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Bacteriological and Physicochemical Study on the Water of an Aquifer in Mexico

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Abstract:
Water pollution through wastewater is a serious problem in Mexico. For this reason, the possibility of contamination of aquifers is latent. In the literature there are reports that some aquifers are contaminated, on the other hand the country has been divided into aquifers 653: 101 are overexploited, they provide 58% of groundwater intended for all uses. Consequently it is important study the aquifers to meet its water quality and take action to prevent contamination and to not put at risk the health of users. The aim of this study is to determine the bacteriological and physicochemical quality of the groundwater in Morelos state which, for administrative purposes, is divided into four aquifers: Cuernavaca, Zacatepec, Cuautla-Yautepec and Tepalcingo-Axochiapan. From 2005 to 2010, bi-monthly samples were drawn from each aquifer for one year to find out if there are contaminated areas to take action. Principal use of water in this state is urban and agricultural. In total, thirty-seven wells were sampled. Aquifer Tepalcingo-Axochiapan showed marked difference in the dissolved solids respect to the other aquifers. The average physicochemical parameters were below the levels permitted by the NOM-127-SSA1-1994, on water for human consumption. Bacteriologically, all the wells showed contamination in at least one sample. Nevertheless, although the dilution capacity of the aquifer has so far prevented the water quality from deteriorating, there are already areas where anthropic contamination is evident.

Keywords: groundwater, water quality, total and fecal coliforms

1.0 Introduction:
An aquifer is the geological formation that stores water and acts as a deposit and reservoir; it is usually fed by rainwater, surface currents and lakes which infiltrate the ground. Aquifer water drains by gravity from the recharge areas to the discharge areas, which might be rivers, lakes or springs (Price, 2007, Foster *et al*., 2003, Jiménez, 2002). Aquifers are an important storage source but overexploitation and other anthropogenic activities, including high urbanization, have resulted in reduced natural recharge and, consequently, serious declines in aquifer levels and water quality (Robles *et al.,* 2011). Groundwater contamination is a serious environmental problem which is difficult to counter and bacteriological contamination is one of the most important kinds because of its impact on human health (Arcos *et al.* 2005). Some studies of groundwater quality have been reported and documented in Mexico. Ramirez *et al*. (2009), for example, found microbiological contamination in wells of the Zacatepec aquifer in Morelos state. Peinado-Guevara *et al*. (2011), found that the Sinaloa river aquifer is highly sensitive to salinity due to its coastal character. Valenzuela *et al.* (2013), concluded that the aquifer mineralization has resulted in deterioration in water. Unlike what it could be expected, the isotopic composition determined that mineralized water from irrigation channels is not yet present in the aquifer. Peña *et al*. (2012), found that the water quality in the San Luis Potosi aquifer is related to the quality of groundwater flow, drainage from surface basin, seepage from irrigation canals, subsurface salt dissolution and leaching of nitrogen fertilizers.

Other studies of Mexican aquifers that have reported findings of bacterial and chemical contamination include those by Salgado *et al*., (2012), Robles *et al*., (2011), González *et al*., (2006), Pacheco *et al*., (2004), Muñoz *et al*., (2004), Borbolla *et al*., (2003), Pérez *et* *al.,* (2002), Granel and Gález (2002) andPacheco *et al*., (2000). The National Water Commission (CONAGUA) has defined four aquifer zones in Morelos state in order to manage the use of groundwater. The four aquifers follow geological and geohydrological aspects and their spatial distribution are based on surface arrangement. The aquifers are identified as the Cuernavaca aquifer, Cuautla-Yautepec aquifer, Zacatepec aquifer and Tepalcingo-Axochiapan aquifer (Lara *et al*., 2003).The CONAGUA studies in Morelos are mainly concerned with hydrogeology, availability and use, and in some cases water quality. The study of the Cuernavaca aquifer conducted in 1995 and 1998 found that nitrate levels exceeded the limits allowed by the NOM 127-SSA1-1994 (10 mg/L) and that dissolved solids were between 50 and 600 mg/L (CONAGUA, 2009a). In 1989, the study of the Cuautla-Yautepec aquifer concluded that the water is suitable for all uses but the upper part of the Cuautla area is contaminated by wastewater infiltration. The total dissolved solids content is 50 to 100 mg/L to the north of the valleys, between 200 and 400 mg/L in the middle part and 400 to 600 mg/L at the end of the aquifer (CONAGUA 2009b). The study of the Tepalcingo-Axochiapan aquifer conducted in 1982 found that the water is good quality and suitable for potable, agricultural and industrial use. Electrical conductivity ranges from 400 to 1,000 µs/cm, with the exception of the Chietla-Atencingo Valley where values range from 1,500 to 2,500 µs/cm (CONAGUA, 2009c).

Mexico has been divided into aquifers 653: 101 are overexploited, they provide 58% of groundwater intended for all uses (INEGI, 2009). Consequently it is important study the aquifers to meet its water quality and take action to prevent contamination and to not put at risk the health of users. The aim of this study was to determine the water quality of the aquifers that make up the groundwater of Morelos state and compare the results with the previously reported contamination.

2.0 Materials and methods:

2.1 Description of the study area:

The Cuernavaca aquifer adjoins the hydrological basins of the Valle de México and the Lerma River to the north, the Cuautla-Yautepec aquifer, to the east, the Zacatepec aquifer in Morelos to the south and the subbasin of the Chalma River of Mexico state to the west (Figure 1). This aquifer runs through unevenly distributed, highly permeable, fractured basalt igneous rocks and medium permeability rocks. 48.3% of the groundwater used is for agricultural use, 46.1% for urban public use, 4.4% industrial and 1.0% services (Lara *et al.,* 2003, CONAGUA, 2009).

The Cuautla-Yautepec aquifer adjoins the hydrological basin of the Valle de México to the north, the Cuernavaca and Zacatepec aquifers to the west, the Tepalcingo-Axochiapan zone to the east and the Amacuzac River Basin to the south, in the states of Morelos and Guerrero (Figure 1) (CONAGUA, 2009a). 81.6% of the water drawn from the aquifer is used for agriculture, 15.1% for urban public use, 1.9% for industry and 1.1% services (Lara *et al.,* 2003). The hydrogeochemical evolution of the Cuernavaca and Cuautla aquifers is generated from the recharge areas in the northern part towards the discharge areas in the middle and the transfer zones in the southern part. This evolution creates an enrichment of ions as the water circulates through the ground (CONAGUA, 2009).

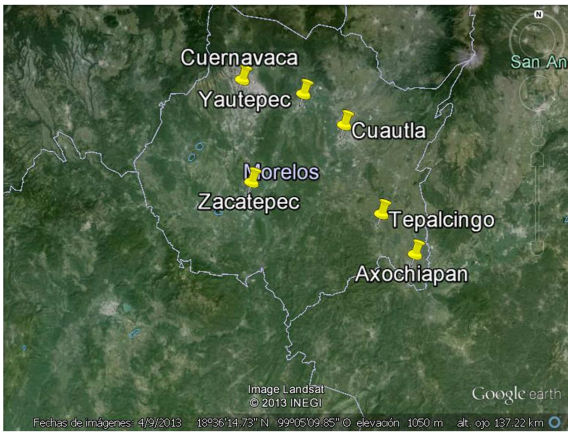

Figure 1: Localization of the Morelos State Aquifers, Mexico.

The Tepalcingo-Axochiapan aquifer is located in the eastern part of Morelos, bordered to the north by the southern flank of the Popocatepetl volcano, to the west by the Huautla mountains, to the east with the foothills of Popocatepetl and to the south by the discharge zone that joins the river Nexapa (Figure 1). Water enters this aquifer in the northern part and runs to the south through volcanic rocks; in the part to the south from Axochiapan towards the Chietla-Atencingo Valley the values are considerably enriched due to the water circulating through or near evaporitic material (CONAGUA, 2009b). Of the total groundwater drawn from the aquifer, 90.8% is used for agriculture, 8.7% for urban public use and 0.5%

for industry and services (Lara *et al.,* 2003). The Zacatepec aquifer adjoins the Cuernavaca aquifer to the north, the Cuautla-Yautepec aquifer to the east and the subbasins of the Chontalcuatlan and San Jerónimo rivers to the west, both in Mexico state (Figure 1).

This aquifer is located in fractured basaltic igneous rocks with high permeability and irregular distribution, and in rocks of the Cuernavaca Formation with medium permeability and irregular distribution. There are three inflows of groundwater to this aquifer. The hydrogeochemical evolution is generated from the underground transfer zones to the north, east and west of the aquifer and towards the discharge zones in the middle and south (CONAGUA, 2009c; Lara *et al*., 2003). Of the total groundwater used from the aquifer, 92.5% is for agricultural use, 5.8% urban public use and 1.4% industrial use (Lara *et al.,* 2003).

2.2 Sampling procedure:

From 2005 to 2010 bimonthly sampling was carried out in the Cuernavaca (CUE), Zacatepec (Z), Cuautla-Yautepec (CUA) and Tepalcingo-Axochiapan (T) aquifers, covering an annual cycle for each one. The samples were drawn from a total of 37 wells (P) and upstream of the chlorine dispenser in order to define the natural conditions of the aquifer.

2.3 Laboratory analysis:

The bacteriological parameters used were total and fecal coliforms along with the following physicochemical parameters: pH, temperature, biochemical oxygen demand (BOD_5), chemical oxygen demand, ammonia nitrogen, total alkalinity and phenolphthalein, total hardness, chlorides, sulfates, dissolved solids, nitrates, nitrites, turbidity and detergents (APHA, 1998). To determine which of the variables studied discriminate more wells, we applied the statistical method: discriminant analysis, which consisted of obtaining: 1, the discriminant functions, variables that made up each function and the cumulative percentage explaining each function; 2, Mahalanobis distances and levels of significance between wells, and 3, the scatter plot of the first two functions, which discriminates the 37 wells (Dallas, 2000).

3.0 Results and Discussion:

The results of the physicochemical and bacteriological parameters were used to calculate the average, minimum and maximum values (Tables 1, 2, 3, 4 and 5). Total hardness and total alkalinity were used to obtain temporary or carbonate hardness and non-carbonate hardness (Table 6). A discriminant analysis was performed which revealed three functions: the first comprising sulfates and turbidity; the second made up of dissolved solids, total alkalinity and total hardness, and the third of total coliforms, fecal coliforms and nitrates. The three functions were statistically significant ($p < 0.05$) and explain 93.2% of the total variation of the data. However, the first two functions alone explain 89.3% of the total variation (Table 7). The Mahalanobis distances obtained are shown in the scatter plot (Figure 2). The results of the dissolved solids, total coliforms and fecal coliforms are shown in Figures 3, 4 and 5. The Mahalanobis distances of wells TP5, TP6, TP7 and TP8, followed by well TP4 (899 – 1810) were furthest away from the other wells and therefore had the greatest differences in the analyzed parameters which made up functions 1, 2 and 3. Nevertheless, there were also other wells that showed important differences such as the group comprising ZP9, ZP10 and ZP11 (835 – 1525); the group of TP1, TP2 and TP3 (804 – 1280 compared to TP5, TP6, TP7 and TP8) and two wells that separated individually, ZP1 and CUEP10 (Figure 2).

Well ZP10 (1138 mg/L) had the highest concentrations of dissolved solids (dissolved salts), followed by ZP11, ZP9, and wells TP5, TP6, TP7 and TP8 (Figure 3). In general, these wells are found at the lowest altitudes, those of the Zacatepec aquifer between 918 and 956 masl and those of the Tepalcingo-Axochiapan aquifer between 1253 and 1018 masl, which may cause the water to become enriched with salts by coming into contact with the various rock units through which it circulates as it flows from the higher elevations to the lower parts. The similarities of the dissolved solids in the other aquifers are probably due to their location since these wells are basically distributed at higher and medium elevations where concentrations of dissolved salts are not very high. In the Cuernavaca Valley area, all the wells except CUEP5, CUEP8 and CUEP10 (1100 to 1150 masl), are found between 1400 and 1880 masl and had the lowest concentrations of dissolved solids. It should also be taken into account that these wells are closer to the recharge zones and therefore receive more rainfall throughout the year (Figure 3).

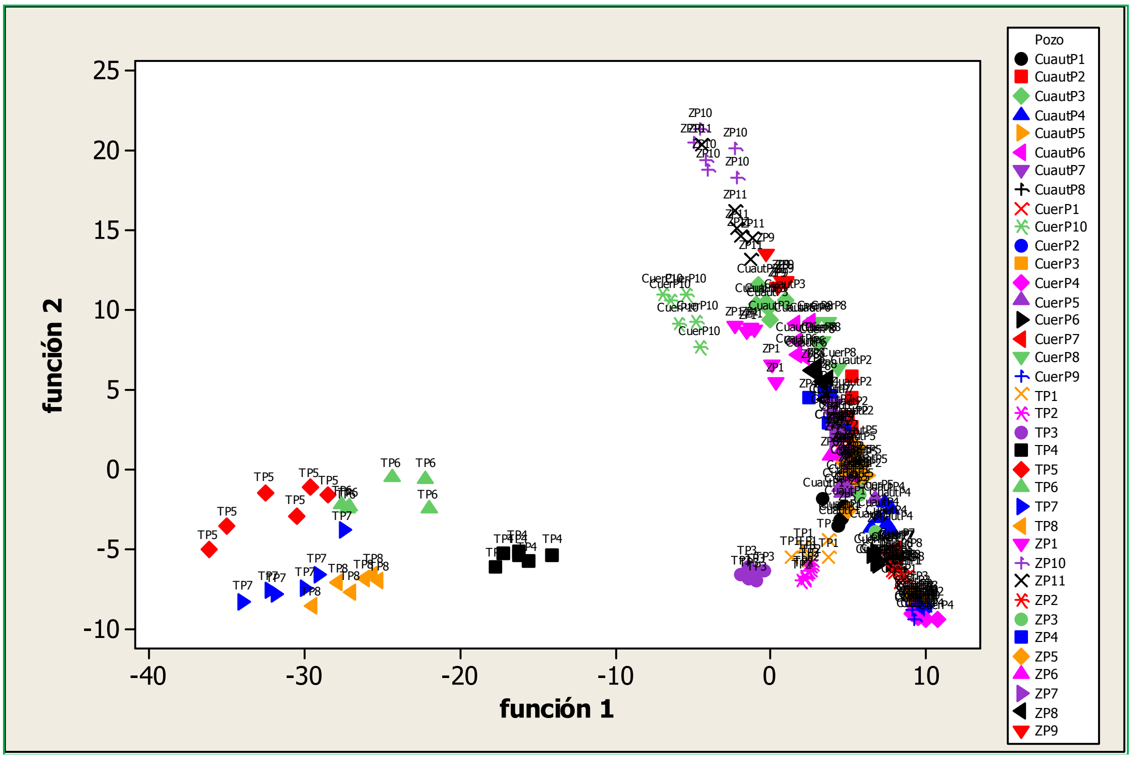

Figure 2: Scatterplot

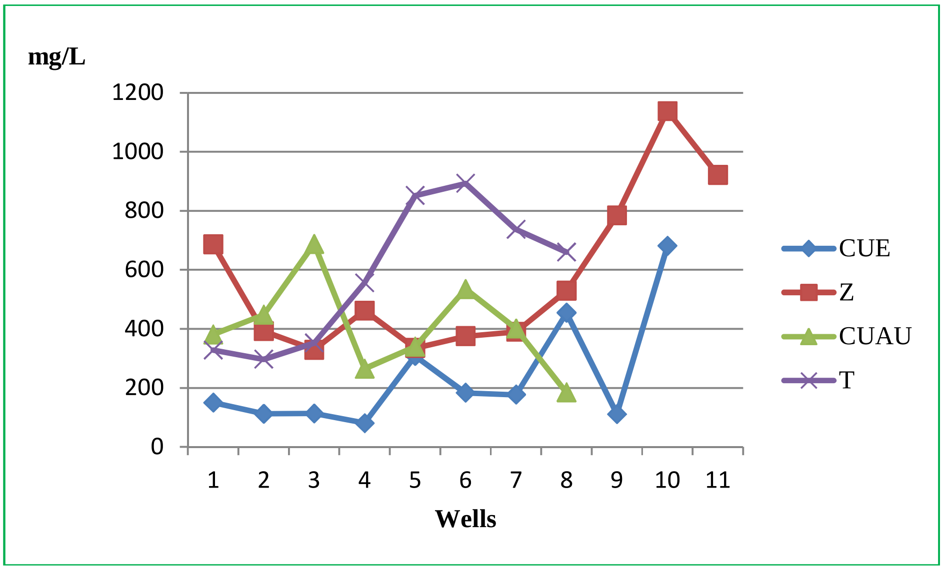

Figure 3: Dissolved solids values

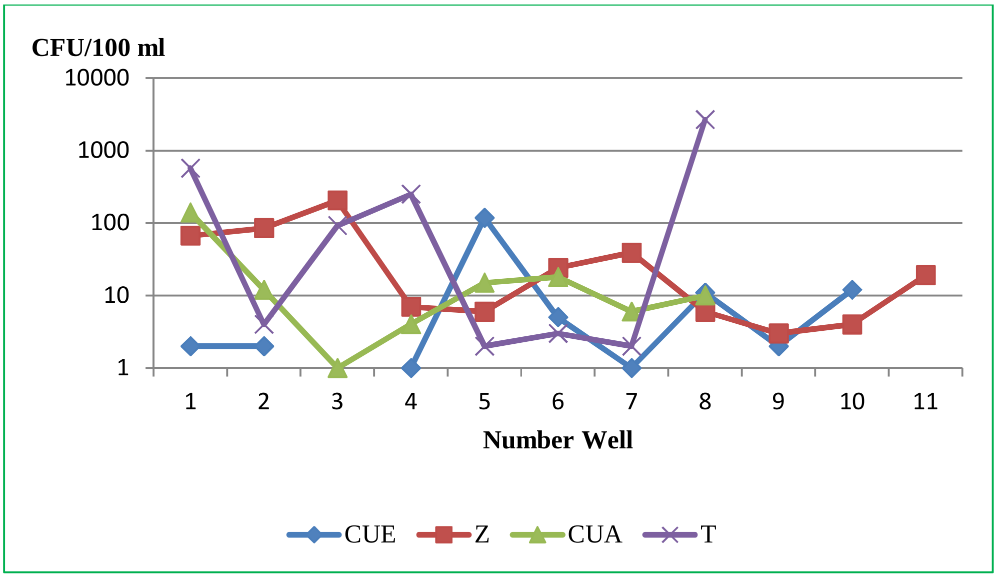

Figure 4: Total coliforms value

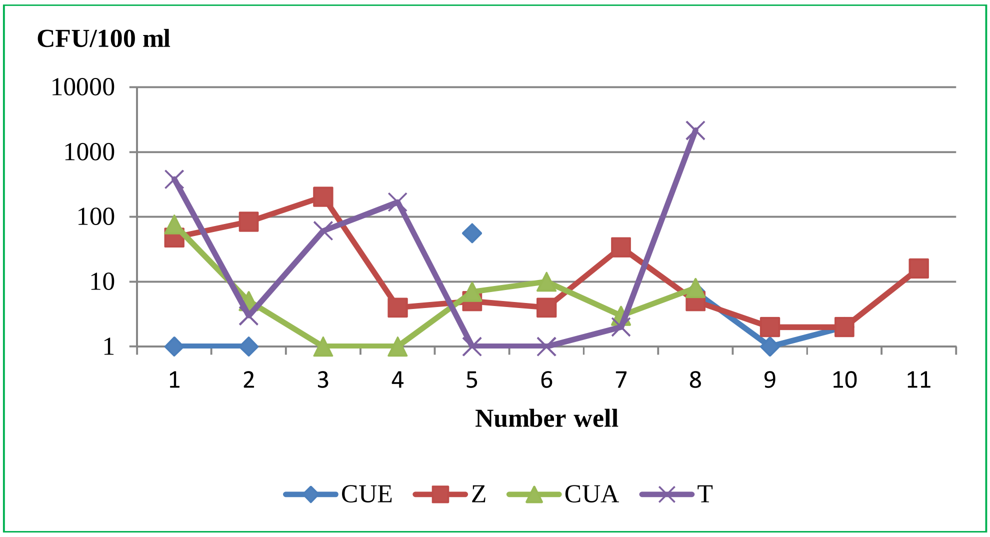

Figure 5: Fecal coliforms value

The classification of the water according to hardness (Romero, 1999), indicates that five wells have soft water (36.9 to 74 mg/L) and are in the Cuernavaca aquifer, four wells are moderate hardness and are in three aquifers: Cuernavaca, Cuautla-Yautepec and Tepalcingo-Axochiapan, fourteen have hard water and belong mainly to the Zacatepec aquifer, and fourteen have very hard water and are located mainly in the Tepalcingo-Axochiapan and Zacatepec aquifers (Table 6).The wells of the Cuernavaca aquifer only have carbonate hardness with the exception of wells 8 and 10 which have both carbonate and non-carbonate (Table 6), the latter probably due to sulfates in well 8 and chlorides and sulfates in well 10, since they had high values for these parameters (Table1). The wells of the Zacatepec aquifer only have carbonate hardness with the exception of wells 9, 10 and 11 which have both hardnesses and non-carbonate hardness in high concentrations (106, 305 and 262 mg/L), probably due to the high sulfate levels in these wells (124, 168 and 143 mg/L) (Table 2). Three wells of the Cuautla-Yautepec aquifer have only carbonate hardness, the rest have both. The non-carbonate hardness is perhaps due to the presence of high sulfate levels (Table 3).

Table I: Cuernavaca Aquifer: average, standard desviation, maximum value and minimum value

		pH	Tempe-rature	Dissolved solids	Nitrates	Alkalinity	Hardness	Chloride	Sulfates	Turbidity
Maximum Limits		6.5-8.5		1000 Mg/L	10 Mg/L		500 Mg/L	250 Mg/L	400 Mg/L	5 NTU
CUEP1	A	6.9 ±0.25	18.8 ±0.83	150 ±11	0.217 ±0.12	144 ±13.7	74 ±13.9	5.3 ±2.9	4.7 ±3.2	1.1 ±3.4
	MaV	7.5	20	172	0.36	169	99	11.9	13.5	12
	MiV	6.5	18	136	0.003	126	52	1.9	2	0.05
CUEP2	A	6.8 ±0.41	18.6 ±0.99	112 ±12.6	0.99 ±0.29	78 ±12	43.6 ±8.2	3.12 ±2.8	4.75 ±3.1	0.153 ±0.11
	MaV	7.3	20	128	1.41	99	57.3	10.9	12.1	0.47
	MiV	6	17	84	0.445	60	27.4	1	2	0.08
CUEP3	A	6.8 ±0.21	18.6 ±0.77	113 ±6.15	0.441 ±0.24	95 ±12.4	48 ±8.8	2.11 ±1.17	5.36 ±4.5	0.166 ±0.115
	MaV	7.2	20	123	0.878	117	57	3.9	18.7	0.46
	MiV	6.5	18	99	0.058	74.2	28.4	1	2	0.07
CUEP4	A	6.9 ±0.62	18.6 ±0.9	80.4 ±10.5	0.715 ±0.26	65.4 ±5.6	38 ±9.5	1.54 ±1.76	4.1 ±2.9	0.139 ±0.09
	MaV	7.7	20	96	1.1	76	55	5.8	8.8	0.35
	MiV	5.2	17	63	0.144	55.6	23.5	0	0	0.07
CUEP5	A	6 ±0.47	21.9 ±0.33	308 ±19.1	2.54 ±0.96	204 ±14.5	196 ±14.1	27.5 ±5.4	69.4 ±10.6	0.408 ±0.88
	MaV	6.6	22.5	340	4.6	228	224	35.9	83	3.18
	MiV	4.7	21	272	1.2	182	173	20.1	53	0.06
CUEP6	A	6.9 ±0.43	21.2 ±1.2	183 ±12.6	0.91 ±0.35	182 ±18.3	91.4 ±11.8	14.9 ±2.5	8.4 ±3	0.225 ±0.136
	MaV	7.6	24	200	1.79	217	111	19	13.7	0.51
	MiV	5.8	19	160	0.39	159	70	11	4.2	0.09
CUEP7	A	6.9 ±0.25	20.1 ±1.4	177 ±11.3	0.874 ±0.25	177 ±14.6	103 ±9.6	3.02 ±2.6	8.4 ±2.9	0.293 ±0.18
	MaV	7.5	24	192	1.28	198	123	9.7	12.8	0.62
	MiV	6.6	19	160	0.458	155	92	1	3.9	0.07
CUEP8	A	6.9 ±0.11	20 ±0.77	454 ±26.5	0.144 ±0.25	325 ±26.1	350 ±22.4	8.15 ±2.9	131 ±23.6	2.77 ±1.6
	MaV	7.1	21	492	0.82	35.6	396	13.9	164	5.9
	MiV	6.7	19	401	0	287	314	4.9	96	0.8
CUEP9	A	6.7 ±0.74	18.2 ±1	111 ±9.1	0.732 ±0.33	75 ±8.8	36.9 ±6.5	3.77 ±8.1	3.8 ±1.9	0.108 ±0.04
	MaV	7.7	20	124	1.5	89.6	46	27.9	7.3	0.18
	MiV	4.6	17	96	0.106	61.8	26.4	0	1.2	0.05
CUEP 10	A	6.5 ±0.42	23.4 ±0.51	681 ±72	2.8 ±1	443 ±30.9	457 ±16.4	82 ±8.6	89.6 ±7.4	0.233 ±0.42
	MaV	6.9	24	772	4.7	482	476	91	99	1.57
	MiV	5.3	23	516	1.3	400	424	62	74.5	0.06

A = Average MaV = Maximum value MiV = Minimum value

Table 2: Zacatepec Aquifer: average, standard desviation, maximum value and minimum value

		pH	Tempe-rature	Dissolved solids	Nitrates	Alkalinity	Hardness	Chloride	Sulfates	Turbidity
Maximum limits .		6.5-8.5		1000 Mg/L	10 Mg/L		500 Mg/L	250 Mg/L	400 Mg/L	5 NTU
ZP1	A	6.8 ±0.19	24.5 ±1	686 ±78.7	2.87 ±2.1	304 ±39.2	373 ±83.3	36.8 ±6.8	82 ±17.9	0.237 ±0.11
	MaV	7.3	26	840	6	368	468	45	105	0.39
	MiV	6.7	23	580	0.33	244	234	20	50	0.12
ZP2	A	6.8 ±0.22	24.8 ±1.36	392 ±26.5	1.91 ±1.27	239 ±36	235 ±34.4	5.64 ±3.29	37.5 ±7.6	0.286 ±0.23
	MaV	7.2	26	453	4.38	299	276	11.2	47.5	0.74
	MiV	6.5	22	360	0.22	187	169	0	21.5	0.085
ZP3	A	6.9 ±0.56	26.6 ±1.46	329 ±66.4	2.1 ±1.75	219 ±57.9	179 ±41.9	4.6 ±4.2	23.2 ±10.3	1.48 ±1.93
	MaV	8.5	30	376	5.2	289	216	12.5	32	4.3
	MiV	6.3	25	152	0.265	74	81	0	4.9	0.07
ZP4	A	6.9 ±0.19	27.6 ±1.6	462 ±56	1.76 ±0.72	361 ±53.5	235 ±36.8	5.9 ±4.5	32.7 ±8	0.178 ±0.085
	MaV	7.2	31	532	2.5	459	276	16	49.5	0.33
	MiV	6.6	26	312	0.101	304	169	0	18.2	0.07
ZP5	A	6.9 ±0.22	24.5 ±0.78	335 ±61	1.33 ±0.96	241 ±34.6	213 ±46.5	8.6 ±7.2	19.1 ±5.4	0.19 ±0.05
	MaV	7.2	26	405	2.94	315	256	28.7	25.4	0.28
	MiV	6.3	23	180	0.012	200	132	0.86	8.6	0.13
ZP6	A	6.8 ±0.33	25 ±1.14	375 ±44.8	1.28 ±0.86	265 ±40	226 ±29.8	8.68 ±4.3	21.4 ±6.6	0.379 ±0.42
	MaV	7.5	27	499	2.5	327	260	15.6	35.9	1.09
	MiV	6.2	23	335	0.083	206	169	0.86	12.7	0.095
ZP7	A	6.9 ±0.36	28 ±2.9	390 ±83	1.31 ±0.81	302 ±48	228 ±50	8.3 ±4.1	31.5 ±17.1	0.188 ±0.117
	MaV	7.8	36	590	2.36	381	308	14.1	82.7	0.38
	MiV	6.3	25	205	0	240	164	0.86	14	0.08
ZP8	A	6.8 ±0.33	26.7 ±1.4	529 ±56	1.32 ±1.14	309 ±48	285 ±58	6.46 ±3.9	63.8 ±23.8	0.241 ±0.212
	MaV	7.6	29	630	4.2	389	366	12.7	103	0.6
	MiV	6.3	24	455	0.019	240	202	0	28.7	0.07
ZP9	A	6.9 ±0.28	29.1 ±1.2	785 ±46	1.81 ±1.19	316 ±50	422 ±147	8.2 ±4.4	124 ±35.8	0.218 ±0.124
	MaV	7.3	31	875	3.5	413	700	14.6	174	0.42
	MiV	6.4	27	700	0.22	244	242	0	61.4	0.1
ZP10	A	7 ±0.22	26.9 ±0.96	1138 ±135	1.76 ±1.14	296 ±43	601 ±153	13.3 ±5.6	168 ±44	0.146 ±0.07
	MaV	7.3	29	1316	3.46	378	784	22.6	218	0.26
	MiV	6.5	26	892	0.113	222	420	2.6	86	0.085
ZP11	A	7.1 ±0.23	26.6 ±0.98	922 ±222	1.39 ±1.15	282 ±45.6	544 ±307	14 ±4.6	143 ±37.3	0.246 ±0.241
	MaV	7.4	28.5	1520	3.2	356	1424	20.3	191	0.73
	MiV	6.8	25.5	502	0.164	204	268	2.6	81	0.08

A = Average. MaV = Maximum value. MiV = Minimum value

Table 3: Cuautla-Yautepec Aquifer: average, standard desviation, maximum value and minimum value

		pH	Tempe-rature	Dissolved solids	Nitrates	Alkalinity	Hardness	Chloride	Sulfates	Turbidity
Maximum limits .		6.5-8.5		1000 mg/L	10 mg/L		500 mg/L	250 mg/L	400 mg/L	5 NTU
CUA P1	A	6.3 ±0.16	18.9 ±1.9	381 ±49	3.4 ±1.1	111 ±20.8	211 ±20.2	30.5 ±8.2	36.4 ±10.8	0.518 ±0.29
	MaV	6.6	22	467	5.37	135	240	42.3	55.9	1.12
	MiV	6.1	16	315	1.65	67	172	16.4	22.3	0.2
CUA P2	A	6.7 ±0.12	20.1 ±2.6	448 ±74.8	2.65 ±0.64	134 ±23.7	301 ±60.8	11.7 ±4.1	139 ±52	0.254 ±0.179
	MaV	6.9	23	580	4.1	167	424	18.4	227	0.71
	MiV	6.5	16	312	1.75	99.6	216	7.2	78	0.1
CUA P3	A	6.8 ±0.11	22.8 ±2.6	688 ±37	3.56 ±1.19	317 ±55	390 ±73.6	28.4 ±5.8	121 ±29.5	0.216 ±0.065
	MaV	7	26	740	5.6	371	477	36.7	188	0.33
	MiV	6.6	19	600	1.74	212	196	17.3	94	0.11
CUA P4	A	5.9 ±0.15	18.6 ±1.8	265 ±24.6	0.989 ±0.272	187 ±25.4	183 ±22.9	8.38 ±7.9	10.1 ±4.9	0.228 ±0.093
	MaV	6.3	21	328	1.73	211	222	31.2	18.9	0.41
	MiV	5.7	16	238	0.659	121	122	1.4	2.9	0.13
CUA P5	A	6.1 ±0.34	21 ±3.1	339 ±137	0.969 ±0.37	252 ±89.9	261 ±14.2	7.5 ±4.1	8.3 ±3.9	0.197 ±0.08
	MaV	6.9	26	403	1.9	305	296	16.7	15.7	0.31
	MiV	5.8	17	295	0.47	166	246	2.3	4.7	0.08
CUA P6	A	7 ±0.36	21.9 ±2.74	535 ±29.9	2.6 ±0.62	280 ±41.3	381 ±23.6	16.2 ±1.9	111 ±29.2	0.381 ±0.233
	MaV	7.4	25	583	4.1	318	415	20	170	0.955
	MiV	6.3	16	488	1.9	179	326	13.6	72.7	0.11
CUA P7	A	7.3 ±0.09	24.9 ±2.3	401 ±39.1	1.02 ±0.16	276 ±60.6	248 ±37.9	6.1 ±2.8	60.3 ±19.4	0.272 ±0.155
	MaV	7.5	28	465	1.24	334	270	11.4	92.7	0.68
	MiV	7.2	21	330	0.68	131	130	2.2	15.2	0.14
CUA P8	A	6.7 ±0.18	20.5 ±2.4	184 ±22.2	0.956 ±0.26	112 ±38.3	111 ±16.9	4.88 ±2.9	8.9 ±7.1	0.13 ±0.11
	MaV	7	24	230	1.31	140	142	10.9	28.8	0.5
	MiV	6.3	16	155	0.49	75	84	1.1	2.12	0.13

A = Average MaV = Maximum value MiV = Minimum value

Table 4: Tepalcingo-Axochiapan Aquifer: average, standard desviation, maximum value and minimum value

		pH	Tempe -rature	Dissolve d solids	Nitrate s	Alkalinit y	Hardnes s	Chlorid e	Sulfate s	Turbidit y
Maximu m limits .		6.5- 8.5		1000 mg/L	10 mg/L		500 mg/L	250 mg/L	400 mg/L	5 NTU
TP1	A	6 ±0.1 4	23.3 ±2.9	328 ±9.6	1.96 ±0.3	138 ±17.3	172 ±9.3	56.1 ±9.1	11 ±2.9	0.773 ±0.206
	MaV	6.3	27	344	2.5	169	186	68	14.7	1.01
	MiV	5.9	20	318	1.7	118	162	43	7.8	0.5
TP2	A	7 ±2.8	288 ±3.5	297 ±11.7	2.05 ±0.33	133 ±8.8	145 ±6.8	49.8 ±4.35	3.8 ±1.8	0.21 ±0.09
	MaV	7.4	33	3.06	2.5	143	155	54	5.9	0.28
	MiV	6.8	25	277	1.6	124	137	44	2.2	0.12
TP3	A	6.4 ±0.1	27.8 ±3.4	352 ±27.7	2 ±0.33	133 ±10.5	185 ±7.6	91 ±4.7	13.2 ±2.2	0.17 ±0.03
	MaV	6.5	33	378	2,5	150	191	97	15.6	0.23
	MiV	6.3	25	300	1.5	121	171	83.7	10.3	0.14
TP4	A	7.6 ±0.4	32 ±5.4	556 ±27.3	2.1 ±0.27	211 ±15.7	320 ±16.8	211 ±12.9	8.1 ±2.1	0.251 ±0.25
	MaV	8.1	41	592	2.6	230	335	230	10.9	0.76
	MiV	7.1	24	515	1.8	189	298	191	5.6	0.12
TP5	A	7.3 ±0.1 8	30.3 ±4.2	852 ±16.6	2.2 ±0.58	304 ±20.7	509 ±23.7	348 ±32.6	30.7 ±5.1	0.216 ±0.08
	MaV	7.6	37	871	3.2	334	535	391	37.8	0.34
	MiV	7.1	27	822	1.4	275	481	311	24.8	0.14
TP6	A	7.3 ±0.1 1	30 ±3.4	893 ±44.5	1.27 ±0.47	289 ±20.6	384 ±24.6	279 ±29.5	22.2 ±4.5	0.265 ±0.07
	MaV	7.5	37	947	2.1	318	422	311	28.8	0.37
	MiV	7.2	28	816	0.817	264	362	245	17.3	0.21
TP7	A	7.2 ±0.1	29.6 ±2,7	737 ±18.8	0.81 ±0.37	259 ±29.7	409 ±14.2	354 ±28.3	14.9 ±2.2	0.145 ±0.01
	MaV	7.3	35	760	1.2	308	426	391	17.8	0.16
	MiV	7	28	710	0.109	224	391	312	12.6	0.13
TP8	A	7.2 ±0.0 9	28.5 ±2.3	660 ±9.5	1.78 ±0.32	228 ±24.1	354 ±18.7	326 ±18.8	8.7 ±2.5	0.251 ±0.05
	MaV	7.3	33	672	2.4	262	372	356	11.4	0.31
	MiV	7.1	27	649	1.5	201	331	306	5.8	0.18

A = Average MaV = Maximum value MiV = Minimum value

Table 5: Total and fecal coliforms: Average, maximum and minimum values

Cuernavaca Aquifer				Zacatepec Aquifer			
Well		Total coliforms	Fecal coliforms	Well		Total coliforms	Fecal coliforms
CUEP1	A	2	1	ZP1	A	67	48
	MaV	100	50		MaV	300	300
	MiV	0	0		MiV	0	0
CUEP2	A	2	1	ZP2	A	85	84
	MaV	8	4		MaV	300	300
	MiV	0	0		MiV	0	0
CUEP3	A	0	0	ZP3	A	205	205
	MaV	3	0		MaV	600	600
	MiV	0	0		MiV	0	0
CUEP4	A	1	0	ZP4	A	7	4
	MaV	31	0		MaV	210	210
	MiV	0	0		MiV	0	0
CUEP5	A	118	56	ZP5	A	6	5
	MaV	1000	1000		MaV	300	300
	MiV	0	0		MiV	0	0
CUEP6	A	5	0	ZP6	A	24	4
	MaV	200	4		MaV	300	125
	MiV	0	0		MiV	0	0
CUEP7	A	1	0	ZP7	A	39	34
	MaV	8	0		MaV	300	300
	MiV	0	0		MiV	0	0
CUEP8	A	11	7	ZP8	A	6	5
	MaV	80	60		MaV	150	150
	MiV	0	0		MiV	0	0
CUEP9	A	2	1	ZP9	A	3	2
	MaV	36	36		MaV	46	46
	MiV	0	0		MiV	0	0
CUEP10	A	12	2	ZP10	A	4	2
	MaV	100	21		MaV	28	25
	MiV	0	0		MiV	0	0
				ZP11	A	19	16
					MaV	400	400
					MiV	0	0

A = Average MaV = Maximum value MiV = Minimum value

Table 5: (continued): Total and fecal coliforms: Average, maximum and minimum values

Cuautla-Yautepec Aquifer				Tepalcingo-Axochiapan Aquifer			
Well		Total coliforms	Fecal coliforms	Well		Total coliforms	Fecal coliforms
CUAP1	A	140	76	TP1	A	570	381
	MaV	400	210		MaV	1998	1998
	MiV	40	25		MiV	280	120
CUAP2	A	12	5	TP2	A	4	3
	MaV	90	55		MaV	20	20

	MiV	0	0		MiV	0	0
CUAP3	A	1	1	TP3	A	92	61
	MaV	5	5		MaV	350	243
	MiV	0	0		MiV	26	10
CUAP4	A	4	1	TP4	A	249	169
	MaV	210	6		MaV	500	350
	MiV	0	0		MiV	100	42
CUAP5	A	15	7	TP5	A	2	1
	MaV	210	180		MaV	10	6
	MiV	0	0		MiV	0	0
CUAP6	A	18	10	TP6	A	3	1
	MaV	210	210		MaV	7	3
	MiV	0	0		MiV	0	0
CUAP7	A	6	3	TP7	A	2	2
	MaV	210	210		MaV	13	7
	MiV	0	0		MiV	0	0
CUAP8	A	10	8	TP8	A	2663	2165
	MaV	210	210		MaV	6999	6999
	MiV	0	0		MiV	1045	1025

A = Average MaV = Maximum value MiV = Minimum value

Table 6: Wells Water classification according to hardness

	Alkalinity	Total Hardness (mg/L $CaCO_3$)	Hardness classification (mg/L $CaCO_3$)	Carbonate hardness (mg/L $CaCO_3$)	Non-carbonate hardness (mg/L $CaCO_3$)
CUEP1	144	75	Soft	74	0
CUEP2	78	43.6	Soft	43.6	0
CUEP3	95	48	Soft	48	0
CUEP4	65.4	38	Soft	38	0
CUEP5	204	196	Hard	196	0
CUEP6	182	91.4	Moderately hard	91.4	0
CUEP7	177	103	Moderately hard	103	0
CUEP8	325	350	Very hard	325	25
CUEP9	75	36.9	Soft	36.9	0
CUEP10	443	457	Very hard	443	14
ZP1	304	373	Very hard	304	69
ZP2	239	235	Hard	235	0
ZP3	219	179	Hard	179	0
ZP4	361	235	Hard	235	0
ZP5	241	213	Hard	213	0
ZP6	265	226	Hard	226	0
ZP7	302	228	Hard	228	0
ZP8	309	285	Hard	285	0
ZP9	316	422	Very hard	316	106
ZP10	296	601	Very hard	296	305
ZP11	282	544	Very hard	282	262
CUAP1	111	211	Hard	111	100
CUAP2	134	301	Very hard	134	167

CUAP3	317	390	Very hard	317	73
CUAP4	187	183	Hard	183	0
CUAP5	252	261	Hard	252	9
CUAP6	280	381	Very hard	280	101
CUAP7	276	248	Hard	248	0
CUAP8	112	111	Moderately hard	111	0
TP1	138	172	Hard	138	154
TP2	133	145	Moderately hard	133	12
TP3	133	185	Hard	133	52
TP4	211	320	Very hard	211	109
TP5	304	509	Very hard	304	205
TP6	289	384	Very hard	289	95
TP7	259	409	Very hard	259	150
TP8	228	354	Very hard	228	126

Table 7: Analysis discriminant

Funtion	Eigen-value	Chi-Square test	p- level	Cumulative percentage of variance	Variables
1	149.7	3762	0.000	62.7	Sulfates and turbidity
2	63.6	2774	0.000	89.3	Dissolved solids, total hardness and total alkalinity
3	9.3	1953	0.000	93.2	Total coliforms, fecal coliforms and nitrates

In the Tepalcingo-Axochiapan aquifer all the wells had both hardnesses, carbonated (caused by bicarbonates) and non-carbonate (probably caused by the high chloride levels found in the wells) (Table 4**).** With regard to bacteriological contamination, wells 8, 1 and 4 of the Tepalcingo-Axochiapan aquifer were the most contaminated with total coliform concentrations of 2663, 570 and 249 ufc/100 ml and fecal concentrations of 2165, 381 and 169 ufc/100 ml (respectively); followed by wells 3, 2 and 1 of the Zacatepec aquifer with total coliforms of 205, 85 and 67 ufc/100 ml and fecal coliforms of 205, 84 and 48 (Figures 4 and 5). The Cuernavaca wells, with the exception of well 5, had the least bacterial contamination, along with those of Cuautla, except well 1. In general, the majority of the wells studied in these two aquifers are in areas with drainage which reduces the direct discharge of wastewater into the ground and therefore the bacterial contamination of the aquifer (Figures 4 and 5). Well 5 of the Cuernavaca aquifer is in the Temixco Municipality, a zone where the lack of drainage and agricultural activity allows the infiltration of contaminants into the aquifer, deteriorating its quality. Generally speaking, all the wells of the four aquifers, with the exception of well 8 of the Tepalcingo-Axochiapan aquifer, fall within the bacteriological values recommended in the Ecological Criteria (< 1000) (SEDUE, 1989). for the water to be considered a suitable supply source for human consumption after purification. The problem arises in some wells which do not go through the disinfection process and therefore cannot be considered suitable for human consumption since they do not comply with the NOM 127- SAA1-1994 (SSA 2000) which requires that total and fecal coliforms are absent.

Since the water from the wells is for human consumption and only some wells undergo a chlorination process, physicochemical parameters were compared with the maximum permissible limits of NOM-127-SSA1-1994 (SSA 2000) (Tables 1, 2, 3 and 4). The average pH values that were outside the permissible limits were CUAP4 with 5.9, CUEP5 and TP1 with 6.0 and CUAP5 with 6.1, and were the most acid values measured. There were also 19 wells that had minimum values below the lower limit of the standard (< 6.5). The wells whose average hardness exceeded the limit were ZP10 with 601 mg/L, ZP11 with 544 mg/L and TP5 with 509 mg/L. The wells whose maximum value exceeded the limit were ZP9 (700 mg/L), ZP10 (784 mg/L), ZP11 (1424 mg/L) and TP5 (535 mg/L). Well ZP10 was the only one whose average (1138 mg/L) and maximum value (1316 mg/L) exceeded the limits of the standard for dissolved solids, while only the maximum value of well ZP11 (1520 mg/L) exceeded the said limit. The average, maximum and minimum values for chlorides which were above the permissible limits were found in wells TP5 (348, 391 and 311 mg/L), TP7 (354, 391 and 312 mg/L) and TP8 (326, 356 and 306 mg/L). In well TP6, only the average and maximum value exceeded the limit (279 and 311 mg/L). The remaining physicochemical parameters were below permissible limits.

The values of nitrates and dissolved solids reported by CONAGUA (2009), in the 1995 and 1998 samplings taken in the Cuernavaca aquifer, do not match those found in this study: the values for nitrates presented by CONAGUA were above the limits of the standard (> 10 mg/L), while those obtained in this study were below permissible limits.

As far as dissolved solids, the concentration level reported by CONAGUA (50 to 600 mg/L) is slightly lower than that obtained in this study (80.4 to 681 mg/L).

The study conducted by CONAGUA in 1989 in the Cuautla-Yautepec aquifer (CONAGUA, 2009a) concluded that the water is suitable for human consumption but that there are already infiltrations of wastewater in the upper section. In general, the wells analyzed in this study also showed water suitable for a potable water supply except for the pH levels in some wells which were below the limit of the standard; this could be corrected directly in the wells. Regarding the bacteriological contamination found, the wells can be considered acceptable as a supply source after disinfection (SEDUE, 1989).

In the study conducted by CONAGUA in 1982 in the Tepalcingo-Axochiapan aquifer, the general conclusion was that the water is fit for human consumption (CONAGUA, 2009b), however, in this study, 2 wells were outside the limits of the standard for pH, 1 for hardness and 4 for chlorides. Bacteriologically, one well is not a suitable supply and in another the highest value fell outside the values recommended in the Ecological Criteria.

4.0 Conclusions:

Due to the dissolved salts content in the aquifer, there is evidence of natural contamination due to the entrainment and dissolution of the said salts with the flow of water; there is a marked difference between the salts content of wells at higher altitude than those at lower altitude. The wells in the lowest zones of Tepalcingo-Axochiapan and Zacatepec are those with the highest values of hardness and, in general, dissolved solids. The wells located in the highest areas of the Cuernavaca Valley had the best quality for both salts content and total and fecal coliforms. The detection of bacteriological contamination in some specific points in the groundwater of Morelos, indicates that dilution is no longer sufficient in those places; this is evidenced by the filtration of bacteria from wastewater discharges directly into the ground and probably related to failures in the construction (SEMARNAT 1997a) and protection (SEMARNAT 1997b) of the wells. The high and medium vulnerability of materials, described in CONAGUA's technical reports, through which the water of the aquifer circulates, is an important factor which allows the infiltration of contaminants that alter the groundwater quality. Nevertheless, the dilution capacity of the aquifers has, until now, allowed more or less the same water quality to be maintained although there are zones where the anthropic contamination is evident, resulting in the degradation of the water quality of the aquifer.

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