Region - Water Conservancy, 2023, Volume6, Issue1
DOI: 10.32629/rwc.v6i1.1238
ISSN Online: 2630-4902

Hydroecological approach for an experimental well field in the Yucatan karst

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Abstract: The experimental well field of FIUADY is a system of 50 m and up to 75 m deep wells. It was built with the purpose of confronting and consolidating the hydrological knowledge of groundwater in the karst plain of northern Yucatan. In this context, the objective of this work is to document the historical behavior of some variables of the physical-chemical and biological environment of the aquifer to sketch models of the habitat of the epikarst microbiota in the northern plain of the Yucatan peninsula. Hydrogeological conformation was documented through drilling debris analysis and underwater video recordings in the well. Measurements of temperature, electrical conductivity, pH and dissolved oxygen were made in October, November, January, February, March and April of different years. For statistical analyses, data were grouped into two periods: recharge (October and November) and discharge (January-April). The results include a schematic hydrogeological profile and statistical analyses of the variables. The minimum and maximum values observed are: temperature °C (26.64, 29.87), electrical conductivity µS/cm (465,46800), pH (6.14, 8.20) and dissolved oxygen mg/L (0.01, 7. 93). It is concluded that: a) in an area of a few square meters there are important variations in the hydrogeological characteristics; b) the hydrogeological behavior of the wells has to do with karstic horizons; their dimensions, connectivity, distribution, density and the way they influence different hydrological stresses; finally c) the presence of crustaceans in the wells and "anomalies" in the concentration of oxygen may have an explanation in biogeochemical processes of dark ecosystems.

Key words: Karst environment; dark habitat; Karst Plateau plain; Yucatan aquifer

1 Introduction

In the Karst Plateau area of the Yucatán Peninsula, there are various habitats of biological communities: from visible mountains (forests, grasslands, wetlands) and cities on plains and Karst Plateau strata, to animal associations (droughts and floods) that can still be observed in caves, to groups virtually imperceptible to human vision. Because they live in channels that humans cannot enter, they are part of a complex network of caves submerged in limestone.

The interaction between these biological systems is dynamic, in such a way that the forests of the surface karst contribute matter and energy to the subsoil through processes such as the infiltration of water into the aquifer (rainfall, irrigation, etc.), and take materials and energy from the underground: ions and Chemical bond generated by biological activities. (Pacheco and Cabrera 1997, Pacheco et al., 2000, Pacheco et al., 2001, Cervantes Martinez et al., 2002, Herrera Silveira et al., 2002, Xuluc Tolosa et al., 2003, Hodell et al., 2005, Vargas Ramos 2007, Hernandez Trerones et al., 2011, Bauer et al., 2011, Pérez et al., 2011, Pérez-Ceballos et al., 2012).

Visible surface karst formations (epikarst), including caves, have been the subject of studies from a biological and ecosystem perspective (Schmitter-Soto et al., 2002, Bauer-Gottwein et al., 2011, Herrera-Silveira et al., 2002, Pérez et al., 2011, Pérez-Ceballos et al., 2012). However, there are other underground Karst Plateau areas that cannot be directly explored by human beings, and there are few studies (Bastwiken et al., 2002; Engel, 2007, 2008, Plunker et al., 2009, Prach et al., 2011, Starr et al., 2012, Okafu, 2011). Because in its state of nature, human beings cannot enter, only through some modifications to the physical space, such as drilling and/or instrument observation, which can generate an understanding of these complex ecosystems.

Human communities, especially cities, have changed the balance and dynamics of biological and environmental subsystems. It is not only because water, food, and substances that are different from those occurring in mountainous or natural ecosystems, are concentrated in narrow spaces, but also because waste and human activities achieve maximum economic productivity through industrialization or extensive use of local natural resources (Hildebrand et al., 1995; Perry et al., 1995; Pope et al., 1996; Graniel Castro and Gonzalez Hita, 2002; Hernández-Terranes et al., 2011).

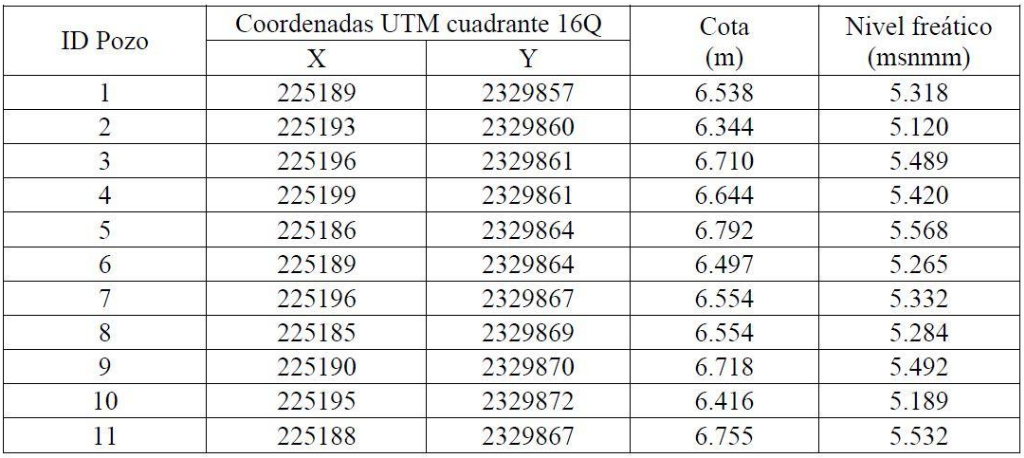
The experimental well field of the Campus of Engineering and Exact Sciences of the Autonomous University of Yucatan was built with the purpose of confronting and consolidating the theoretical knowledge of the hydrological behavior of groundwater in the karst plain of northern Yucatan. At present it has favored the academic training of engineering students and has allowed contributions to the scientific knowledge of the Yucatan karst (Sánchez y Pinto et al. 2005). The objective of this work is to document the historical behavior of some variables of the physicochemical and biological environment of the aquifer, through the monitoring and analysis of these variables measured and recorded in the experimental well field of the Campus of Exact Sciences and Engineering (UADY) to sketch models of the habitat of the epikarst microbiota in the northern plain of the Yucatan Peninsula and to study biogeochemical processes of the karst aquifer.

2 Method

2.1 Study area

The hydrogeological experimental field (CEH) of wells is located in the north of the Merida city, the geographic location was obtained with GPS and topographic surveys with a total station. The location, elevation and height above mean sea level in meters (WGS84 Geoid model) of each well are shown in Table 1.

Table 1. Geographical position of the wells in the experimental field, elevation and calculation of height in meters above mean sea level (msnmm) based on an INEGI level bank and the WGS84 geoid model



ID Pozo	Coordenadas UTM cuadrante 16Q		Cota (m)	Nivel freático (msnmm)
	X	Y		
1	225189	2329857	6.538	5.318
2	225193	2329860	6.344	5.120
3	225196	2329861	6.710	5.489
4	225199	2329861	6.644	5.420
5	225186	2329864	6.792	5.568
6	225189	2329864	6.497	5.265
7	225196	2329867	6.554	5.332
8	225185	2329869	6.554	5.284
9	225190	2329870	6.718	5.492
10	225195	2329872	6.416	5.189
11	225188	2329867	6.755	5.532

2.2 Hydrological profile and physical habitat architecture of the epikarst

For the physical and lithological description of the study area, two sources of information were used: a) During the drilling of the wells in this experimental field, samples of detritus were taken, from which inferences were made about the lithological composition of the different strata. b) Videos were taken with an underwater camera model R-Cam 1000 with a record of the depth of the shots.

2.3 Hydrological conditions

Measurements of atmospheric conditions were made using an automated weather station located 50 m from the experimental well field. Measurements of the physical-chemical groundwater environment in the area of the experimental well field were made in 2003 (February-April), 2004 (January), 2008 (November) and 2014 (October). The equipment used was Hidrolab Quantum multiparameter probes.

In November 2008, measurements of temperature (°C), electrical conductivity (µS/cm), pH, dissolved oxygen (mg/L) and redox potential (mV) were taken. Measurements were made in 9 wells at 1 m depth intervals (the first measurement at 20 cm below the water table). Measurements began at 9:40 am and ended at 15:30 (a period of 5:50 h). The central tendency statistic evaluated in the variables observed in the experimental field of wells was the median, and variation was recorded by recording minimums and maximums in the measurement period.

In October 2014, measurements of temperature, pH, electrical conductivity, dissolved oxygen, redox potential and chlorophylls were taken. These measurements were made to a depth of 20 m, between 7:30 AM and 12:30 PM.

The data were grouped into two epochs: a. recharge including the months of October and November; b. discharge including the months of January, February, March and April.

For the statistical analysis (descriptive and graphical), we used EXCEL tools as well as the statistical analysis environment R-Project and StatGraphics CENTURION 18.

3 Results

Fig. 1 shows the distribution of the wells in a horizontal plane and a vertical section of the experimental well field (hydrogeological profile), in which the karstified regions of the aquifer are schematized. In total, 11 wells have been constructed for experimentation, one of them with a depth of 70 m.

The statistical values of the physical-chemical variables are presented in Table 2. The statistical parameters estimated were: mean, median, range, maximum, minimum and number of observations made in the experimental well field.

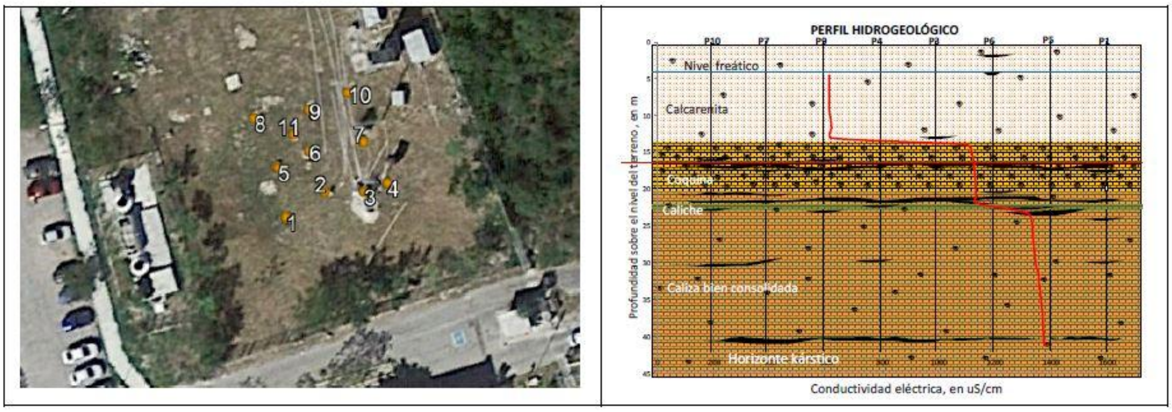


Fig. 1. Location of wells and hydrogeological profile of the HEC

Table 2. Summary statistics of the variables temperature, electrical conductivity, pH and dissolved oxygen measured in the experimental well field

Estadísticos	Temperatura (°C)	Conductividad eléctrica (µS/cm)	pH	O_2 Disuelto (mg/L)
Media	27.71	2954.58	6.78	2.48
Mediana	27.62	1344.00	6.76	2.12
Rango	2.23	46335.00	2.06	7.92
Mínimo	26.64	465.00	6.14	0.01
Máximo	28.87	46800.00	8.20	7.93
No de Observaciones	1258	1201	1248	854

Fig. 2 shows the temperature stratification in measurements taken at times of maximum and minimum recharge; the wide variation of temperature in the surface waters is notable, and as depth increases, the variability decreases; temperatures are between 26.5 °C and 29 °C.

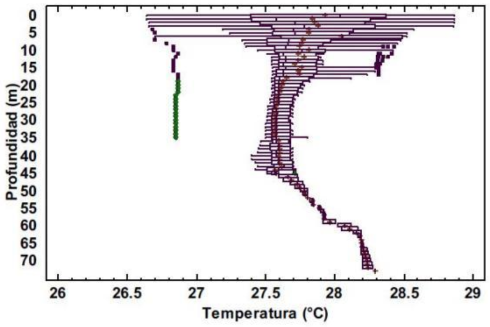


Fig. 2 Vertical distribution of measured temperature in °C in the experimental well field

Fig. 3 shows, by means of a box-and-whisker plot, the distribution of temperature values at the time of maximum (recharge) and minimum recharge (discharge) of the aquifer; in the months of recharge (October-November) the temperature is higher and with less dispersion.

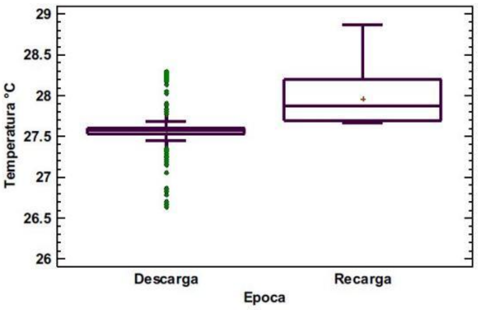


Fig. 3. Graph of the dispersion of temperature measurements (°C) in the experimental well field. Discharge corresponds to January to April and recharge to October and November

The electrical conductivity shows a vertical arrangement (Fig. 4), in which in the first 10 m depth, there is little variation and the values remain low (465 µS/cm) until 46 m, where a transition occurs until reaching very high electrical conductivities (>40000 µS/cm).

In general terms, the electrical conductivity is low (<1500 µS/cm), except for the high values found in waters below 45 m. Fig. 5 shows the distribution of the electrical conductivity values for the discharge and recharge periods using a box-and-whisker plot.

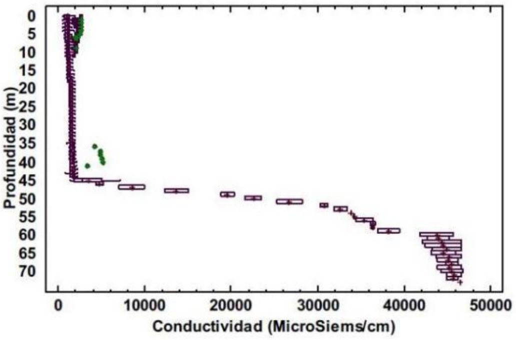


Fig. 4. Electrical conductivity profile in the experimental well field

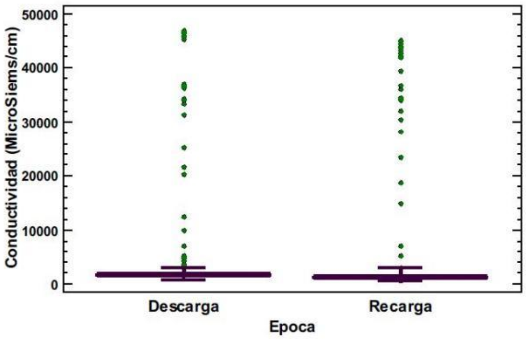


Fig. 5. Box-and-Whisker plot of electrical conductivity measurements in µS/cm measured at the times of maximum recharge (recharge) and minimum aquifer level (discharge)

The pH of the aquifer water in the experimental well field shows a stratification presented in Fig. 6.

Fig. 7 shows a comparison of the pH values measured during the discharge and recharge periods; the pH during the recharge period is more acidic and more variable than during the discharge period or minimum aquifer level.

An important variable in the metabolism of aquatic ecosystems is the concentration of dissolved oxygen. Fig. 8 shows a vertical profile, in which high values at the surface and very low dissolved oxygen concentrations at depths greater than 6 m are noticeable.

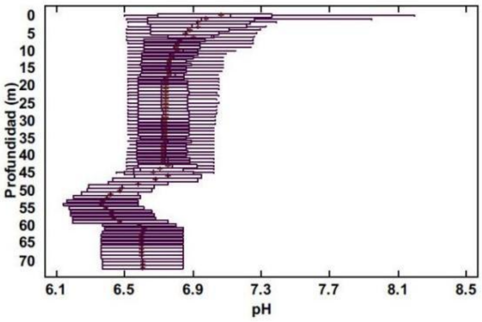


Fig. 6. Profile of pH measurements showing stratification with changes at 15 and 45 m depth

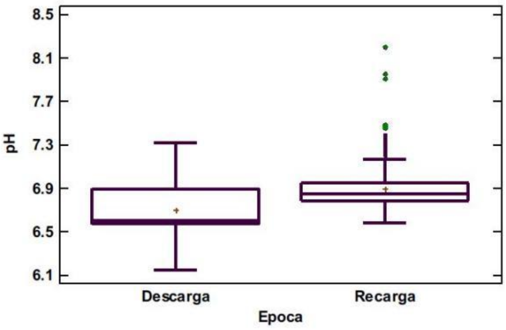


Fig. 7. Comparative graph of pH measurements in the experimental well field during the discharge and recharge periods (maximum aquifer level)

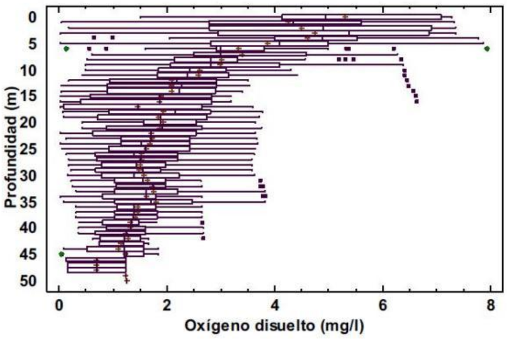


Fig. 8. Vertical profile of dissolved oxygen measurements in mg/L performed in the experimental well field

On the other hand, dissolved oxygen concentrations are lower during the recharge period than during the discharge period and this can be seen in Fig. 9.

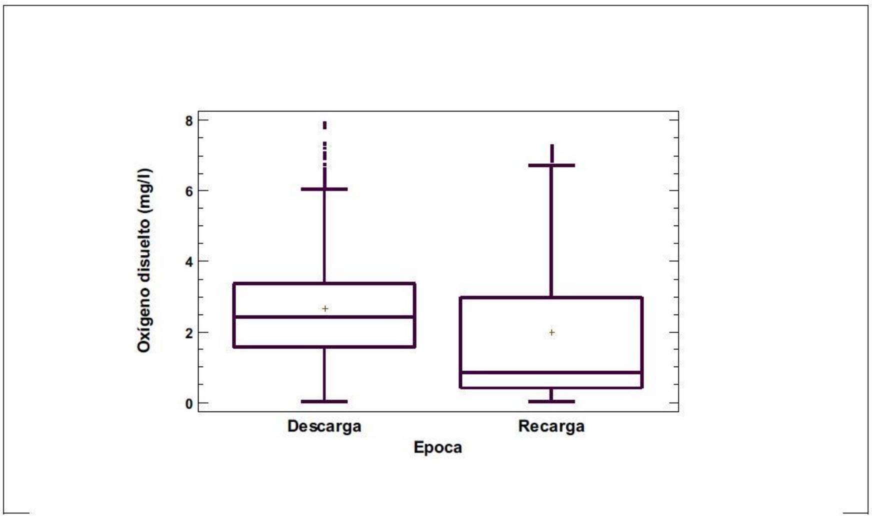


Fig. 9. Comparison of dissolved oxygen concentrations in the dePozos experimental field during the discharge and recharge periods of the aquifer

In the underwater videos, crustaceans were observed at 42 m, 43 m and 51.6 m depth. Identification of organisms only allows for group level. However, reports of macrocrustaceans in the epicontinental aquatic systems of the Yucatan Peninsula include Agostocaris bozanci, Yagerocaris cozumel, Janicea antiguensis, Calliasmata nohochi (Escobar- Briones et al. 1997), undescripted prokaryote (Kornicker and Iliffe 1992) and the ripedia speleonectes tulumensis (Smitter-Soto et al. 2002). Fig. 10 shows a photograph taken from one of the videos at 42.2 m depth.

Fig. 10. Underwater photograph of macro crustaceans inhabiting the epikarst in the vicinity of the FIUADY experimental well field

4 Discussion

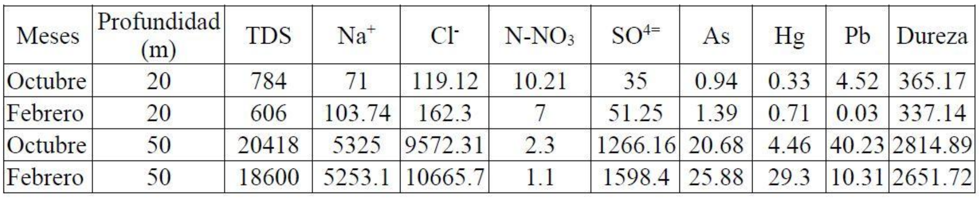
The experimental well field is a window, from which one can observe the aquifer ecosystem taking place in the subway epikarst; its lithological structure and the architecture of its karst expressions (cavities) show great complexity manifested in the observations: both in the components that appeared in the detritus (during the drilling of the wells) and in the video images, in which three karstic horizons (horizontal strata with presence of cavities) could be appreciated whose horizontal connectivity, in some way has been evaluated by tracer tests and pumping tests (Sánchez and Pinto et al. 2005, Zetina-Moguel et al. 2007, Gutiérrez- Díaz 2011).

The construction of the wells in the experimental field vertically connected the different karst horizons and this somehow masks the hydrogeological (combined the different hydrostatic pressures corresponding to the karst horizons), biogeochemical (allows the exchange of chemical and biological components) and biological (allows or facilitates the passage of organisms between karst horizons, in vertical migrations) behaviors. Nevertheless, it offers the possibility of inferring based on observations about the different ecosystem processes that develop in this dark zone of the karst.

Although no ion measurement campaigns have been conducted in the experimental well field, nor microbiological evaluations, there are measurements made in a CONAGUA monitoring well located in the same study area; in this well, ion determinations were made at two depths (20 and 50 m) and in the months of February and October (Heise 2013). Some of these determinations are presented in Table 3.

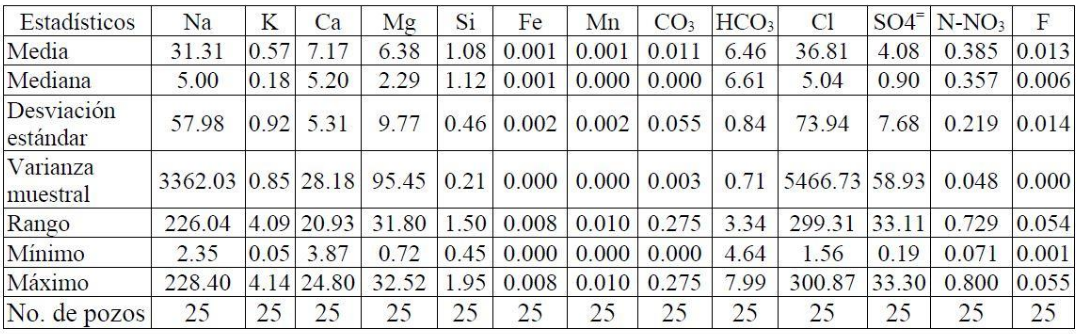
Heise (2013) also released ion composition data for 25 wells around Merida, including the CONAGUA well located next to the experimental field. A statistical summary of these determinations is presented in Table 4. And a statistical summary of the fecal and total coliform determinations performed by Heise (2013) in wells in the city of Mérida between 10 and 50 m depth is presented in Table 5.

Table 3. Ion concentration of a well near the experimental park (milliequivalents/L)



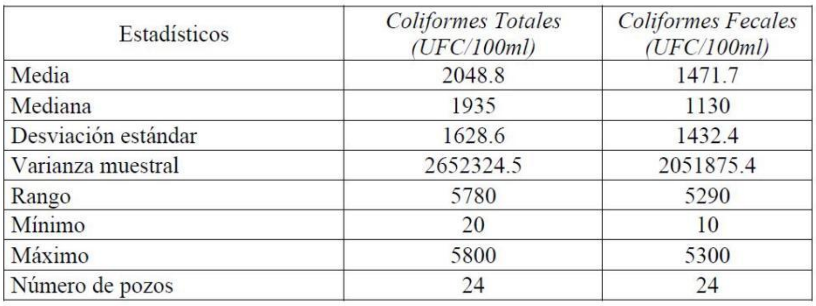
Meses	Profundidad (m)	TDS	Na^+	Cl^-	$N\text{-}NO_3$	$SO^{4=}$	As	Hg	Pb	Dureza
Octubre	20	784	71	119.12	10.21	35	0.94	0.33	4.52	365.17
Febrero	20	606	103.74	162.3	7	51.25	1.39	0.71	0.03	337.14
Octubre	50	20418	5325	9572.31	2.3	1266.16	20.68	4.46	40.23	2814.89
Febrero	50	18600	5253.1	10665.7	1.1	1598.4	25.88	29.3	10.31	2651.72

Table 4. Summary of ion measurements conducted by Hayes (2013) in Merida City, with depths ranging from 2 to 50 meters. The results are expressed in milliequivalents of joints (meq/L)



Estadísticos	Na	K	Ca	Mg	Si	Fe	Mn	CO_3	HCO_3	Cl	$SO4^=$	$N\text{-}NO_3$	F
Media	31.31	0.57	7.17	6.38	1.08	0.001	0.001	0.011	6.46	36.81	4.08	0.385	0.013
Mediana	5.00	0.18	5.20	2.29	1.12	0.001	0.000	0.000	6.61	5.04	0.90	0.357	0.006
Desviación estándar	57.98	0.92	5.31	9.77	0.46	0.002	0.002	0.055	0.84	73.94	7.68	0.219	0.014
Varianza muestral	3362.03	0.85	28.18	95.45	0.21	0.000	0.000	0.003	0.71	5466.73	58.93	0.048	0.000
Rango	226.04	4.09	20.93	31.80	1.50	0.008	0.010	0.275	3.34	299.31	33.11	0.729	0.054
Mínimo	2.35	0.05	3.87	0.72	0.45	0.000	0.000	0.000	4.64	1.56	0.19	0.071	0.001
Máximo	228.40	4.14	24.80	32.52	1.95	0.008	0.010	0.275	7.99	300.87	33.30	0.800	0.055
No. de pozos	25	25	25	25	25	25	25	25	25	25	25	25	25

Table 5. Total coliform and fecal coliform determinations in 24 wells in the city of Mérida between 10 and 50 m depth (from data published by Heise 2013).



Estadísticos	*Coliformes Totales (UFC/100ml)*	*Coliformes Fecales (UFC/100ml)*
Media	2048.8	1471.7
Mediana	1935	1130
Desviación estándar	1628.6	1432.4
Varianza muestral	2652324.5	2051875.4
Rango	5780	5290
Mínimo	20	10
Máximo	5800	5300
Número de pozos	24	24

This reported chemical composition somehow shows the physicochemical (temperature, electrical conductivity, pH, O2) chemical (ionic composition: anions and cations) and microbiological (coliforms: microbiological groups associated with homeothermal organisms) environment that can be expected in the experimental wellfield. From previously published experimental data related to epikarst aquatic systems (Heise 2013 and Moore 2014), it appears that analysis of vertical stratification in the well field can be of great importance (aquifer management knowledge and technology).

It is sufficient to address the measurement issues in groundwater (in wells) and open systems (caves): in both wells and open systems, the oxygen concentration in deep water (40 meters and 50 meters deep) increases from 1 milligram/liter to approximately 3 milligrams/liter (Hesse, 2013), despite seeking explanations in physical processes. Today, it is known that oxygen is generated through chemical synthesis in dark systems (ETTwing et al., 2012), which is another possibility of oxygen source in Karst Plateau aquifers.

Observations of crustaceans at depths of 42.2 m, 43 m and 51.6 m were made in the experimental well field of the School of Engineering. Arthropods are particularly sensitive to anthropogenic contaminants, and their existence at these depths in the experimental well field (which is a system far from a cenote or other open aquatic ecosystem or exposed to light and photosynthetic processes) can only be explained by the presence of allochthonous organic matter (detritus and debris from photosynthesis) and/or autochthonous organic matter from chemosynthesis in the dark epikarst systems as well as other processes that are part of the biogeochemical cycles of the karst and have remained hidden from observation.

5 Conclusion

In an area of a few square metres (minimum distance of 3 m and maximum of 16.2 m between wells) and a depth of 50 and 75 m, important variations in the physico-chemical behaviour of the groundwater can be found as a result of the connection of the wells with the karst horizons crossed, thus establishing a vertical connection between them.

The hydrogeological behaviour of the wells is related to karst horizons of different connectivity and in many cases allows the presence and possibility of observing microorganisms.

The presence of crustaceans in the wells and the "anomalies" in the concentration of dissolved oxygen with respect to depth can be explained by biogeochemical processes of dark ecosystems.

Acknowledgments

We are grateful to The Academic Institution Support and Consolidation Program (PADECA) of Yucatan Autonomous University for Postgraduates, Research and Liaison General Coordination; thanks to the members of Hydraulics and Hydrology academic institutions of the School of Engineering for their support in carrying out research activities.

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