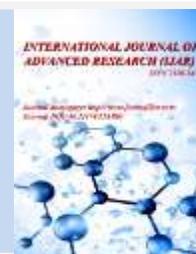




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RESEARCH ARTICLE

ANALYSIS OF MICROBIOLOGICAL CONTAMINATION IN AQUIFERS, IN THE URBAN REGION OF OBLIGADO AND HOHENAU – PARAGUAY.

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Abstract

In Paraguay, 85% of homes have water supply from enhanced sources, 63% are delivered by a distribution system. Likewise, 79% of homes have sanitary drains and 11% are connected to an effluent treatment system (Secretaría Técnica de Planificación del Desarrollo Económico y Social, 2015), this condition hints to superficial pollution problems as well as underground water. The Capiibary Stream watershed, situated in the Department of Itapúa, Paraguay and established on the Guarani Aquifer System (SAG, in Spanish), aquifers exploited by deep wells where the presence of fecal coliform is found in 60% of sampled wells (Protección y Manejo de Aguas Subterráneas en Paraguay PAS-PY, 2012). The study calculated variations in total coliforms in groundwater watershed detected in the center of Obligado and Hohenau, the analysis of groundwater property was based on data from 59 water samples taken over a 10-year period (2006-2016) in 17 deep wells, variations of total coliforms were estimated. For the statistical processing, the analysis of variance and contrast of means (Duncan test) with margin of error 5% were performed. It was determined the variations of the overall coliforms in the study period 2006 to 2016, the presence of total coliforms topped the maximum acceptable threshold. Similarly, deep wells were detected in Obligado, whose standards extended up to 998 CFU / 100ml. Lastly, the results were contrasted with World Health Organization (WHO, 2006) parameters and the Official Paraguayan Standards ERSSAN (ERSSAN, 2017) Law N°. 1614/2000.

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Introduction:-

Global groundwater extraction increased from 312 km³/year in the 1960s to 743 km³/year in 2000. Nearly 70% of the water extracted is used for farming, the remaining 30% corresponds to human consumption. Also, half of drinking water in urban regions comes from groundwater (Wada et al., 2010).

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Some viral and bacterial pathogens existing in human and animal waste contaminate groundwater and they are harmful to human health. In 2012, it was estimated that more than 500,000 diarrhea deaths were caused by microbiologically polluted water (Prüss-Ustün, 2014). Consistently, 50% of the world's population meets their primary requirements from contaminated groundwater at some point (Macler & Merkle, 2000).

World Health Organizations recommends that water intended for human consumption not to contain total coliforms (0 CFU/ml). Notably, 61% of all countries in the world consider this parameter as a foundation for regulations related to the provision of water for human consumption, including Canada, USA, Costa Rica, El Salvador, Bolivia, Brazil, Peru and Uruguay. Whereas 39% of the world's countries allow values higher than zero, for example, in Chile, Colombia and Ecuador, they admit up to 1 CFU/ml, as well as in Mexico, Ecuador, Honduras, Paraguay and Nicaragua the range is between 2 to 4 CFU/ml of total coliforms.

In Paraguay, according to information published by the Permanent Household Survey (EPH) 2008, 68.4% of homes had access to a household connection to drinking water, whereas the rest of the population is self-supplied basically through wells with or without pumping equipment, artesian well or additional resources. In urban areas, drinking water provision through network connection was of 79.8%, but just 14% of urban households had access to sewage system, furthermore only half of these homes had some kind of water treatment. Unfortunately, indigenous communities belonging to different ethnic groups have the lowest levels of access to public services: scarcely, 5.9% have a connection to a clean water system and just 3.3% to sewerage or other effluent treatment system. At the national level, the growth of drinking water coverage has improved substantially since the mid-1990s. While in 1995 only 39.1% of the population had a home connection, in 2007 it reached a coverage of just over two thirds of the total population (69.3%). However, in 1995 only 39.1% of the people had water connection at home, in 2007 it reached a coverage of about two thirds of the entire population (69.3%). Throughout the same period, coverage in the rural area experienced the biggest increase in water connection at home. As outlined in Paraguay's Strategic Water and Sanitation Sector Strategic Plan, the investment requirements to meet the Millennium Development Goals (MDGs) for the 2008-2015 period is US \$ 733 million; where 88% of these are situated in urban areas and just 12% in rural areas cited by (Spanish Agency for International Development Cooperation, AECID, 2017).

The Capiibary stream watershed is found within the Guaraní Aquifer System (SAG), in the Department of Itapúa, Paraguay; which represents a significant cross-border underground water body shared by Argentina, Brazil, Paraguay and Uruguay; where the aquifers (Alto Paraná formation and Misiones formation) serve as water reservoirs and supplies. They are exploited by deep wells to supply the urban area of Obligado and Hohenau.

As background on groundwater quality in Paraguay, which is part of the study area and particularly in the Arroyo Capiibary watershed, it can be mentioned studies carried on in SAG, project under the Environmental Protection and Sustainable Development of the Guaraní Aquifer System (PSAG) that was launched in March 2003 and completed in January 2009 (PSAG, 2009). SAGPY Project for Environmental Protection and Sustainable Development of the Guaraní Aquifer System (SAGPY, 2009) and PAS-PY. Project "Sustainable Management and Protection of Groundwater in Paraguay" (PAS-PY, 2012), where microbiological studies have discovered an alarming contamination of fecal coliforms in more than 60% of wells sampled under the PAS-PY project (2012), particularly in urban areas of some major municipalities that form make up the Capiibary stream watershed, including urban areas of Obligado and Hohenau. This situation is constant in different areas of Paraguay, a condition that is due to the deficiency of a sewerage system and effluent treatment plants as well as latrines and blind wells being the main (direct) human supply water wells sources of pollution and this is directly related to the lack of protection boundaries for deep artesian wells (PAS-PY, 2012).

The presence of total coliforms arises concern since the whole surface of the Capiibary stream watershed is situated on the Guaraní Aquifer System (SAG). Typically, groundwater does not contain microbiological pollutants such as *Escherichia coli* and fecal as well as total coliform, excepting it has been contaminated by percolation from superficial water or sewage connections. Frequently, bacterial contamination in groundwater is due to deficient well construction, inadequate well maintenance as well as the influences of the aquifer vulnerability.

The purpose of this study was to calculate the variation of the total coliform content in Hohenau and Obligado urban areas groundwater during the period of 2006-2016.

Material and Methods:-

The study was performed in two districts in the Department of Itapúa in Paraguay, the district of Obligado in the Abbeg stream watershed that is situated at the coordinates: longitude 55° 40'5.97" and latitude 27° 06' 29.60 "; and the unnamed stream watershed in the district of Hohenau within the coordinates: longitude 55 ° 35 '58.89" and latitude 27 ° 04' 36.81" according to the geographical projections (Figure 1).

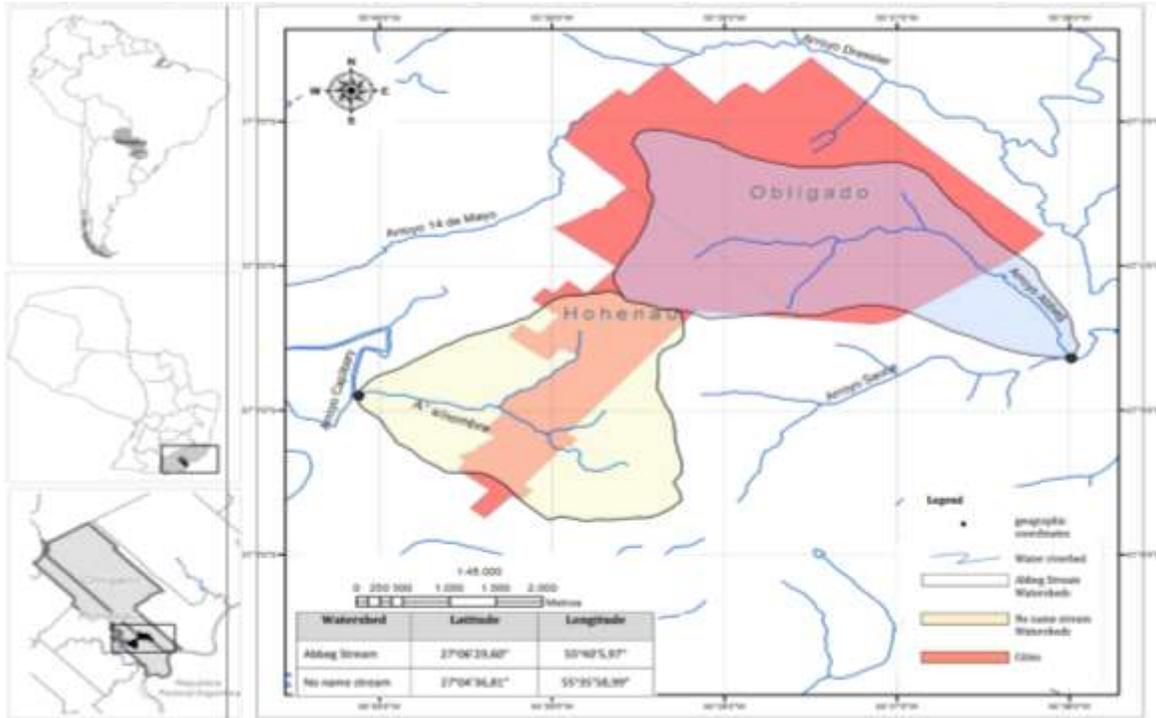


Figure 1:- Location of the research area. Paraguay, department of Itapúa, districts of Hohenau and Obligado, geographic coordinates of the watershed capacity in study.

Most of the urban center of Obligado is situated on the O watershed, it has an area of 741.39 ha and its main channel (called Abbeg stream) has a length of 4 849.60 m, see Figure 2; and a great part of the urban center of Hohenau is located on the H watershed that has an area of 598 ha and the length of its main channel is 3217.18 meters, see figure 3.

The region considered is characterized by extraordinary water wealth in terms of quality, quantity and depth of groundwater since it is located on the Guarani Aquifer (Misiones formation) (Faculty of Science and Technology, 2010). This formation contains sedimentary rocks sandstone that store large volumes of water in its pore spaces (PAS-PY, 2012).

Different soil types (USDA Soil Taxonomy) are developed in the area of study, predominantly Ultisol 10 soils in the upper and middle parts of the watershed, and at a lower level ULTISOL 2 in the lower watershed. The ULTISOL 10 is given on basaltic rock and to a smaller degree on sandstones, but constantly on the appropriate slopes with drainage surface. Soils are classified as II, III and V, with a dominance of class III: slopes from 8 to 15%, efficient soil depth 75-100 cm, drainage and quick penetrability (MAG, 1995).

Data collection:-

Data from deep wells gathered under the SAG 2009, PSAG-PY 2009 and PAS-PY 2012 projects were used in this project, and the information was accomplished (until 2016) through interviews with key stakeholders in charge of water supply to the population where the research was carried out.

Wells were coded for better data management and statistical calculation thereof. Seventeen wells situated on the study area were chosen and 59 water samples were evaluated (Figures 2 and 3).

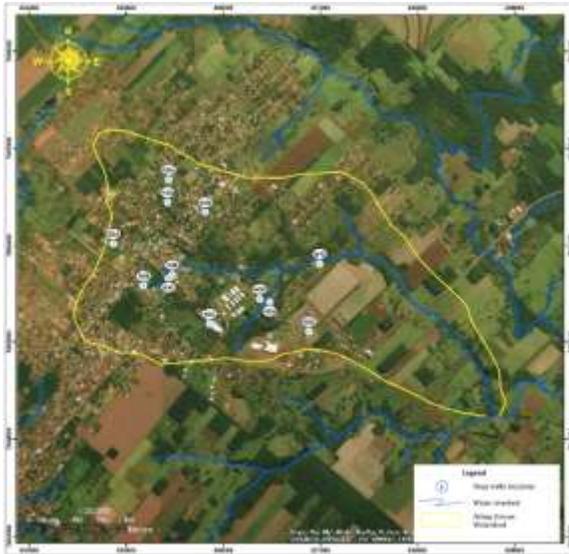


Figure 2:- Position of wells in “O” Small Watershed, There were 11 wells that were coded, the nomenclature to identify them is as follow 1OC, 2OC, 3OB, 4OB, 5OB, 6OB, 7OB, 8OA, 9OA, 10OA, 11OA (letter “O” for the Abbeg stream small watershed, the numbers from 1 to 11 correspond to the order number and the letters ABC source material) and the location of the treatment plant is identified with the nomenclature. WT2



Figure 3:- Position of wells in “H” Small Watershed, six were the wells that were coded, the nomenclature to identify them is as follow 12HB, 13HB, 14HB, 15HB, 16HB, 17HB (letter H for the small watershed of the stream without name, the numbers 12 to 17 corresponds to order number and source material B), and the location of the treatment plant is identified with the nomenclature. WT1

It was analyzed data collected between 2006 and 2016, excluding years 2007 and 2011 period when there was not water quality analysis. Consequently, the period of study is 9 years. These Wells are controlled by private sectors and Sanitation Boards.

The average annual and cyclical rainfall throughout the analysis period was 1711.7 mm according to data from two meteorological stations located in the area of study, see Table 1. Rainfall data during the study period (2006 to 2016) can be seen in Figure 5, this information was gathered at the Federation of Production Cooperatives Ltda. website (FECOPROD, 2017), this station is 25 km away in straightforward line from the study area, additional source employed was METEORED from the city of Posadas, Misiones, Argentina, this station is in a straight line 48 km away from the area of study. (METEORED, 2017)

Table 1:- Seasonal rainfall during 2006-2016.

Seasons	2006	2008	2009	2010	2012	2013	2014	2015	2016	Total
Precipitatio in millimeters										
Autum	257.3	514.7	306.4	440.2	371.1	404	609.2	410.8	223.4	3537.1
Winter	323.4	256.7	591.7	35.6	183.2	205	427.8	269.2	241	2855.6
Summer	284.5	207.4	325.3	272	190.4	464.2	507.8	431.6	518.4	3201.6
Spring	775.2	704.7	599.4	517	928.5	372.6	528.4	878.2	507.6	5811.6
	1640.4	1683.5	1822.8	1586.8	1673.2	1445.8	2073.2	1989.8	1490.4	1711.7

Source: (meteored, 2017), (fecoprod, 2017). Seasonal rainfall during the period 2006 to 2016.

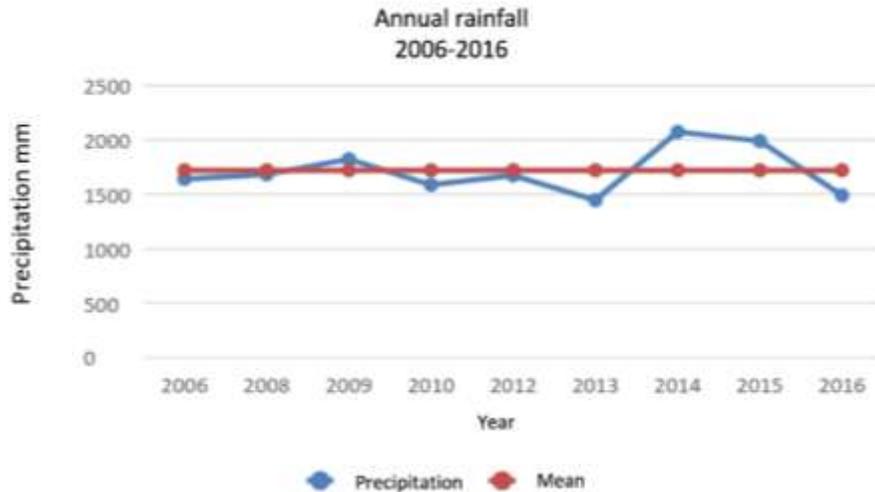


Figure 4:- Annual rainfall distribution (2006-2016).

Source: (METEORED, 2017), (FECOPROD, 2017). Average of annual rainfall, in the graph it is shown the fluctuation of precipitation over time during the period 2006 - 2016.

Statistical Analysis:-

To identify significant differences between variables, it was performed analysis of variance as well as contrast of means, likewise, Duncan test was applied at 5% significance using the statistical program Infostat (2017p Version) (Di Rienzo, et al, 2017). It is important to mention that wells with a single data have been discarded since they produce a very marked statistical distribution.

For the analysis of the variable presence of total coliforms per well, wells with only one data have been discarded due to the fact that it generates a very marked statistical dispersion.

The outcomes were compared with levels established in the environmental guidelines related to the quality of water for human consumption in accordance with the World Health Organization (WHO, 2006) and the Official Paraguayan Standards ERSSAN (ERSSAN, 2017), to confirm the decline of water quality.

Results:-

Total coliforms

Presence of total coliforms per well:-

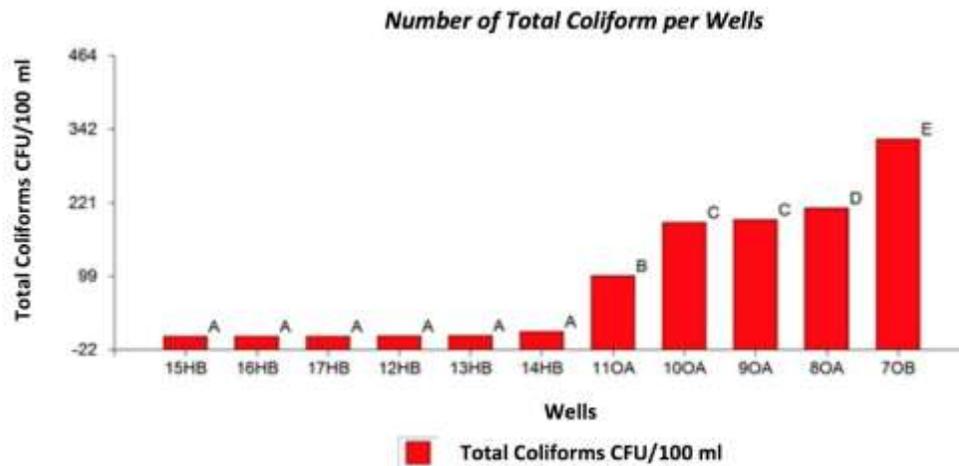


Figure 5:- Microbiological water quality, distribution of total coliforms in wells spread in the area of study. The nomenclature indicates that the O codings belongs to the Abbeg stream small watershed and H coding corresponds to the unnamed stream small watershed, which connects to the wells of Hohenau water provider. Letters A and B match with the geological formation codification (A: sandstone, B: Basalt).

The Duncan test average contrast revealed a statistically significant difference between wells B formation: basalt, and wells A formation: sandstone, which suggests that the basalt formation wells are statistically similar to each other, except for well 70B that reveals a very significant statistical difference.

Distribution of total coliforms along the period of study:-

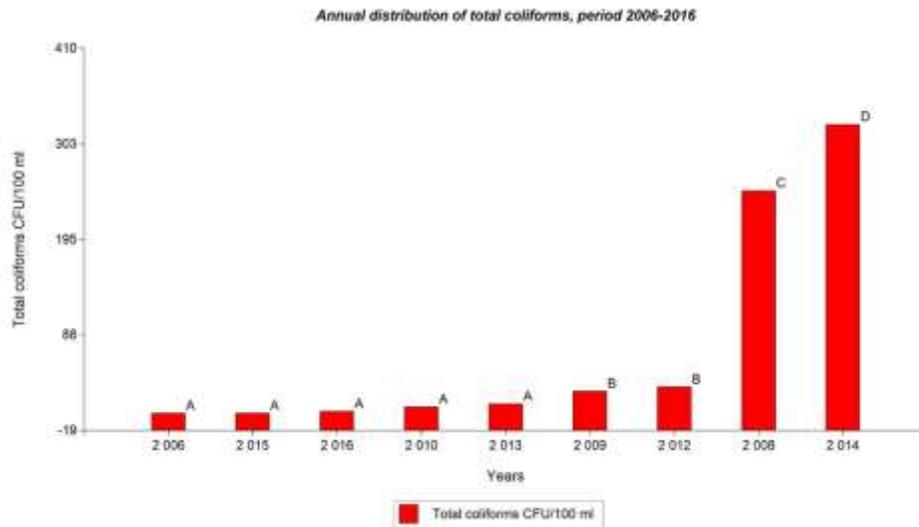


Figure 6:- Annual distribution of total coliforms, 2006-2016.

In Figure 6, it is shown the presence of total coliforms that was detected in waters of the wells examined. The highest concentrations of total coliforms were documented in 2014, these values varied from 302 to 410 CFU/100ml, followed by 2008 when they were between 195 and 302 CFU/100ml of total coliforms.

The excessive incidence of total coliforms in 2014 and 2008 may be associated to excessive rain, these rains may influence permeation or drag sewage, it can be affirmed that in 2014 period of greatest precipitation when the study was carried out, samples were acquired in autumn (season with the highest rainfall record), also considering the year 2008, it was documented a high number of total coliforms, nonetheless that year rains were below the average during the period of study, see figure 4, being the season of highest rainfall during the year.

In 2015, the concentrations of total coliforms were lower, although it was a year of great rainfall, close to 2014 record, however in this particular year samples were taken in summer and winter (period of lower rains recording), so it is given a lower total coliforms registration.

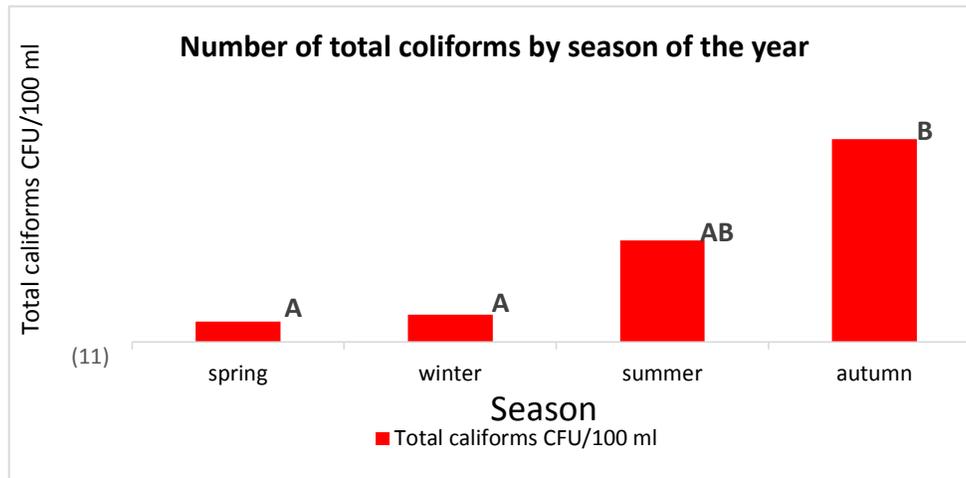
Distribution of Total Coliforms be season:-

Figure 7:- Presence of total coliforms according to seasons of the year.

The number of total coliforms as shown in Figure 7, happens in greater quantity in the summer and autumn, in table 1, the seasons with the most abundant rainfall during the period of study are correspondingly spring, summer and autumn. See table 1.

Discussion:-

Once the historical data collected from 2006 to 2016 was analyzed, it can be affirmed that groundwater is contaminated by total coliforms, the group of coliform bacteria is applied as a general test of water quality monitoring and it has been applied all around the world to carry out studies on drinking water, aquatic systems contamination, raw wastewater sources of contamination as well as systems of wastewater treatment and recreational waters (Rose & Grimes, 2001); those reasons explain why these waters cannot be provided to the population without previous treatments, as cited by Hunter *et al.* (2000), who expose that bacteria, although not generally pathogenic in themselves, are indicative of potentially pathogenic microbes presence and consequently as an index of sanitary insufficiencies in the water source.

Furthermore, small watershed H wells 12HB, 13HB, 14HB, 15HB, 16HB, 17HB under study which present coliforms in a smaller percentage than the small watershed O, it diverges from the latter in two aspects a) the wells are sited in places with low population and lower population pressure as seen in figure 4, besides b) all of the wells according to their profile have their perforation in basalts, which reduces the possibility of direct entry or due to slow coliforms transfer there is no proliferation in the study area.

The finding of coliforms in wells could be due to its structural deficiency (although it was not the subject of study in this paper), as (Rodríguez, Gauna, Martínez, Acevedo, & Romero, 2012) mentioned, the finding of coliforms is possibly due to fecal matter contamination that may have come from non-jacketed wells or near surface water tables. Similarly, the presence of total coliforms in deep wells, is due to the rupture of struts or because water is extracted at a lower depth as mentioned by Jawson *et al.*, (1982)

Conclusions:-

It was statistically determined the presence of total coliforms during the period of study 2006-2016, therefore, groundwater undergoes microbiological contamination.

It can be emphasized that the most abundant precipitation during the period of study was documented in spring, summer and autumn, which is associated to the greater presence of total coliforms.

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