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Evaluation of the Water Quality of Three Water Supply Wells in the Urban Area of Chilpancingo, Guerrero, México

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Abstract: Water quality is essential and indispensable for human and environmental health, however, the growing demand for water resources to satisfy needs has become a global problem and a priority for public health, due to water discharges. waste without any treatment, which has caused a decrease in the availability and contamination of surface and groundwater. Because the supply of water for human use and consumption must have adequate quality to prevent and avoid the transmission of diseases. The physicochemical and microbiological quality of the water from 3 underground wells that supply the population of Chilpancingo was evaluated, and it was determined if it is suitable for human use and consumption. The parameters that were determined were pH, Total Dissolved Solids, Ammoniacal Nitrogen, Nitrites, Nitrates, Sulfates, Total Hardness, Chlorides, Total Coliforms and Fecal Coliforms, in addition to the presence of Escherichia coli and Fecal Streptococci. The results indicated that the water from the three wells that supply the population does not comply with the Maximum Permissible Limits, established by NOM-127-SSA1-1994. The presence of Escherichia coli and fecal Streptococci are an indicator of fecal contamination from human sources or warm-blooded animals, which is why this water is not suitable for human consumption and is considered unsafe for the health of the population.

Keywords: Water Pollution, Groundwater, Public Health, *Escherichia coli*

1. Introduction

Water is an indispensable natural resource for human life and environmental sustainability; however, population growth has generated an increasing demand for this water resource, causing its scarcity [1]. Water, in addition to being used for human consumption, is used in other anthropogenic activities such as domestic use, agricultural and industrial activities, energy production, among others, thus maintaining economic activities [2]. On the other hand, the discharge of wastewater into aquatic ecosystems without any prior treatment has led to the deterioration of the quality of surface and groundwater. which are the main sources from which human populations are supplied [3, 4].

Water pollution, a product of human activities, is one of the most concerning problems worldwide, because every day the availability of water is less and the little water available to meet the basic needs of the population may contain some type of contaminant or pathogen that can cause diseases [5]. In the United Nations World Water Development Report, it mentions that more than two billion people do not have access to this water resource with the required quality for human use and consumption, therefore, waterborne diseases are associated with a significant burden of disease worldwide, especially among populations lacking access to the most basic water and sanitation services, being responsible for approximately two million deaths per year [6].

The main risk of waterborne disease transmission in public groundwater supply systems is pollution with fecal matter through infiltrations, with microbiological contamination being the main cause of more than 90% of intoxications [7]. The main microorganisms transmitted through water include bacteria (*Escherichia coli*, *Salmonella spp.*, *Shigella spp.*, *Vibrio cholerae*), viruses (enterovirus, rotavirus, adenovirus), and protozoa (*Giardialamblia*, *Cryptosporidiumparvum*, *Entamoebahistolytica*) and helminths (*Ascarislumbricoides*).

The supply of water for human use and consumption with adequate quality is essential to prevent and avoid the transmission of gastrointestinal and other diseases, for which it is necessary to establish limits in terms of its microbiological, physical, organoleptic, chemical and radioactive characteristics. In order to ensure and preserve the quality of water in supply systems until it is delivered to the consumer, water must undergo potabilization treatments. In Mexico, Official Mexican Standard NOM-127-SSA1-1994 [8] establishes the permissible limits for water quality and drinking water treatment for human use and consumption, which must be met by public and private water supply systems or by any individual or legal entity that distributes water throughout the country. The microbiological, physical, chemical, radioactive and organoleptic characteristics are part of the treatment for its potabilization based on the type of contamination. The potabilization of water from a particular source must be based on quality studies and tests for treatment at the laboratory level to ensure its effectiveness [8].

In the city of Chilpancingo, Guerrero, southern Mexico, there is a shortage of water due to rapid and disorderly urban growth in recent years, the lack of infrastructure projects to expand and improve the drinking water network, as well as the decrease in the availability of groundwater and surface water in the hydrological basin where the city is located. The population has found itself in the need to satisfy the scarcity of water through the supply by means of pipes, without guaranteeing the quality, affecting their family economy and putting their health at risk, due to the use of untreated water. Monitoring water sources to identify the origin of fecal contamination is of utmost importance to correct deficiencies, eliminate sources of contamination, locate alternative water sources or implement a treatment that reliably reduces pathogenic microorganisms in the water supplied to this population.

This research is focused on evaluating the physicochemical and microbiological quality of water extracted from three supply wells and supplied by pipes to the population of the urban area, according to the Mexican Official Standard NOM-127-SSA1-1994, "Environmental health, water for human use and consumption, permissible quality limits and treatments that water must undergo for its potabilization", in order to identify the presence of contamination indicators that put the health of the population at risk.

2. Materials and Methods

2.1. Study Area

The urban area of the city of Chilpancingo de los Bravo is located in the center of the State of Guerrero, southern Mexico, between parallels 17°37'45" and 17°37'11" north latitude and meridians 99°22'36" and 99°59'28" west longitude, at an altitude of 1242-1350 msnm, and has a warm sub-humid climate (Figure 1). The city has a total population of 225,728 inhabitants and has a total of 58,037 inhabited private homes, of which 1,011 have no toilet or sanitary facilities and 586 do not have drainage [9]. It extends over an approximate area of 82.6 km2 along the Huacapa River, which captures practically all of the rainwater runoff. In the vicinity of the north-south course of the Huacapa River, there are an undetermined number of unregistered or clandestine groundwater extraction wells that supply the population, mainly during the dry season. The city has a wastewater treatment plant, located south of the urban area, with an activated sludge process and a capacity of 250 lps, which discharges into the Huacapa River and is operated by the Comisión de Agua Potable y Alcantarillado de Chilpancingo (CAPACH).

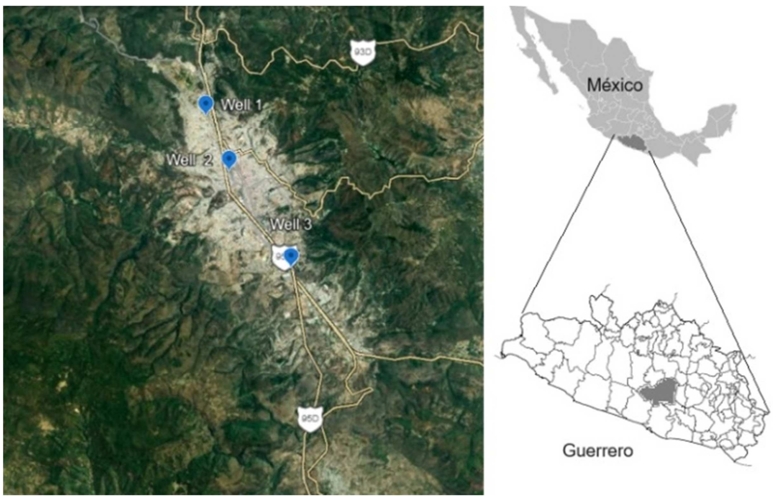

Figure 1. *Location of three groundwater extraction wells to supply the population of Chilpancingo de los Bravo, Guerrero, Mexico.*

2.2. Sampling

Sampling was performed in March 2022 in 3 groundwater wells located near the Huacapa riverbed, which supply water to the population of Chilpancingo, Guerrero (Figure 1). Sampling was carried out according to the sanitary procedures established in the Mexican Official Standard NOM-014-SSA1-1993 for sampling water for human use and consumption in public and private water supply systems [10]. For physicochemical analyses, single samples were collected in amber glass bottles. Samples for microbiological analysis were taken in 250-ml sterilized plastic bottles with hermetic lids and wide mouths. Samples were transported and stored at 4°C at the Environmental Chemical Analysis Laboratory of the Autonomous University of Guerrero until analysis.

2.3. Physicochemical Analysis

The samples were kept refrigerated in the Environmental Chemical Analysis Laboratory of the Autonomous University of Guerrero until the time of analysis. Different physicochemical parameters were selected for analysis in the samples collected in the study area: Temperature, Hydrogen Potential (pH), Electrical Conductivity (Ce), Total Dissolved Solids (TDS), Total Alkalinity, Total Hardness, Chlorides, Nitrates, Nitrites, Sulfate, Turbidity, Total and Fecal Coliforms and *Escherichia coli*.

2.4. Microbiological Analysis

The microbiological analyzes were carried out following the procedures established in the Mexican Standard NMX-AA-042-SCFI-2015 [11].

2.4.1. Positive and Negative Control Insolates

All previous quality assurance activities in microbiology were considered for the preparation of media, materials and their corresponding controls. Positive and negative controls with control strains were included in parallel to establish continuity according to the quality control system. For total coliforms the positive control was *Escherichia coli* and the negative control was *Staphylococcus aureus*, an organism that is Gram positive and does not ferment lactose. For fecal coliforms and *E. coli*. *E. coli* was used as a positive control and *Enterobacter aerogenes* as a negative control.

2.4.2. Presumptive Test

For sample preparation and inoculation of the medium prior to testing, the sample was mixed by shaking vigorously to obtain a uniform distribution of the microorganisms depending on the nature of the water and the expected bacterial content, and the necessary dilutions were made at this stage. Dilutions were made and aliquots were inoculated into the presumptive medium. For aliquots greater than or equal to 10 mL, tubes containing double concentration culture medium were used. Series consisting of at least 3 dilutions were used: 10 mL, 1.0 mL and 0.1 mL of sample according to the expression of results required, each series containing 3 or 5 tubes. The inoculated tubes were incubated from 24 h to 48 h ± 3 h at 35ºC ± 0.5ºC. The incubated tubes were examined after 24 h of incubation and those that showed turbidity and gas formation inside the inverted tube (Durham tube) were recorded as a positive reaction. Incubation was continued for 24 h ± 3 h in those tubes that did not show these changes and examined again.

2.4.3. Confirmation Test

Gas formation and turbidity are presumptive results of coliforms and confirmatory tests are necessary. Each of the tubes with a positive reaction were seeded to tubes with broth for confirmatory tests according to the determination of total coliforms, thermotolerant fecal coliforms and/or *E. coli*. To confirm the presence of coliform organisms, tubes were incubated with reseeded bright green bile lactose broth at 35ºC ± 0.5ºC and examined for gas production over a 24 h to 48 h ± 3 h period. To confirm the presence of fecal coliform organisms (thermotolerant), tubes were incubated with EC broth or reseeded bright green bile lactose broth at 44.5°C ± 0.2°C for 24 h ± 2 h and gas production was examined. To confirm the presence of *E. coli*, the reseeded tryptone water or peptonized water tubes were incubated at 44.5°C ± 0.2°C for 24 h ± 2 h. After the incubation period, 0.2 mL to 0.3 mL of Kovac's reagent was added to all the reseeded tubes; the development of a red coloration at the top of the tube after gentle agitation denoted the production of indole, characteristic of the presence of *E. coli*, to enumerate the MPN/100 mL of E. coli, the series of tubes used for expression of results was taken into account.

2.4.4. Oxidase Test for Total Coliforms

Some bacteria found in water may meet the definition of coliform organisms in many respects, but they are capable of producing gas from lactose only at temperatures below 37 °C. As a result, they give negative results in routine confirmatory tests for coliform organisms, and their presence in water is not usually considered significant. Species of the genus *Aeromonas* spp, which are naturally present in water, interfere with the determination only at temperatures of 37 °C or lower, the oxidase confirmatory test is required only when total coliforms are being determined [11]. The oxidase test was carried out with pure subcultures of lactose-fermenting organisms grown on nutrient agar medium as follows: two to three drops of freshly prepared oxidase reagent were placed on a filter paper placed on a Petri dish. With a glass rod, wooden stick or platinum metal handle with a rounded tip, a small portion of the colony was dispersed on the filter paper with oxidase reagent. The appearance of a deep blue-purple color within 10 s was considered as a positive reaction and negative reaction was taken as the absence of color appearance.

2.4.5. Expression of Results

With the number of tubes from the confirmatory tests that gave positive reactions, the most probable number of coliform, thermotolerant and *E. coli* organisms in 100 mL of sample was calculated, referring to the MPN statistical tables [11].

3. Results

In this research, the quality of groundwater from three supply wells in the urban area of the city of Chilpancingo, Guerrero, Mexico, was evaluated. The sampling and the analyses were carried out on March.

3.1. Physicochemical Parameters

The values of the physicochemical parameters analyzed according to NOM-127-SSA1-1994 [7], their arithmetic means ± standard deviation (AM ± SD) are presented in Table 1. Based on the pH results obtained, we can observe that the groundwater is neutral to slightly alkaline, with an arithmetic mean of 7.4. The highest values of Ce, TDS and Salinity were obtained in well 2, and the lowest values in well 1. The same behavior is observed in the values of ammoniacal Nitrogen, ammonium ion, Nitrites, Nitrates and Sulfates (well 2 > well 3 > well 1). The results of total alkalinity, bicarbonates and total hardness show a different behavior, the highest values were obtained in well 3, while the lowest values were obtained in well 1. On the other hand, no concentrations of carbonates or hydroxides were detected in the three wells analyzed.

Table 1. *Physicochemical analysis of the water of three sampled wells in the city of Chilpancingo, Guerrero, Mexico.*

Sample	Well 1	Well 2	Well 3	AM	SD
pH (pH units)	7.4	7.3	7.5	7.4	0.1
Ce (µs/cm)	944	1081	1003	1009	69
TDS (mg/L)	462	527	492	493	33
Salinity (ppm)	0.464	0.532	0.495	0.5	0.03
Total alkalinity (mg/L)	678	871	911	820	124
Bicarbonates (mg/L)	679	871	911	820	124
Carbonates (mg/L)	0	0	0	0	0
Hydroxides (mg/L)	0	0	0	0	0
Ammoniacal Nitrogen (mg NH_3//L)	0.6	1.08	0.84	0.84	0.24
Ammonium ion (mg NH_4^+/L)	0.65	1.17	0.91	0.91	0.26
Nitrites (mg NO_2^-/L)	4.4	8.8	8.8	7.33	2.54
Nitrates (mg NO_3^-/L)	0.07	0.15	0.09	0.91	0.26
Sulfates (mg SO_4^{-2} /L)	380	402	396	393	11
Total hardness (mg $CaCO_3$/L)	551	629	682	621	66
Total chlorides (mg/L)	295	271	271	279	13.6

* pH = Hydrogen Potential; Ce = Electrical conductivity; TDS = Total Dissolved Solids

3.2. Microbiological Parameters

The contents of organisms resulting from the analysis of the water samples are presented in Table 2.

Table 2. *Results of the microbiological analyses of the water of three sampled wells in the city of Chilpancingo, Guerrero, Mexico.*

Sample	Well 1	Well 2	Well 3
Total Coliforms (MPN/100mL)	40	52	38
Fecal Coliforms (MPN/100mL)	15	12	20
Escherichia coli	PRESENCE	PRESENCE	PRESENCE
Enterococcus faecalis	PRESENCE	PRESENCE	PRESENCE

* MPN = Most Probable Number

Based on the results obtained, it is observed that the water of the three wells has the presence of total and fecal coliforms. The Most Probable Number (MPN) of Total coliforms is higher in well 2 > well 1 > well 3, and for Fecal coliforms the behavior is different, well 3 > well 1 > well 2. Similarly, *Escherichia coli* can be observed in the three sampled wells, as well as the presence of *Enterococcus faecalis*.

4. Discussion

4.1. Compliance with Mexican Official Standard

The results of the physicochemical analysis of the water from the three wells show that some of the parameters analyzed do not comply with the maximum permissible limits established by NOM-127-SSA1-1994 (Table 3). Eight parameters analyzed and established by NOM-127-SSA1-1994, the water from the three wells complies with the maximum permissible limits in pH, Total Dissolved Solids and Nitrates. Electrical conductivity, salinity, total alkalinity, bicarbonates, carbonates, hydroxides, and ammonium ion are not established in the standard, but are also important indicators to determine if the water is suitable for human consumption. The groundwater from Well 1 does not meet the maximum allowable limits established for Ammonia Nitrogen, Nitrites, Total Hardness and Total Chlorides. Water from Well 2 does not meet the maximum allowable limits established for Ammonia Nitrogen, Nitrites, Sulfates, Total Hardness and Total Chlorides. Water from Well 3 does not comply with the maximum permissible limits established for Ammoniacal Nitrogen, Nitrates, Total Hardness and Total Chlorides.

Table 3. *Physicochemical analysis of the water of three sampled wells compared with the Maximum Permissible Limits established by NOM-127-SSA1-1994.*

Sample	Well 1	Well 2	Well 3	Permissible Limits
pH (pH units)	7.4	7.3	7.5	6.5 – 8.5
TDS (mg/L)	462	527	492	1000
Ammoniacal Nitrogen (mg NH_3//L)	0.6	1.08	0.84	0.50
Nitrites (mg NO_2^-/L)	4.4	8.8	8.8	0.05
Nitrates (mg NO_3^-/L)	0.07	0.15	0.09	10
Sulfates (mg SO_4^{-2} /L)	380	402	396	400
Total hardness (mg $CaCO_3$/L)	551	629	682	500
Total chlorides (mg/L)	295	271	271	250

* pH = Hydrogen Potential; TDS = Total Dissolved Solids

The presence of ammonium facilitates microbial multiplication, and its detection in the water of the three wells is considered an indication of probable recent contamination, since, in groundwater, NH4 or free ammonia generally appears only as traces, increasing in concentration when the medium is strongly reducing [12]. Likewise, the nitrite concentrations in the water of the three wells can be considered as an indication, due to their instability, of possible recent contamination, showing the non-drinkability of this water due to its toxicity. The concentration of nitrites in the water of the wells may be of chemical origin, caused by the discharge of urban and industrial wastewater and by the use of nitrogenous organic fertilizers in agricultural areas. However, the concentration of nitrates does not exceed 10 mg/L, so the presence of nitrite and ammonium alone cannot be considered as a result of contamination. The location of the wells (very close to the Huacapa River) is an important factor in determining the sources of contamination. Aquifers in areas where there are high temperatures and abundant atmospheric precipitation, such as in Chilpancingo, are exposed to easy contamination of organic origin, both from the decomposition of organic matter in the soil and from animal or human fecal waste that is directly or indirectly discharged into the Huacapa River.

The hardness of the water in the three wells may be determined by its origin, a product of the rock formations where the aquifer is located. The limestone formations in the subsoil increase the hardness of the water in the wells. The hardness of the water from the three wells analyzed does not suggest adverse health effects considering its use by the population of Chilpancingo; however, the hardness of this water causes the precipitation of carbonates forming scale in the piping systems of the houses. Finally, the values of total chlorides and nitrite content obtained in the water from the three wells are typical indicators of contamination by domestic wastewater discharged into a natural waterway, in addition to confirming that the water presents microbiological contamination.

4.2. Microbiological Contamination of Groundwater and Risk to Human Health

NOM-127-SSA1-1994 establishes that water supplied by the distribution system must not contain E. coli or fecal coliforms in any 100 ml sample. Total Coliform organisms should not be detectable in any 100 ml sample; in supply systems in localities with a population of more than 50,000 inhabitants. The results of the microbiological analyses of the water from the three wells show that they do not comply with the maximum permissible limits established by NOM-127-SSA1-1994 for total and fecal coliforms (Table 4).

Table 4. *Microbiological results obtained from the water of the three sampled wells and Maximum Permissible Limits established by NOM-127-SSA1-1994.*

Sample	Well 1	Well 2	Well 3	MPL
Total Coliforms (MPN/100mL)	40	52	38	2
Fecal Coliforms (MPN/100mL)	15	12	20	ND
Escherichia coli	P	P	P	NA
Enterococcus faecalis	P	P	P	NA

* MPL = Maximum Permissible Limits; P = PRESENCE; = ND = Non-detectable; NA = Not applicable

The presence of *Escherichia coli* and *Enterococcus faecalisis* an indicator of fecal contamination from human sources or warm-blooded animals, making this water unfit for human consumption and considered unsafe for the health of the population.

It is worth mentioning that due to the water shortages that exist today in the city of Chilpancingo, society tends to acquire this resource by buying water pipes, this water is used for personal hygiene, having direct contact with pathogens that put their health at risk. Diseases such as typhoid fever, dysentery, cholera and gastrointestinal infections among others, are caused by pathogenic bacteria that are transmitted through contaminated water, such as total coliforms [13].

On the other hand, the presence of E. coli is of great concern, since this bacterium is among the most frequent intestinal pathogens transmitted by water, whose diarrheal pathotypes are considered an environmental and public health problem worldwide. Ingestion of water containing fecal debris is the most frequent route of transmission of intestinal diseases affecting vulnerable populations [1]. Diarrheal diseases are one of the main causes of morbidity/mortality in children under 5 years of age, in addition to a high demand for health services and pediatric hospitalizations in Mexico [14].

4.3. Groundwater Treatment to Reduce the Health Risk to the Population

The physicochemical and microbiological results obtained show that the groundwater extracted from the wells requires some form of treatment before being used by the population. NOM-127-SSA1-1994 establishes the treatments to which water must be subjected for its potabilization. It also mentions that specific treatments must be applied when the microbiological contaminants, physical characteristics and chemical constituents of the water exceed the established permissible limits.

In the case of chemical constituents that exceed the Maximum Permissible Limits, the recommended treatments established by NOM-127-SSA1-1994 are shown in Table 5.

Table 5. *Microbiological results obtained from the water of the three sampled wells and Maximum Permissible Limits established by NOM-127-SSA1-1994.*

Chemical component	Treatments
Ammoniacal Nitrogen	Coagulation-flocculation-sedimentation-filtration, degassing or column desorption.
Nitrites and Nitrates	Ion exchange or coagulation-flocculation-sedimentation-filtration.
Sulfates	Ion exchange or reverse osmosis
Total hardness	Chemical softening or ion exchange
Total chlorides	Ion exchange, reverse osmosis or evaporation

In the case of microbiological contamination by bacteria, helminths, protozoa and viruses, water should be disinfected with chlorine, chlorine compounds, iodine, ozone, ultraviolet light; ionic or colloidal silver; coagulation-sedimentation-filtration; multi-stage filtration.

Chlorination is an effective chemical method for the treatment of water contaminated with microorganisms. The cost, availability and ease of technical handling of some form of chlorine make this method the most suitable. Sodium hypochlorite is a liquid chemical used as a bleach and disinfectant. The active ingredient has the chemical formula: $NaClO$, which represents a minimum available chlorine concentration of 130 g/L (11.01% by mass). The World Health Organization recommends that water should be treated with sufficient chlorine to ensure a concentration of 0.5 mg/L, minimum 30 minutes [15]. When using chlorine compounds for water potabilization, residual chlorine measurement should be monitored to maintain the free residual chlorine concentration within the permissible limit established by NOM-127-SSA1-1994.

In the urban area of Chilpancingo, Guerrero, Mexico, groundwater sources, which serve as drinking water supply for the population, have a certain degree of contamination by nitrogen compounds and microorganisms of fecal origin, as a result of population, industrial and agricultural development in the area. It is of utmost importance to carry out a study to locate point and diffuse sources of contamination and carry out the necessary activities to eliminate them in order to preserve water quality and reduce the risk to the health of the population.

5. Conclusions

The supply of water for human use and consumption with adequate quality is essential to prevent and avoid the transmission of gastrointestinal and other diseases, for which it is necessary to establish permissible limits in terms of microbiological, physical, organoleptic, chemical and radioactive characteristics, in order to ensure and preserve the quality of the water in the systems, until it is delivered to the consumer.

The physicochemical and microbiological characteristics, specifically total coliforms, fecal coliforms, *Escherichia coli*, and *Enterococcus faecalis*, of three wells supplying water to the population of Chilpancingo, Guerreo, Mexico, indicate contamination by domestic wastewater. Ingestion of water with fecal debris is the most frequent route of transmission of intestinal diseases affecting vulnerable populations.

Since the piped water supply system does not use any treatment method for water disinfection, it is recommended that the distributed water be dosed with chlorine, maintaining the concentration of free residual chlorine within the permissible limit established in the Mexican Official Standard NOM-127-SSA1-1994 [7].

The disorderly growth of the human population in urban areas in Mexico has caused the municipal water and sewage systems to cover less and less the growing demand for water for the entire population. Studies of the quality of water from groundwater sources that supply water to urban areas are of utmost importance because scarcity has increased the supply of water without prior treatment, exposing public health to risk.

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Conflicts of Interest

The authors declare no conflicts of interest.

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