the October-April period to 0 mg L^{-1} (Figure 4).

These results demonstrate anoxic conditions and a contaminated river (Lampert and Sommer, 1997). This could be due to wastewater discharge by the local populations into what is known locally as Barranca del Águila of large quantities of organic matter, which increase the concentrations of bacteria (Figure 7), which, in turn, on decomposing the organic material, consume oxygen. This decrease in the concentration of oxygen in the water produces, in turn, the death of aquatic organisms, upon which anaerobiosis and the consequent bacterial putrefaction of proteins occur, resulting in the release of methane gas and hydrogen sulfide, a foul-smelling toxic gas characteristic of the region (Brooks, D. 2004; Breitburg, D. 2002; Melrose, *et al.* 2007).

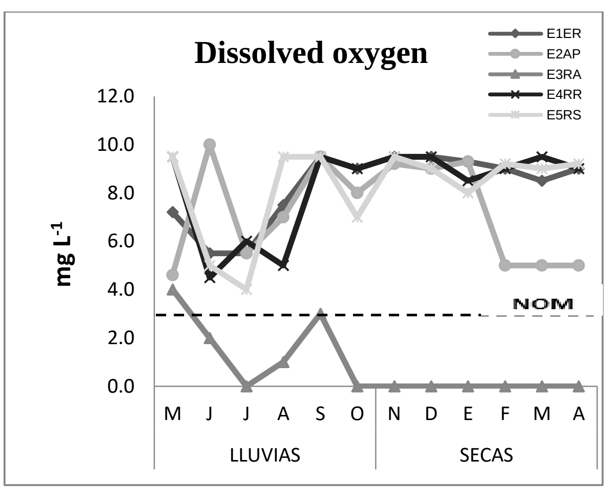

Figure 4 Average values for the dissolved oxygen obtained in the rainy and dry season at each sampling station. (Fernández *et al*, 2010)

The average values for nitrates varied at an interval of 10.1 - 39 mg L^{-1}, values which exceeded the limits established by NOM-127-SSA1-1994 of 10 mg L^{-1} NO3, and by the Federal Law for potable water use, which indicates that the permissible nitrate limits must be from 10 to 5 mg L^{-1} NO3. This increase could be due to the consumption of nitrogen compounds, which are commonly used in the agricultural practices of the region, such as inorganic fertilizers based on phosphorus and nitrogen, and which are received in the watershed. The speed with which these substances are carried is greater than the speed with which they are degraded, producing both soil contamination and the consequent contamination risk to the River water (Fernandez, *et al*. 2010).

In no case did the average sulfate ion values obtained exceed the permissible limit set by the NOM, which is < 400 mg L^{-1}. The values oscillated between 30.2 and 110.7 mg L^{-1} in the rainy season and between 6.8 and 98.6 in the dry season.

The average ammonium values obtained in the rainy and dry season follow a similar trend across all sampling sites and exceed the limits permitted under both the Federal Law, which stipulates 0.06 mgL^{-1}, and NOM-127-SSA1-1994. The average values oscillated between 40 and 75 mg L^{-1}. The highest ammonium concentration was recorded at station E3RA, where the water is used for agricultural irrigation, with values oscillating between 69 -75 mg L^{-1}. The results show that the ammonium levels are above 10 mg L^{-1}, which indicates ammonia contamination caused by the decomposition of urea by the bacteria present in wastewater (Figures 5, 6 and 7).

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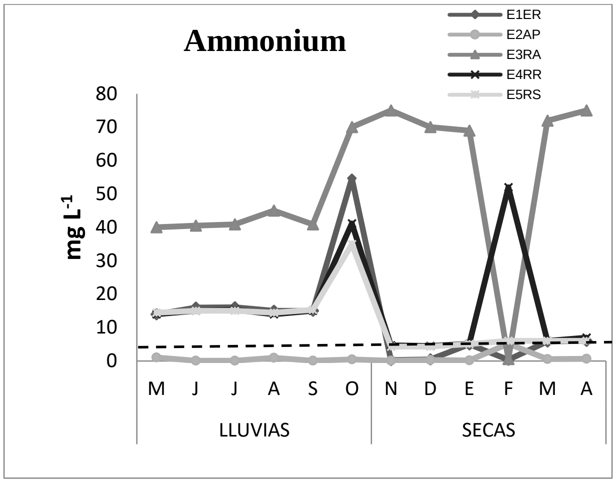

Figure 5 Average ammonium values obtained in the rainy and dry seasons at each sampling station.--- Permissible limit (NOM-127-SSA1-1994)

Relating the ammonium values obtained to the increase in organic material characteristic to the region points to an increase in the bacterial populations and a consequent decrease in oxygen levels. Once all the oxygen has been consumed, anaerobic decomposition commences, producing methane, ammonium, and hydrogen sulfide, a situation which was observed at station E3RA. The low concentration of ammonium in the potable water at station E2AP, between 0.1 and 5.2 mgL^{-1} for both seasons of the year, was found within the limits set by the NOM. The other sampling stations did not comply with the NOM (Figure 5). Both the ammonium ion and the nitrates are typical indicators of water contamination and indicate the degradation of organic material.

According to the National Water Commission (CONAGUA, 2013), DBO_5 values above 30 mg O_2 L^{-1} are characteristic of highly contaminated water, while values below 3 mg O_2 L^{-1} indicate very low organic contamination. Following these criteria, and according to the DBO_5 values obtained at the five sampling stations, the water from the microbasin is found to be within the contaminated category throughout the sampling period (Figure 6).

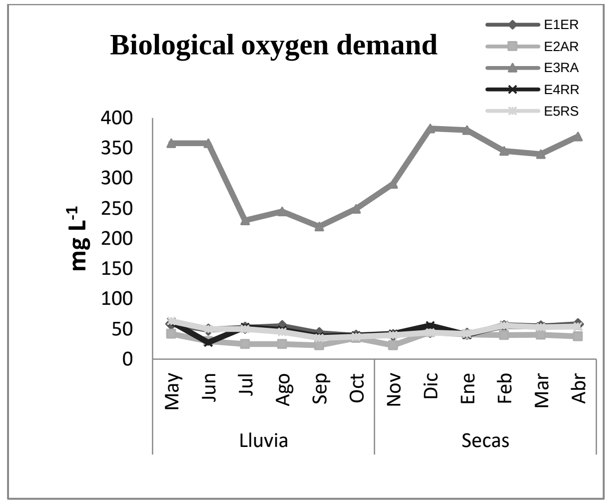

Figure 6. Values obtained for the biological oxygen demand (DBO_5) in the rainy and dry seasons at each sampling station

In accordance with NOM-001-SEMARNAT-1996 for the public and urban use of water, the DBO_5 values obtained oscillate between 23 and 63.1 mg O_2 L^{-1} were found to be within the maximum permissible limits, except E3RA sampling station. The average values at station E3RA oscillate between 220.2 and 382.3 mg O_2 L^{-1} which, according to the CONAGUA classification, are found within the category of heavily contaminated and, according to NOM-001-SEMARNAT, exceed the maximum permissible limits for use in agricultural irrigation (Figure 6).

According to the CONAGUA classification, the water used at station E2AP is for human use and consumption and is found within the acceptable category in the rainy season and in the contaminated category in the dry season. Although there is no NOM for potable water in relation to DBO_5, it is clear that these results correspond to the concentrations of fecal coliforms counted at each station in the two seasons of the year that were sampled (Figure 7).

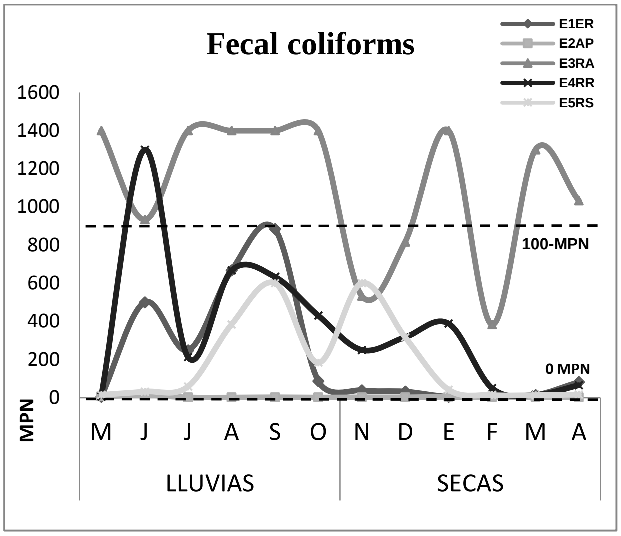

Figure 7 The values obtained for fecal coliforms in the rainy and dry seasons in each sampling station. NOM-001-SEMARNAT-1996 (1000 MPN/100 mL) NOM-127-SSA1-1994 (0 MPN/100 mL).

The average *E. coli* values in the Atoyac River watershed varied at an interval between 0.8 and 140E05 NMP/100 mL (Figure 7). The highest average values were observed at station E3RA across all the months of the year sampled. The high concentration of fecal coliforms is associated with the large quantity of organic material produced by discharge from nearby municipalities received by the Barranca del Águila, which coincides with that reported by Rodríguez, *et al* (2013). The lowest concentrations, 0.8 – 37.0 MPN/100 mL, were found at station E2EP, where the water is used as potable water. These values exceed the permissible limits under NOM-127 SSA1-1994 and indicate the presence of fecal contamination, highlighting the importance of disinfecting the water before use and consumption.

The average values at station E1ER oscillated between 4.3 and 883.3 MPN/1000 mL and were found to be within the maximum permissible limits for the discharge of contaminants into national waters under NOM-001-SEMARNAT-1996 (1000 MPN/100 mL).

However, they exceed the MPL under NOM-127 SSA1-1994.

Stations E4RR and E5RS are sites designed for recreational activities and, for all the months sampled, presented values that exceed the MPL under NOM-127 SSA1-1994, which means that bathers and those consuming fish are also at a high risk of contracting diseases. All the sites sampled on the river did not comply with the MPL under NOM-127 SSA1-1994 and are found to be contaminated (Figure 7).

These average values for *E. coli* coincide with the alterations to the chemical and physical parameters found when evaluating water quality, given that they are associated with organic contamination and are directly related to the concentration of *E. coli*.

Conclusions

This study concluded that, in accordance with the criteria established under NOM-001-SEMARNAT-1996, NOM-003-SEMARNAT-1997, NOM-127-SSA1-1994, the Federal Law - 2012, and CONAGUA - 2013, the river water used for human consumption is classified between acceptable and contaminated. Moreover, the water used in agricultural irrigation is highly contaminated and that used for recreation is found to be between highly contaminated and contaminated. Therefore, the water in the River Atoyac in the Tentzo microbasin is, in its current condition, not suitable for use by the inhabitants of the municipalities of Atoyatempan and Molcaxac.

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