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Water Quality of Houses in 13 Municipalities in the State of Mexico

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Abstract**—***Thirty-nine houses in 13 municipalities in the State of Mexico were each sampled at 3 or 4 points (supply line, water tank, cistern, kitchen faucet or water bottle), to determine the water quality. Two bacteriological and 18 physico-chemical parameters were determined. Thirty-eight houses had at least one parameter outside the limits permissible by Mexican regulations; 26 houses were bacteriologically contaminated, and 36 houses were below the established range for residual free chlorine. Furthermore, manganese levels were outside the limit permissible in 26 houses. Municipality 13 presented the greatest difference in total alkalinity, total and calcium hardness, manganese and dissolved solids compared to the other municipalities, which is attributed to the remoteness of this municipality from the others, and the difference in soil type.*

Keywords**—** *Drinking water, physicochemical parameters, total and fecal coliforms.*

I. INTRODUCTION

In Mexico, of the 1.489 billion m^3 of rainfall received annually, only 22.2% remains in surface basins and 6.2% goes into underground aquifers. However, its distribution is quite irregular; in the north of the country the dry season is long, while the south has a prolonged rainy season. Agriculture accounts for 76.6% of its use, followed by public supply, at 14.5%, industrial supply at 4% and the remaining 4.9% for electricity production [1].

The World Health Organization (WHO) mentions that diseases attributed to the consumption of contaminated water have had major repercussions on health, as is the case with diarrheal diseases which occupy sixth place in importance in the world. In 2011, the WHO reported the deaths of 2 million people from diarrheal diseases and another 4 billion sufferers, mentioning that the situation could be improved by better water quality [1, 2, 3].

Other studies include those of Briñez *et al.*[4], who found that 63.8% of the municipalities of Tolima presented non-potable water; Kumar *et al*.[5], evaluated the quality of drinking water in an Indian district, finding high bacterial contamination. Tabor *et al*.[6], found that 77% of 35 samples of household water in a city in Ethiopia was bacteriologically contaminated and that 57% lacked free residual chlorine; in addition, the poor management of the water increased its contamination. Hernández *et al*.[7], using a multivariate risk analysis, showed a risk of contracting water-borne infections that was directly related to water quality due to lack of maintenance and infrastructure of the deteriorated supply system. Padilla *et al.* [8], provided evidence that the water in a subbasin in Guatemala is unsuitable for direct consumption by the population. Lamrani *et al*. [9] studied groundwater in Morocco in two areas susceptible to anthropogenic contamination, obtaining high values of fecal coliforms, fecal streptococci and a conductivity of 2000 µS with laxative effects on consumers. In a village in India, Shiamala *et al*. [10] found that dissolved solids and total alkalinity in some seasons exceeded the norm. Radha *et al*. [11], in Sivakasi, India, conducting a study of potable water, well water and drain water, concluded that biologically, all the sites exceeded the standard.

Many studies have been done in Mexico on the quality of potable water, among them that of Rubio *et al*. [12], who concluded that the quality of water from a dam in Chihuahua, Mexico, is acceptable for environmental and agricultural purposes. Cázares-Méndez and Alcántara-Araujo [13] found that potable water in Ciudad Nezahualcóyotl did not meet the microbiological quality required for it to be deemed potable. Jiménez *et al*. [14], state that in Mexico City, the COFEPRIS recently detected the presence of fecal coliforms in household water from three delegations, and in some cases reported high levels of residual free chlorine. Orozco *et al.* [15], found that coliforms and color surpassed the norm in water wells in Chiapas, perhaps due to leachates from a nearby garbage dump. Pacheco *et al.* [16] found that 45% of the water in municipalities in Yucatán have some kind of biological contamination and that based on the Mexican standard, 52.83% is of medium quality. Pérez *et al.* [17] found higher concentrations of arsenic and manganese in groundwater in a municipality in Hidalgo state than permitted by the standard, and which may be due to the soil type.

However, there are places in the country where demographic growth and migration towards large cities or metropolitan areas increase the demand for water consumption. An example of this is the State of Mexico, which is primarily supplied by groundwater, where the high demand for water, the overexploitation of some aquifers, poor management of wastewater or simply the lack of treatment given to this kind of water, causes strong contamination, putting consumers at risk. Therefore, due to the scarcity of studies conducted in the metropolitan area of the State of Mexico, this study aims to determine the quality of the water in houses in thirteen of its municipalities [1, 18].

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II. Materials and Methods

Sampling Site

The State of Mexico covers 22,351 km^2 (1.1% of the entire country). It has a population of 15,175,862 inhabitants (13.5% of the country's population), the majority of which is urban [19, 20].

Sampling Procedure

Thirteen municipalities were selected and three houses in different locations were sampled in each one, making a total of 39 houses. In each case, 3 or 4 sampling points were selected (supply line or kitchen faucet, cistern and/or tank, water bottle or other relevant point). For the physico-chemical determinations, the samples were taken in 1.5-litre bottles and for the bacteriological analyses in sterile flasks with sodium thiosulfate added prior to sterilization.

Laboratory Analysis

Two bacteriological parameters were determined: total coliforms and fecal coliforms, and 18 physico-chemical parameters in accordance with the standard methods [21]. A descriptive analysis was conducted of the results obtained. To determine which of the studied variables most differentiated the municipalities, a discrimination analysis was applied, which consisted of obtaining: 1) the discriminating functions, the variables that comprise each function, and the cumulated percentage of explanation of each function; 2) the Mahalanobis distance and levels of significance between the municipalities, which allows the differentiation of the thirteen municipalities [22]. For this analysis, we used the MINITAB statistical package, version 16

III. Results and Discussion

Of the 39 houses sampled, 38 were outside Standard 127 in at least one parameter; only one house met the standard for all the parameters analyzed, this belonging to municipality 5. In the bacteriological analyses, 26 of the 39 houses were contaminated (Fig. 1), leaving 13 without bacterial contamination (municipalities 1, 3, 5 and 6 with two houses each and municipalities 7, 8, 9, 11 and 13 with one house each).

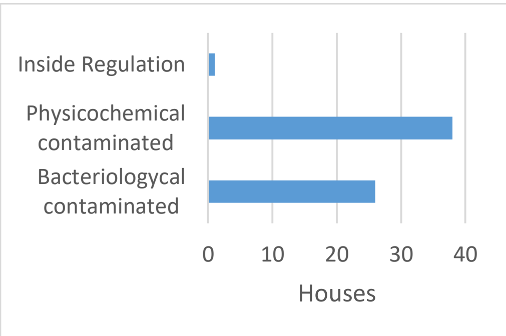

Fig. 1. House number whit parameters bacteriological and physicochemical outside Regulations Mexican.

The municipalities where all three sampled houses were found with bacteriological contamination were 2, 4, 10 and 12. Twelve of the 32 houses sampled at the supply line presented bacteriological contamination at intake, (Fig. 2), which was related to little or no chlorination. Of the 20 houses with clean supply, 10 were maintained free of coliforms and the other 10 had interior contamination. There was no direct supply to seven of the houses and samples were only taken from inside the house; bacteriological contamination presented in five of those houses, indicating a lack of cleaning and/or maintenance of the water tanks.

In the physico-chemical analyses, residual free chlorine was within the range of the standard in only three houses (municipalities 3, 5 and 6), 35 houses were below the lower limit of 0.2 mg/L, and one house was over 1.5 mg/L. Manganese was above 0.15 mg/L in 26 houses; this contamination is probably due to the municipalities being in the physiographic province of the Neovolcanic Axis and are mostly volcanic rock whose composition often possesses trace elements such as manganese. In six houses, the pH was outside the norm (municipalities 1, 5, 8 and 9 with one house each and 10 with two houses). Five houses had a pH less than 6.5 and one was over 8.5. The nitrates in 5 houses were above 10 mg/L. Nitrites and ammoniacal nitrogen were outside the norm in only one house, while dissolved solids, turbidity and chlorides were outside the norm in two houses, and lastly, color in three houses (Fig. 2).

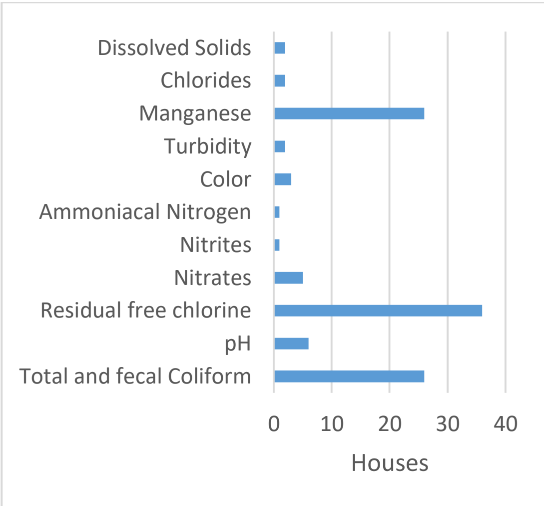

Fig. 2. Houses with parameters outside the Mexican regulations from the supply.

Regarding hardness, 11 houses (28.2%) had soft water, 11 others (28.2%) had moderately hard, 13 houses (33.3%) had hard water and 4 houses (10.2%) very hard water. In terms of hardness type, 92% of the houses had carbonate hardness, the rest had carbonate and non-carbonate hardness. Based on alkalinity, all the houses had bicarbonate (HCO_3) as the predominant anion.

Of the 32 water bottles analyzed, 24 were bacteriologically contaminated and four had residual free chlorine above 0.1 mg/L, which according to the standard for bottled water should be less than or equal to 0.1 mg/L. Bacteriological contamination suggests poor washing of the bottles in the

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purifying plants and/or inadequate maintenance of the purification equipment.

In order to see the variability between municipalities, a discrimination analysis was performed in which three functions were found that together describe 73.1% of the variations. Function 1 consisted of total alkalinity, calcium hardness and manganese and explained 38.17% of the variability. Function 2 consisted of total hardness, dissolved solids and conductivity and explained 22.55% of the variability, while function 3 comprised nitrates, free chlorine and sulfates and explained 12.38% of the variability of the data (Table 1).

TABLE 1. Results of the discriminant analysis between the municipalities.

Function	Characteristic value	X^2	Cumulative variance percentage	Variables
1	7.30	756	38.17	Alcal. Tot, Dureza Ca, Mn
2	4.31	569	60.72	Dureza Tot., Solid.dis., conduct.
3	2.37	421	73.1	Nitratos, cloro libre, sulfatos

Observed significance level (p) = 0.000

The analysis of Mahalanobis distances showed that municipality 13 presented greater distances than other municipalities (Table 2), due to the parameters that formed the three functions in the discrimination analysis. The large difference between municipality 13 and the others could be due primarily to its remoteness from the other municipalities and the type of soil formation, in addition to the volcanic rock type that explains the presence of manganese. Furthermore, the transport of fine materials by water runoff in the formation of the soil, and the saline lake previously located in the settlement area of this municipality explain the high concentration of dissolved solids and conductivity, as well as inorganic matter in the form of ions such as calcium and carbonates [23].

The municipalities with the shortest distances, i.e. greater similarity between the parameters represented in the functions, were municipality 5 with 1 (2.6), and municipality 12 with 2 (9.3) and 3 (10.3) (Table 2).

The similarity between municipalities in these parameters may be attributable to the proximity of one municipality to another, and to the dominant soil type, since all the municipalities that presented similarities, whether close or not, tend to have a similar composition, dominated mainly by vertisol, phaeozem and leptosol, among others; besides presenting generally the same type of rock, such as andesite.

Bacteriological and/or physico-chemical contamination of water for human consumption is not only a problem in the State of Mexico, but also in other Mexican states as mentioned in the studies of Cázarez and Alcántara[13], Jiménez *et al.* [14], Orozco *et al.* [15], Pacheco *et al.* [16], and Pérez *et al* [17], among others. Other studies mention the same problem in other countries, for example, Briñez *et al.* [4], Kumar *et al.* [5], Tabor *et al.* [6], Lambrani *et al.* [9], Hernández *et al.* [7] and Shimala *et al.* [10].

TABLE 2. Mahalanobis Distance between the Municipalities. Red numbers = greatest differences (p-level = 0.000)

Municipio	1	2	3	4	5	6	7	8	9	10	11	12
1												
2	21.9											
3	18.4	14.7										
4	33.7	49.4	29.8									
5	2.6	16.6	11.2	35.3								
6	15.8	46.6	31.9	49.6	20.1							
7	43.1	40.1	22.8	19.3	33.1	60.9						
8	32.5	25.7	15.1	30.5	25.8	55.4	16.7					
9	42.3	28.8	16.8	41.4	28.7	64.9	14.8	16.3				
10	29.7	40.7	44.4	56.2	31.4	91.3	59.7	37.6	64.3			
11	18.1	31.3	32.9	35.8	20.1	28.9	41.2	34.1	44.2	23.9		
12	19.2	9.3	10.4	43.6	14.8	36.4	34.3	16.7	19.9	35.9	26.5	
13	82.7	84.6	64.7	40.1	82.0	87.2	43.6	49.1	63.5	99.7	47.8	71.4

IV. CONCLUSIONS

Only one house met the standard for all the parameters analyzed, this belonging to municipality 5

More houses (36) fell outside the norm for residual free chlorine than for any other parameter, followed by manganese with 26 houses and total and fecal coliforms with 26 and 21 houses, respectively.

The water supply is less than adequate given that of the 32 houses sampled at the supply line, 12 presented bacteriological contamination and manganese exceeded the permissible limits in 26 houses.

The lack of adequate chlorination from the supply turns the water supply into a focal point of bacteriological contamination.

Bacteriological contamination inside the house is another concern; although the quality of water entering some houses was adequate, the lack of cleaning and/or maintenance of water tanks and piping was the main problem.

Environmental conditions (atmosphere and soil) in the vicinity of the faucet or water storage also influence changes in water quality.

Hard water was the predominant water type in the sampled houses (35).

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Municipality 13 presented the greatest difference compared to the other municipalities due to its remoteness from the others and the soil type.

Lastly, the use of bottled water does not necessarily guarantee good quality water since, in some cases, the bottled water was actually contaminated while the water supply, such as in the tanks of some houses, was of good quality.

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