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PRELIMINARY STUDY OF SELECTED DRINKING WATER SAMPLES IN MEXICO CITY

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Keywords: drinking water, bacteriological pollution, physicochemical quality, indicator bacteria

ABSTRACT

Mexico City is a critical example of drinking water supply and pollution, due to its population of nineteen million within a closed basin, 2300 m above sea level. The increasing urbanization has diminished the rate of aquifer reload, and a large amount of water is brought from lower and more distant zones, with increased energetic and ecological costs. To obtain data about drinking water at selected points in the city, 63 locations were sampled from April to December in 1989 (209 total samples). Where available, samples were taken from municipal network intakes, cisterns, roof tanks and kitchen tap water. At least one location was tested in 24 of the 27 Municipal Districts in the city. Measured physico-chemical parameters were: temperature, pH, alkalinity, hardness, chloride, sulfate, silica, total solids, suspended solids and conductivity (K_{25}). Biological analysis were total and faecal coliforms, and faecal streptococci. Based on principal component analysis ordination, data were arranged into six groups of water quality. Drinking water quality at the municipal network intakes was good in 53% of the cases, although pollution was detected when water was distributed by tank trucks, when it came from local wells in the State of Mexico, or when water had a high suspended solids content. Drinking water was often polluted inside the houses due to poor domestic handling.

RESUMEN

La Ciudad de México es un ejemplo crítico de los problemas de abasto de agua potable y contaminación, debido a su población de 19 millones habitando una cuenca cerrada, localizada a 2300 msnm. La creciente urbanización ha disminuído la tasa de recarga del acuífero que la provee del recurso. Un gran volumen de agua debe ser traído de zonas más bajas y distantes, con el consecuente incremento de los costos energéticos y ecológicos. Para generar datos acerca del agua potable en puntos seleccionados de la ciudad, se muestrearon 63 localidades de abril a diciembre de 1989 (209 muestras en total). Cuando fue posible, se tomaron muestras de la red municipal, cisternas, tanques y llaves de cocina. Por lo menos se muestreó un lugar en 24 de los 27 Distritos Municipales en la ciudad.Los parámetros fisicoquímicos medidos fueron: temperatura, pH, alcalinidad, dureza, cloruros, sulfatos, sílice, sólidos suspendidos, sólidos totales y conductividad (K_{25}). Los análisis biológicos fueron: coliformes totales, fecales y estreptococos fecales. Con base en un análisis de componentes principales, los datos fueron ordenados en seis grupos de calidad de agua.La calidad del agua para beber en las tomas de la red municipal fue buena en el 53% de los casos, aunque se detectó contaminación cuando el agua fue distribuida por carros-pipa, cuando provino de pozos locales en el Estado de México o cuando presentó un alto contenido de sólidos suspendidos. El agua para beber tuvo mayor contaminación en las muestras tomadas dentro de las viviendas debido al manejo incorrecto de la misma

INTRODUCTION

The constant growth of human population and its technological development has led to a worldwide increase in the demand for good quality water. Nevertheless, the relatively small amount of available freshwater, its unequal distribution over the continents, as well as its increasing pollution are turning good quality water into a scarce supply.

With a population of nineteen million (Mora 1992), Mexico City is a critical example of this problem. The city is located in the central area of the Mexican Volcanic Belt (MVB), which runs along latitude 19°N and acts as the natural boundary between

North and Central America (Verma 1985). It lies in an artificially opened endorrheic basin, the Valley of Mexico, 2300 m above sea level, surrounded by mountains as high as 5600 m above sea level (**Fig. 1**). A number of problems highly stress the City: since the 17th century A.D., sewage and unexploited rain water had to be discharged outside the basin to avoid floods in the lower areas of the City during the summer rainy season; nowadays, groundwater supplies are overdrawn, the remaining forests nearby are under strong deforestation pressure, and the population is still increasing due to both high birth rates and to uncontrollable immigration (Bassols 1977, DDF 1986, DGCOH 1982, Perló 1991). The above problems lead to a decrease in aquifer recharge and force water importation from lower and more distant zones. Increasing energetic, economic and ecological costs are thus burdening the Valley of Mexico, with nationwide impact, particularly considering that 20% of Mexico's population lives in the City.

For these reasons, Mexico City's water resources presently come from different sources (**Table I**), and such origins influence the quality of the water supply. On the other hand, the distribution of drinking water in Mexico is shared by three institutions: "Dirección General de Construcción y Operación Hidraúlica" (DGCOH), that supplies the City zone within the Federal District (DF); "Comisión Estatal de Aguas y Saneamiento", which operates the network distribution in different areas in the State of Mexico municipalities, and the "Comisión Nacional de Aguas del Valle de México", which operates the distribution in both DF and State of Mexico, under different criteria to the other companies. In addition each individual "delegation" (administrative district) and municipality in Mexico City is in charge of the network distribution and maintenance within their jurisdiction; there is not continuous system in the City's political divisions, and the drinking water is frequently supplied from local wells or carried by tank trucks. As a result, water quality can be strongly affected by its political delimitation. Therefore the drinking water supply is potentially quite variable in Mexico City. Drinking water is frequently related to incidence of gastrointestinal illnesses in the City (seventh cause of general mortality, and second cause of pediatric mortality, Velázquez *et al.* 1992). Moreover the groundwater extracted is becoming more saline and soils are becoming more highly alkaline due to the overdraft of the valley's aquifer; such phenomena are related to increasing pipe corrosion and electrical engine degradation in houses and industries.

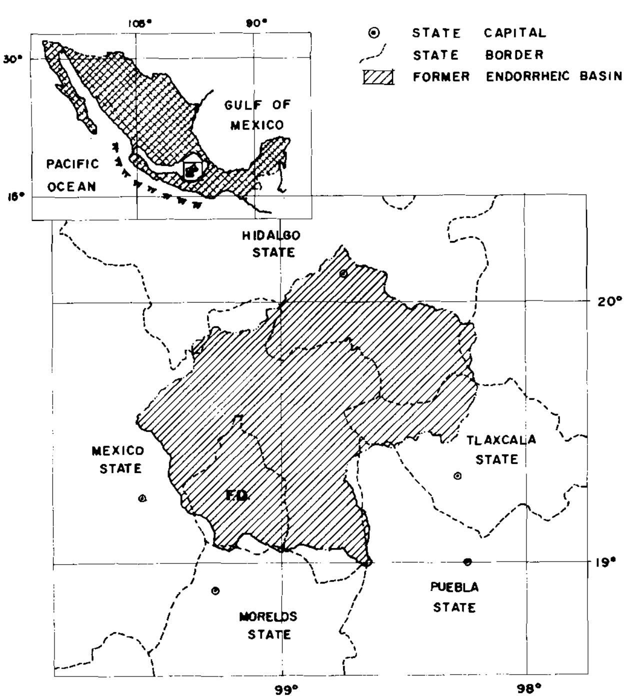

Fig. 1. Basin of the Valley of Mexico.

TABLE I. MEXICO CITY'S WATER SUPPLIES*

SOURCE	AMOUNT (m^3 sec^{-1})	%
Río Lerma Basin	11	18.3
Río Cutzamala Basin	4	6.6
Valley of Mexico aquifers	40	66.8
Reused treated water	2	3.3
Regulated surface water	3	5.0
Total	60	100.0

* From Guerrero (1991). Reproduced with permission of Fondo de Cultura Económica, México

Almost all domestic residences with municipal network services in Mexico City have high capacity containers for chlorinated drinking water (roof tanks and cisterns) in order to ensure sufficient supply of water for the dry season (October through May), when there is a risk of water shortage. In this way, the water supply from such containers is continuous, except for those cisterns which are used as secondary reservoirs and are not continuously connected to the roof tanks.

These reasons led us to perform this study to obtain data on the quality of the water supplied by the municipal network in comparison to the water quality inside the domestic network in selected points of Mexico City.

MATERIAL AND METHODS

Samples were taken from two to five sources of sixty-three locations in Mexico City from April to December 1989. The sources were the main municipal network intakes, cistern, roof tank and kitchen tap water. At least one location was checked in 24 out of 27 Municipal District in Mexico City, except for Los Reyes, Chimalhuacán and Milpa Alta, which have lower population densities. The mean sampling number was three for each District, and the highest number of sampled locations (seven) was in Iztapalapa. The total number of samples was 209.

Some physicochemical (ASTM 1989, APHA 1985) and bacteriological parameters (APHA 1985) were analyzed: Temperature (°C, mercury thermometer), pH (potentiometric), conductivity (K_{25}, potentiometric), total and suspended solids (gravimetric), total and phenolphtalein alkalinity (sulfuric acid titration, potentiometric, pH end = 4.7), total and calcium hardness (EDTA titration), silica (SiO_2, colorimetric), sulfate (turbidimetric), chloride (argentometric titration), total coliforms, faecal coliforms and faecal streptococci (tested by Multiple-tube Fermentation Technique -cells/100 ml-).

The bacteriological analysis were carried out within 2 to 24 h after the sampling. Samples were maintained refrigerated at 4°C. To neutralize chlorine, 1 mL of 10% sodium thiosulfate was added to 1 L of sample. Temperature, pH and conductivity were measured *in situ*. Alkalinity and hardness were analized within the first 24 h after sampling, and were performed on refrigerated samples. The remaining physicochemical parameters were applied within 7 days after sampling, with samples treated with 1 mL chloroform per L of sample and refrigerated at 4°C to inhibit microbial activity (Ros 1979).

RESULTS AND DISCUSSION

Table II shows results from the 209 samples taken from housing in Mexico City. Data are presented separately for municipal service and indoor sources. Average physicochemical results varied little between housing storage and circulating water; bacteriological numbers varied more, as will be discussed later.

Municipal network intakes

Principal component analysis classified the municipal network intakes into six chemical quality groups (the first vector explaining 57.4% of variability with dissolved solids and conductivity as relevant parameters; the second, explaining 13.1% of variability with faecal streptococci and suspended solids as relevant parameters; **Fig. 2**). There is a gradual decrease in salt content (summarized by conductivity, and including bicarbonates, chlorides, sulfates, calcium, magnesium, sodium plus potassium, and silica) from group **a** to **f**. A higher salt content is observed in the northern part of the city (group **a** and **b**; **Fig. 3**, **Table III**) and decreases to the south and west (group **d**, **e** and **f**; **Fig. 3**, **Table III**). Such results can be related to the City's water supplies: out of town, the Cutzamala and Lerma systems are freshwater and enter to city from the south-west; local wells feed the city in the south-east (Xochimilco, DF), and in the north-east (Ecatepec, close to the Texcoco lake in the State of Mexico) (DGCOH 1982). Those related to Texcoco (Ecatepec) are from local supplies and had a higher saline content maybe due to their high soil alkalinity. Those connected to Xochimilco are freshwater (INEGI 1987). Furthermore, there is a clear gradient of local climate in the Valley of Mexico, drier in the north than in the south (DGCOH, 1982).

Although none of the quality groups surpassed the World Health Organization's (WHO) guiding values or the acceptable limit set by the "Secretaría de Salubridad y Asistencia" (SSA 1996) for total dissolved solids (1000 mg L^{-1}; WHO 1995; NOM-127-SSA1-1994), some samples of group **a** approached the limits. Some samples surpassed the 1988 Mexican standard for alkalinity (400 mg L^{-1}, DOF 1988) in this group and were classified as "very hard" (PAHO 1987). Water in groups **b** and **c** is respectively "very hard" and "hard" as well. Samples in groups **d** and **e** were classified as "moderately hard", and those in group **f** as "soft" (PAHO 1987). Sites with group **a** and **b** water are prone to pipe and boiler encrustation problems, while locations with group **f** water will be susceptible to metallic pipe corrosion (although such effects could be diminished by the high silica content of water). Sulfates, sodium, calcium and chlorides did not exceed the WHO guidelines (500 mg L^{-1}, 200 mg L^{-1}, 100-300 mg L^{-1} 250 mg L^{-1} respectively; WHO 1995) or the acceptable limit set by the SSA (400 mg SO_4 L^{-1}, 200 mg Na L^{-1}, 250 mg Cl L^{-1}; NOM-127-SSA1-1994).

Silica is a parameter without quality restriction in Mexico. Nevertheless, it is interesting to compare its values to those of continental waters because high silica content can place an undesirable risk on high-pressure boilers when dealing with untreated water (ASTM 1982). Measured silica was high (from 26

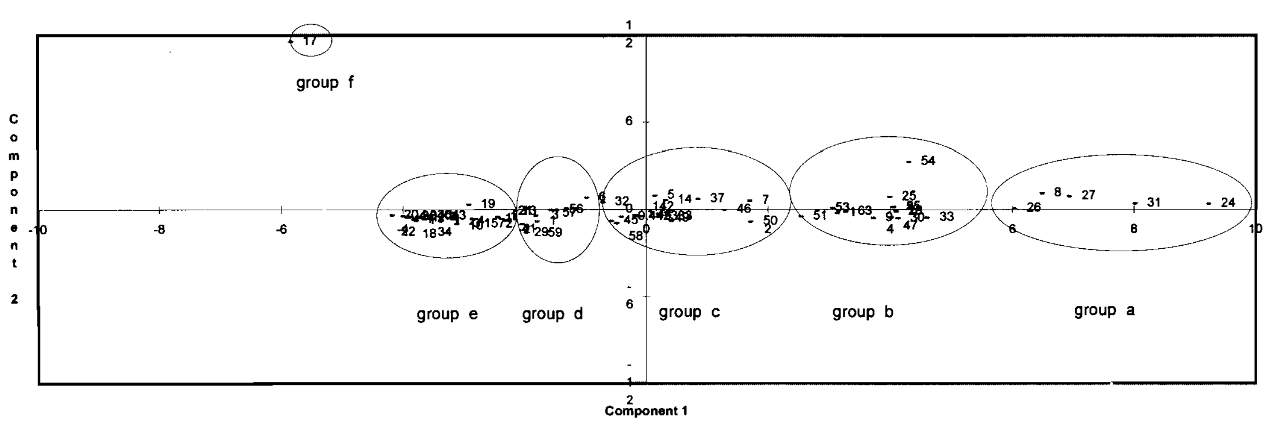

Fig. 2. Groups of water quality from principal component analysis, for Mexico City

TABLE II. MEAN, STANDARD DEVIATION (SD), MINIMUM (m), AND MAXIMUM (M) VALUES FOR SAMPLED HOUSEHOLDS IN MEXICO CIT

	All data n = 209				Municipal intakes n = 58				Cisterns n = 31				Roof tanks n = 49				
VARIABLES	**Mean**	**SD**	**m**	**M**	**Mean**	**SD**	**m**	**M**	**Mean**	**SD**	**m**	**M**	**Mean**	**SD**	**m**	**M**	**M**
Temperature	20	3	10	37	20	5	15	25	21	3	16	26	20	2	10	25	2
pH	7.5	0.4	6.5	8.6	7.3	0.3	6.5	8.1	7.6	0.5	6.5	8.6	7.5	0.3	6.7	8.1	7.
Tot. Alk.	203	110	33	500	199	115	33	500	224	113	34	445	199	109	47	468	19
Phenolph. Alk.	0.2	1.6	0.0	20.0	0.0	0.0	0.0	0.0	1.0	4.1	0.0	20.0	0.0	0.0	0.0	0.0	0
Tot. Hardness	133	68	21	326	130	71	21	318	139	66	21	292	131	68	47	113	13
Ca^{++} Hardness	53	25	12	116	51	26	13	116	57	25	12	111	52	26	24	114	5.
Mg^{++} Hardness	80	44	8	212	79	46	8	203	82	43	8	182	79	44	21	199	7
$CO_3^{=}$ (1)	0.1	1.0	0.0	12.0	0.0	0.0	0.0	0.0	0.6	2.4	0.0	12.0	0.0	0.0	0.0	0.0	0
HCO_3^- (1)	125	70	20	411	121	70	20	305	136	69	21	271	122	66	28	285	12
OH^- (1)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cl^-	38	36	0	198	38	39	0	198	45	41	0	158	37	36	4	146	3
$SO_4^{=}$	23	19	2	95	23	21	3	95	22	18	2	78	22	19	2	92	2
Ca^{++} (2)	21	10	5	47	21	10	5	47	23	10	5	44	21	10	10	46	2
Mg^{++} (2)	20	11	2	52	19	11	2	49	20	10	2	44	19	11	5	48	1
Na^+ and K^+ (3)	27	32	0	169	28	34	0	169	34	37	0	150	27	32	0	154	2
SiO_2	58	17	21	89	57	17	26	89	61	17	29	89	59	18	23	86	5
Tot. Solids	354	194	92	946	351	200	101	946	387	199	92	800	347	194	116	874	34
Susp. Solids	2.0	11.0	0.0	161.0	4.0	20.0	0.0	161.0	2.0	2.8	0.0	14.0	1.0	1.5	0.0	8.0	1.
Dis. Solids	352	183	92	785	347	180	101	785	385	196	92	786	346	192	116	866	34
K_{25}	507	291	71	1392	494	302	71	1392	559	301	80	1200	496	290	144	1263	49
Total Colif.	576	838	0	>2000	251	601	0	>2000	1005	921	0	>2000	634	893	0	>2000	63
Faecal Colif.	94	391	0	>2000	35	258	0	>2000	175	472	0	>2000	90	401	0	>2000	8
Faecal Strept.	10	56	0	600	1	4	0	25	45	135	0	600	5	17	0	113	4

Calculated from: (1) total and phenolphtalein alkalinity (APHA 1985), (2) total and calcium hardness, (3) ionic balance (APHA 1985). Units are in m
alkalinity and hardness, mg $CaCO_3$ L^{-1}; K_{25}, μSiemens cm^{-1} at 25 °C; biological indicators, cells/100 mL

TABLE III. MEAN (Mn), STANDARD DEVIATION (SD), MINIMUM (m), AND MAXIMUM (M) VALUES FOR THE SIX WATER QUALITY GROUPS
FROM MUNICIPAL NETWORK INTAKES)

VARIABLES	**Group a**				**Group b**				**Group c**				**Group d**				**Grou**	
	Mn	**SD**	**m**	**M**	**Mn**	**SD**	**m**	**M**	**Mn**	**SD**	**m**	**M**	**Mn**	**SD**	**m**	**M**	**Mn**	**SD**
Temperature	22	1.6	20	24	22	2.1	18	25	21	2.1	17	25	18	3.1	15	25	20	1.4
pH	7.2	0.5	6.5	7.6	8.0	0.3	6.5	7.9	7.0	0.3	6.8	8.1	7.4	0.2	7.0	7.6	7.3	0.3
Tot. Alk.	405	71	338	500	331	29	273	389	214	41	128	296	137	30	82	178	80	14
Phenolph. Alk.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tot. Hardness	282	27	236	318	206	22	169	257	128	17	77	155	101	22	88	161	62	8
Ca^{++} Hardness	108	8	98	116	80	8	67	98	58	9	35	68	37	6	30	51	28	3
Mg^{++} Hardness	174	21	138	203	127	22	102	181	78	15	32	101	64	17	49	110	33	7
$CO_3^{=}$	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
HCO_3^-	247	43	206	305	202	18	166	237	131	25	78	181	84	18	50	109	49	9
OH^-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cl^-	120	48	72	198	66	24	38	120	38	24	4	101	18	13	5	40	8	3
$SO_4^{=}$	66	20	43	95	42	19	14	90	17	10	3	42	16	9	3	32	11	5
Ca^{++}	43	3	39	47	32	3	27	39	20	4	14	27	15	3	12	20	11	1
Mg^{++}	42	5	34	49	31	5	25	44	19	4	8	25	16	4	12	27	8	2
Na^+ and K^+	92	54	37	169	53	20	21	108	28	20	0	89	12	16	0	42	2	2
SiO_2	76	2	73	79	72	9	56	89	69	17	49	115	52	9	36	63	39	11
Tot. Solids	772	139	640	946	562	58	502	732	361	56	260	450	232	43	183	308	150	24
Susp. Solids	1.0	0.6	0.0	1.0	1.0	2.5	0.0	9.0	1.0	1.1	0.0	5.0	1.0	1.5	0.0	5.0	2.0	1.7
Dis. Solids	771	138	640	945	561	55	502	723	360	55	260	445	231	41	183	303	148	22
K_{25}	1095	221	855	1392	823	70	725	991	513	101	343	691	338	85	245	486	198	29
Total Colif.	215	220	0	>2000	225	559	0	>2000	582	857	0	>2000	27	68	0	220	27	96
Faecal Colif.	6	10	0	>2000	1	5	0	15	134	495	0	>2000	0		0	0	1	2
Faecal Strept.	1	1	0	2	3	7	0	25	1	2	0	8	0		0	0	0	0.3

* Only one data point. Units are in mgL^{-1}, except for temperature, °C; alkalinity and hardness, mg $CaCO_3$ L^{-1}; K_{25}, μSiemens cm^{-1} at 25°C; biological indic

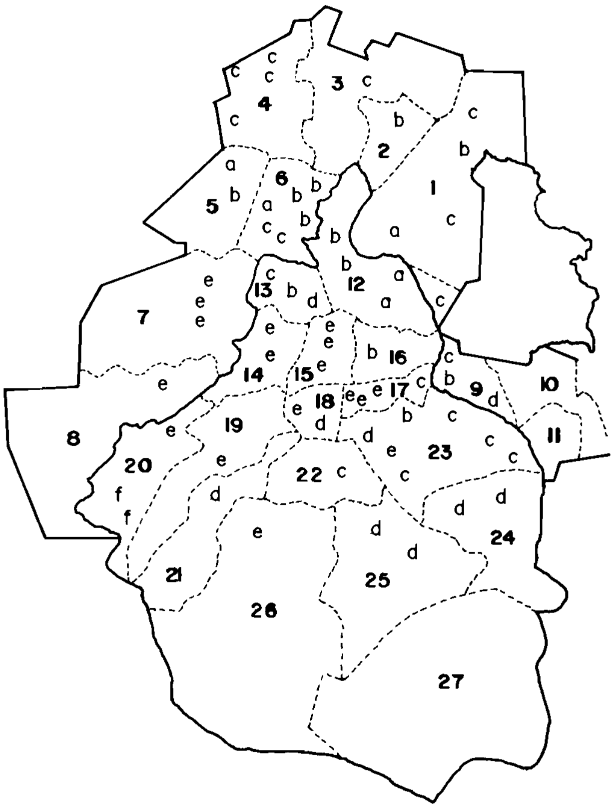

Fig. 3. Groups of water quality (a to f) from municpal network intakes in Mexico City. Political divisions: State of Mexico, 1. Ecatepec, 2. Coacalco, 3. Tultitlán, 4. Cuautitlán Izcalli, 5. Atizapán de Zaragoza, 6. Tlalnepantla, 7. Naucalpan, 8. Huixquilucan, 9. Nezahualcóyotl, 10. Chimalhuacán, 11. Los Reyes. Federal District, 12. Gustavo A. Madero, 13. Azcapotzalco, 14. Miguel Hidalgo, 15. Cuauhtémoc, 16. Venustiano Carranza, 17. Iztacalco, 18. Benito Juárez, 19. Álvaro Obregón, 20. Cuajimalpa, 21. Magdalena Contreras, 22. Coyoacán, 23. Iztapalapa, 24. Tláhuac, 25. Xochimilco, 26. Tlalpan, 27. Milpa Alta

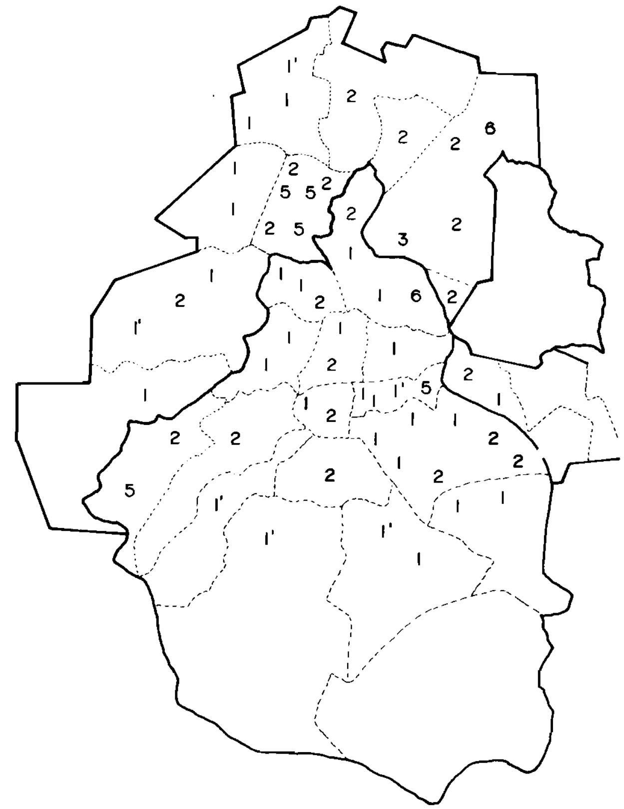

Fig. 4. Bacteriological quality of water from municipal network intakes in Mexico City

		TC	FC	FS
1	Drinking water	2[1]	0[1]	
1'	Slightly polluted	10[2]	0[2]	
2	Direct contact allowed		200[3,4]	61[3]
3	Agricultural use for irrigation of directly consumed vegetables	<1000[4]		
4	Industrial use not involving direct water processing		<1000[4]	
5	Recreational use without direct human contact. Flora and fauna conservation	>2000	<2000[4]	
6	Very polluted water	>2000	>2000	

[1]DOF 1988, [2]PAHO 1987, [3]USEPA 1986, [4]SEDUE 1988

TC= total colif., FC= faecal colif., FS= faecal strept.

to 89 mg SiO_2 L^{-1}); values exceeded those most often seen in natural waters with a pH under 8.5 (usually not more than 80 mg SiO_2 L^{-1}; Margalef 1983, Hutchinson 1957); the MVB is a volcanic zone, rich in near-surface deposits of young, erodible volcanic ash that could explain such figures; nevertheless, SiO_2 concentrations published for sodic-crater lakes in the MVB gave much lower values (under 39 mg SiO_2 L^{-1}, Vilaclara *et al.* 1993).

Following accounts of published criteria (USEPA 1986, DOF 1988, SEDUE 1988), a second bacteriological classification was done with the municipal network intakes, also resulting in six groups of bacteriological water quality (**Fig. 4**). Bacteriological qualities were highly variable throughout all the studied area (**Fig. 4**), although its qualities are generally worst in some municipal districts in the northern part of the city.

Taking into account both classifications, group **c** was mainly located in the northern and eastern areas of the city, and presented high levels of pollution due to total and faecal coliforms. Group **f** (mainly in the southwest) was also polluted by total coliforms and faecal streptococci. The suspended solids had their highest values in this group. The solids could be a result of broken or badly preserved pipes, a continuous health risk due to microorganism pollution originated from the drainage system (Ezcurra 1990). Groups **a** and **b** showed pollution mainly due to total coliforms. Groups **d** and **e** presented less pollution, and the water is found mainly in the south, downtown and west of the city.

Cisterns, roof tanks and kitchen tap water

The percentages of indoor samples with values not exceeding Mexico's drinking water criteria (2 total coliform cells/100 mL, 0 faecal coliform cells/100 mL; NOM-127-SSA1-1994) were calculated in addition to a "slight pollution" criteria (below 10 and 0 cells/100 mL respectively; PAHO 1988). Compared with the 47 % of municipal network intakes that were not safe for drinking, we found that 73% of all kitchen tap water samples were bacteriologically polluted, and therefore, unsafe (**Table IV**). This fact means that bacteriological pollution increased 26% from municipal network intakes to kitchen tap probably due to impro-per handling. There was also a high proportion (73%, 65% respectively) of undrinkable water in cisterns and roof tanks (**Table IV**).

The main problems observed were infrequent cleaning and disinfection of cisterns and roof tanks (less than the regular criteria of "twice a year and after every municipal network breaking"); an inadequate isolation of water inside storage tanks, allowing contact with bacteriologically polluted air (Mexico City reported 40% of open air faecalism, that is, people who defecate in gardens, building sites or in the streets; Vizcaíno 1980); and finally, using cisterns designed to provide water only when the municipal supply is cut (old stored water).

TABLE IV. PERCENTAGE OF DRINKABLE AND UNDRINKABLE WATER FOR THE MUNICIPAL NETWORK INTAKES, CISTERNS, ROOF TANKS AND KITCHEN TAP WATER SAMPLED

Sample locality	Bacteriological quality: Drinkable no. of samples		Undrinkable no. of samples		Total number of samples
Municipal network intakes	31	53%	27	47%	58
Cisterns	7	22%	24	78%	31
Roof tanks	17	35%	32	65%	49
Kitchen taps	17	27%	46	73%	63

CONCLUSIONS

Drinking water surveyed in Mexico City generally had a good physicochemical and poor bacteriological quality (drinkability of 53%). Nevertheless, municipal water was not chemically drinkable in some sampled locations at Tlalnepantla and Atizapán, mainly due to high alkalinities (group **a**). Municipal water was not bacteriologically drinkable when coming from tank trucks, from local wells in the State of Mexico, or when the water had a high content of suspended solids (group **f**). However, the water frequently became biologically polluted inside the domestic distribution network, mainly due to inadequate storage, lack of proper cleaning and disinfection of cisterns and roof tanks, and improper isolation from the polluted environment, together with old stored water in cisterns. Silica was found to have high concentrations that could give problems to high-pressure boilers with untreated water, although this does not endanger public health.

Control resampling of eleven locations (44 samples) in Mexico City during the period 1992 through 1994 showed that conditions of drinking water pollution were not essentially changed, even after the broadcast of media programs for educating the population about a conscientious use of water.

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