Analysis of the vegetation-soil-water interaction and external factors on the water availability in a rain forest

Ramos J.[1*], Gracia J.[1], Ortiz S.[1], González-Chávez, J. L.[2], Iturbe R.[1]
1 Instituto de Ingeniería, UNAM 2 Facultad de Química, UNAM
[*]jramosh@iingen.unam.mx

Abstract

Degradation of water quality due to human and natural causes leads to the loss of the environmental value of an ecosystem. This paper establishes how land use changes have a major impact affecting water quality. Nine aguadas with and without direct human impact were monitored and results show that water quality is associated to: deforestation once nude the land it produces water erosion, rock washing in the subsurface and surface favouring the presence of inorganic elements, and human activities that press the aguadas for different water uses. These factors tend to overpass the resilience capability of the ecosystem.

Keywords: water quality, aguadas, rain forest, karstic soils, sustainability

1. Introduction

A healthy ecosystem can be defined in various ways, however establishing the natural conditions of the system in terms of quantity and quality it makes possible to identify whether an ecosystem can withstand significant changes in its composition without affecting its functions, or whether an ecosystem is very sensitive to small changes in its physicochemical constituents leading to degradation of the ecosystem and loss of biodiversity.

The ability of aquatic systems to keep the ecosystem healthy depends of the availability of water and its physical, chemical and biological composition. It is important to recognise that the physico-chemical degradation of the water generated by the human being is given in a gradual way, so in the beginning it gives an opportunity to the ecosystem to adapt or recover. However, many of the changes that occur are not detected on time or they increase in a very short period of time making the ecosystem unable to recover and requiring human actions to re-render the services linked to it due to the system could reduce its capacity to get a gradual recovering or adaptation (resilience). In general, degradation of water quality due to human and natural causes leads to the loss of the environmental value of the ecosystem, since natural resources such as water, vegetation and soil can have negative effects on species diversity and processes that take place in it for a given period of time.

In the case of water, availability depends of several factors that involve the establishment of their ecological interactions as well as external factors such as the presence of humans. Once settled, they could modify land use, thus also alters the climate in the region and together with the climatic change, it could modify significantly the environment response, particularly in the zones near a water body. For example, upstream changes of forest into agriculture, or neighbourhood, alter the system and its surrounding area, causing erosion and increasing sedimentation, which results in a morphometric change in water bodies. Also, forcing seasonal patterns of flow (surface and sub-surface) and varying on physicochemical-microbiological characteristics of water bodies as the type and amount of pollutants enter water bodies due to in large part to surface runoff. Consequently, this changes the biodiversity inside and outside the zone, thus it is important to recognise the different forms related to nature degradation and, in particular, those linked to humans as the principal cause of pollution. Natural causes (e.g. natural rock substrates) are also sources of contamination, but these rarely generate health problems since the processes of weathering, transport and sedimentation are slow and the ecosystem has the capacity of filter them. When this capacity of the ecosystem is reduced, it implies that natural resources, as water, are not longer used for specific purposes. For example, the use of resources by the inhabitants includes agricultural activities (using methods such as logging and burning), fishing, hunting and gathering, and also direct uses such as water for drinking, bathing, recreation, etc., which as the population grows these are in greater demand applying larger pressure on a variety of natural resources (Chapman, 1996). This is more relevant if a large part of the poorest population is considered to be directly dependent on the ecosystems for their existence (MEA a,b, 2005; UNEP, 2010; UN, 2010). If the body of water is located near of population centres, the effects that are presented are negative, even if these are of low intensity, on the diversity of species and processes that take place during a given period of time (UNESCO, 2012).

In terms of water quality, UNESCO (2012) indicates that it is a relative term, since it is in function of the intended use. It is also crucial to consider that water does not exist pure in nature, as it may be affected by rock or soil materials produced by rock bedding or erosion, evapotranspiration, dust deposition, and salt hauling on the wind, by percolation of organic matter and soil nutrients. Also, hydrological factors such as runoff, and biological processes in aquatic and terrestrial environments (soil) can alter the physical and chemical composition of water (dissolved or suspended matter). Although some salts and dissolved minerals are necessary to maintain the health and vitality of organisms, other substances are harmful to human health and to the ecosystem including metals, pesticides, and organic toxins, among others. At the end of the day, the type of substance and its concentration will result in a contaminant or not of the water. Thus, according to the UN (2010), clean, safe and quality freshwater is a key resource for human, social and economic development, but it also represents an increasing threat to the same development as the availability of water also modify the hydrological cycle and water quality.

The aim of this paper is to establish water quality in water bodies belonging to rural towns, which have modified, in different degrees, the land use as response to their community necessities. In the case of pollution of these water bodies, it is important to determine if these are associated to human use of the natural resources (soil, vegetation and water) or if these are a common response of the environment. Finally, the paper also aims to establish if these water bodies have the quality to continue with the net use.

2. Study zone

Nine Aguadas (a type of cenotes) were monitored at the Natural Protected Area "Calakmul Biosphere Reserve" (RBC), of which the importance is based on sustaining the ecosystem for different species, as well as being used as a source of water supply for animals and humans (Fig. 1). The RBC is characterised by a very particular climatology, edaphology and vegetation, representing a great contribution to the maintenance of essential ecological processes, such as water and climate regimes, and the ecological and evolutionary processes that determine the biodiversity of the area. The latter contains ecosystems characterized by their great diversity, wealth and fragility. It has more than 80% of plant species of the Yucatan Peninsula, besides 350 species of birds and approximately 100 species of mammals. The vegetation is a mixture of high and medium rainforests with temporarily flooded low rainforests and aquatic vegetation. The fauna of the area corresponds to the neo-tropical region where endemic, threatened and endangered species are included, such as white-lipped peccaries, tapir, jaguar, puma, king vulture, and ocellated turkey, among many others. It is also important as a biological corridor that allows the displacement in both directions of the species between the sub-regions of the Yucatan Peninsula and the sub-humid and humid climate zones to the south (Domínguez and William, 1996). In addition, the reserve is one of the groupings of archaeological zones of the most outstanding Mayan culture of the country (INE, 1999).

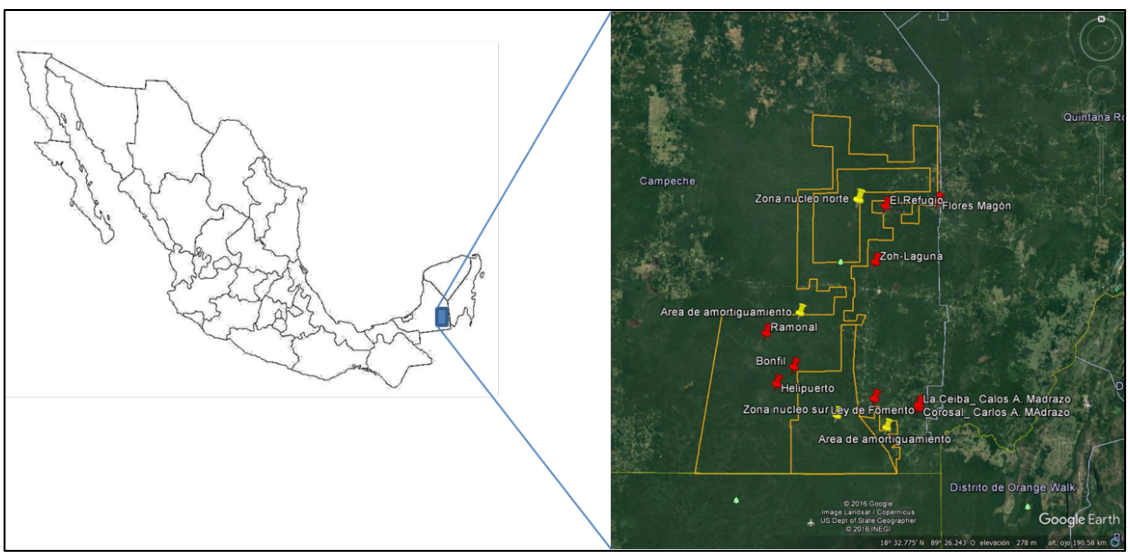


Figure 1. Nine Aguadas (red points) monitoring at the RBC (yellow line), Campeche, Mexico.

Climatologically, RBC is a typical tropical forest, for which temperature variations are small, and seasonality is defined by two periods as well as the whole Yucatan Peninsula: rainy season from March to October and dry season from November to February (Alcocer et al., 1998). The temperature ranges from 23 °C in January to 28 °C in May, and the average annual precipitation is 1,050 mm, within a tropical Savana type climate with warm moist breezes. There are few surface water bodies, and rivers are short, thus the most important source of water is moving underground. However, since 85% of rainfall is evapotranspirated, instead of being a site with abundant water it presents major drought problems mainly due to the factors of climate and hydrogeology, making the hydrological system complex. Fresh water is scarce with characteristics associated with marine intrusion, deforestation and groundwater contamination (Alcocer et al., 1998; Ward et al., 1985).

The main type of rock is sedimentary limestone corresponding to the Tertiary period and covering most of the region. Due to the lack of clays and silt (marls) of the Upper Tertiary above the limestone, rainwater (charged with CO_2) is rapidly filtered dissolving the rocks (mainly formed with carbonate minerals - calcite, aragonite). As water has eroded the limestone over thousands to millions of years, the main characteristic of water movement in the zone is associated to the cave systems formed through limestone bedrock. In RBC three types of surfaces can be identified according to the permeability of rock types: null (accumulates permanent water), low (temporary water flow) and high (karstic soil). García et al. (2002) mentioned that most of the surface corresponds to high permeability type forming a karstic relief, which gives rise only to intermittent runoff. Also, they mentioned that most of the surface where water is stored (called *Aguadas*) are allocated in the southern part of the RBC, where only nearby communities can benefit from this vital resource.

The *Aguadas* are water bodies formed by the accumulation of precipitation and because their soil reduction is not so severe, not all soluble material is eliminated by the movement of groundwater, allowing the formation of other geological units that produce clay or sand. The *Aguadas* are a type of cenote that means hole in the surface land and were a Mayan's sacred places. They do not have a defined form and have shallow waters. Additional to the natural *aguadas*, some artificial ones were built in order to storage rain water to have availability during the drought season.

3. Methodology

Nine aguadas with and without direct human impact were monitored to assess the effect on the water quality at the Calakmul Biosphere Reserve (RBC). Three of them are in the northern area: Refugio is used for recreational use, fishing and within the rural population; Flores Magón for recreational use, fishing and allocated in a natural depression out of the rural population area; and Zoh-Laguna for recreational use and fishing at the southwest of the town. The other three are in the southern area: Carlos A. Madrazo with La Ceiba for human water supply (faraway of the rural population), Corosal for the neighbourhood use, and Ley de Fomento (La Misteriosa) for recreational use faraway of the rural population. Finally, the last three are in the Archaeological Zone: Ramonal, Bonfil and Heliport, all of them for environmental uses.

A water quality assessment was done to determinate microorganisms and physical and chemical compounds concentration contained in the water on the basis of established limits in the Mexican Federal Norms (NOM-127-SSA1-1994, in DOF, 2000) in order to establish the degree of pollution. Water samples were collected in high density polyethylene containers previously washed in a solution of 10% nitric acid, followed by repeated rinsing with distillate water. Until collection, containers were kept in a sealed storage container. Water samples were stabilized with nitric acid (0.5% HNO_3). Samples were tested for pH, temperature, redox potential, dissolved O_2, hardness, alkalinity, conductivity, total dissolved solids, salinity, chloride, sulphates and COD (Chemical Oxygen Demand). Due to strategic problems to measure effectively faecal coliforms, it was used the qualitative Swab and Samplers Test (Merck Millipore[R], 2011) to measure total coliforms as an indicator of the faecal ones. The method consists in pour water from the source into a vessel of the equipment, then put the membrane upside down for 30 seconds, remove the unabsorbed water and reintroduce the membrane. The membrane is a swab containing a buffer solution and the swab is incubated for 24 hours at a temperature of 35°C to 37°C. Direct counting of the colonies developed on the membrane was then carried out.

For determination of concentrations of metals in waters, a multi-standard calibration method was applied: Perkin Elmer 10 mg/ml of twenty-nine metals (ICP-MS Standard, Matrix: 5% HNO_3, Perkin Elmer Life and Analytical Sciences) according to the requirements of the NMX-AA-131/2 (DOF, 2014) measuring aluminium (Al), arsenic (As), barium (Ba), beryllium (Be), calcium (Ca), cadmium (Cd), cobalt (Co), chromium (Cr), copper (Cu), iron (Fe), potassium (K), manganese (Mn), molybdenum (Mo), sodium (Na), nickel (Ni), lead (Pb), antimony (Sb), selenium (Se), tin (Sn), strontium (Sr), titanium (Ti), thallium (Ta) and vanadium (Va). This ICP method can detect the majority of the metal ions below 0.1 mg/l (Nham, 2010; Thomas, 2004). It is highly recommended if there is a doubt about the presence of these compounds to apply the test. As potentially toxic metals are resulting from anthropogenic activities these cause severe disturbance of ecosystems (Abdallah, 2008; Martorell et al., 2009). Although in these areas is not expected to have significant traces of metal concentrations as there is not industry, there is a possibility that agricultural activities could introduce them in the environment.

4. Results

4.1 Microorganisms

According to the Swab and Samplers Test Kits manual (Merck Millipore[R], 2011), the presence of total coliforms is confirmed by the formation of blue colonies and occurs in small or large colonies scattered throughout the sample. Otherwise, green, gray, or cream colonies are not colonies of coliforms. The results are a report of the coliform density as the number of colonies in 100 mL of sample. The presence of large colonies indicates the presence of pathogens in the *Aguada*. Samples from El Ramonal, Bonfil and Heliport were not incubated; however, given the climatic conditions the colony growth occurred. In general, the aguadas contain a small amount of coliforms.

The colonies presented in the sample of Flores Magon were 97, predominating those of blue colour. The same can be observed in La Misteriosa and in the Corosal, although the number of colonies was very numerous to be able to count them. The same situation can be associated in the samples of the Ramonal and the Heliport where there was a large blue colonies growth but as they were not incubated they did not develop defined colonies. These results were expected since these aguadas have a greater exposure to the impact originated by humans and domestic animal. It should be mentioned that in the Corosal aguada, additional to the presence of domestic animals and humans, it was observed a great amount of aquatic lily that is removed when it saturates the water surface. The presence of lily is mainly associated with the organic matter and nutrients contained. Thus, the most common input come from wastewater disposition in rural areas, and even in urban areas where drainage or septic tanks could present leaks that contribute with large numbers of coliforms and other bacteria to surface water and groundwater. But also, stormwater runoff from rural or urban areas can transport waste material from domestic pets and wildlife. Besides that, as this is a forest, it is expected that stormwater runoff also carries nutrients from the soil once deforestation take place, as well as waste material from, trees and native animals. The later is the case of Ramonal and Heliport aguadas, which are inside the forest.

In El Refugio, Bonfil and La Ceiba (cenote) were observed larger sizes (of the order of 50 to 100) of yellowish colonies. These colonies do not indicate the presence of coliforms. Also, this result is expected since the aguadas are well protected by the inhabitants or communal authorities, and Bonfil and La Ceiba are faraway of the community. Fig. 2 shows results obtained in the locality of Carlos A. Madrazo for both La Ceiba (unaltered) and Corosal (altered) aguadas.

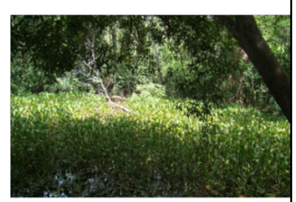
Date	Site and time	pH	No. colonies	Swab	
03/05/2014	Carlos A. Madrazo La Ceiba 2:20 pm	8	50		
Date	Site and time	pH	No. colonies	Swab	
03/05/2014	Carlos A. Madrazo Corosal 4:22 pm	8	muy numerosas para contar		

Figure 2. Aguadas La Ceiba (unaltered) and Corosal (altered) in Carlos A. Madrazo locality.

4.2 Phisyco-chemical parameters

The supply water for human consumption and use with an adequate quality is regulated by the NOM-127-SSA1-1994 in DOF, 2000) that establish permissible limits in terms of bacteriological, physical, organoleptic, chemical and radioactive characteristics. Table 1 presented the parameters measured and the method used according with the Mexican Standard Norms (NMX) in order to meet the NOM-127-SSA1-1994.

Table 1. Parameters measured and the method used according with the Mexican Norms (NMX)

Parameter	Method	NOM-127-SSA1-1994
pH	NMX-AA-008-SCFI-2000	6.5-8.5
T (°C)	NMX-AA-007-SCFI-2000	
Eh redox (mV)		
Dissolved O2 (%)	NMX-AA-012-SCFI-2001	
Dissolved O2 (ppm)	NMX-AA-012-SCFI-2001	
Hardness (ppm CaCO3)	NMX-AA-072-SCFI-2001	500
Total Alkalinity (ppm CaCO3)	NMX-AA-036-SCFI-2001	
Total Acidity (ppm CaCO3)	NMX-AA-036-SCFI-2001	
Conductivity (mS/cm)	NMX-AA-093-SCFI-2000	
Total Dissolved Soils (ppm)	NMX-AA-034-SCFI-2001	1000
Salinity		
Sulphates (ppm)	NMX-AA-074-1981	400
Chlorides (ppm)	NMX-AA-073-SCFI-2001	250
Chemical Oxygen Demand (mg O2/ L)	NMX-AA-030-SCFI-2001	

Table 2 presents results obtained for the nine aguadas (1:La Ceiba, 2:Coroal, 3:La Misteriosa, 4:Ramonal, 5:Bonfil, 6:Heliport, 7:Regugio, 8:Flores Magon and 9:Zoh-Laguna).

Table 2. Physico-chemical parameters measured in the nine aguadas.
Limits are expressed in mg/L, except where otherwise indicated.

Parámetro	**NOM-127-SSA1-1994**	**Noth**			**Centre**			**South**		
		La Ceiba	**Corosal**	**La Misteriosa**	**Ramonal**	**Bonfil**	**Heliport**	**Refugio**	**Flores Magón**	**Zoh-Laguna**
pH	6.5-8.5	7.2	7.2	7.4	7	6.7	6.7	7.4	7.6	7.2
T (°C)		25.4	26.4	32	26	26.7	30.5	26.4	29.4	25.9
Eh redox (mV)		193.6	137	2.14	183	180	63.4	261	190	170
Dissolved O2 (%)		0	2.6	40.6	0	0	1.4	36.3	37.4	31.6
Dissolved O2 (ppm)		0.14	0.17	2.94	0	0	0.09	2.56	2.01	2.42
Hardness (ppm CaCO3)	500	204.3	175.1	175.1	103.1	107	186.8	136.2	159.5	95.3
Total Alkalinity (ppm CaCO3)		212.8	166.5	106.4	115.6	120.3	166.5	87.9	138.8	69.4
Total Acidity (ppm CaCO3)		27.2	25.3	8.7	18.5	15.5	42.7	7.8	12.6	12.6
Conductivity (mS/cm)		0.36	0.296	0.289	0.25	0.219	0.322	0.169	0.255	0.131
SDT (ppm)	1000	180	148	144	125	109	161	85	127	66
Salinity		0.17	0.14	0.13	0.12	0.1	0.15	0.08	0.12	0.06
Sulphates (ppm)	400	0	0	0.048	0	0	0	0.016	0.016	0
Chlorides (ppm)	250	0.009	0.013	0.018	0.019	0.009	0.014	0.009	0.009	0.009
DQO (mg O2/ L)		33.12	33.12	47.84	47.84	33.12	62.56	47.84	47.84	33.12

Relating to pH, all sites present values according to the Norm: Bonfil and Heliport are slightly acids, Ramonal is neutral and the rest are slightly alkaline. This is according to the findings of Pearse et al. (1936) who reported pH values of 6.8–8.6 for water in cenotes in north-western Yucatan state, and Herrera-Silveira et al. (1997) that reported a mean pH value of 7.5 (7.2–8.6) from a variety of aquatic ecosystems in the Yucatan Peninsula (Alcocer et al., 1998). The pH >7, particularly in the rainy season, is result of the degradation of the karstic rocks dissolving $CaCO_3$. Also, Alcocer et al. (1998) confirm the presence of $CaCO_3$ washes layers by their lower conductivity and salinity values and higher temperature. This agrees with Table 2 results since conductivity have values between 0.131–0.36 μS/cm and salinity between 0.06-0.17mg/L, that almost corresponds to distillate water. High temperature was observed in Flores Magon, Heliport and La Misteriosa with 29.4^{o}C, 30.5^{o}C and 32.0^{o}C, respectively; the rest are quite constant with an average of 26.0^{o}C (25.4-26.7). These values agrees with the observed by Ward et al. (1985) of 24.65-28.29^{o}C, and by van der Kamp (1995) and Pearse et al. (1936) of 21.9-28.5^{o}C that also compared them with the atmospheric temperature values (Alcocer et al., 1998). However, according to Herrera-Silveira et al. (1977 in Alcocer et al., 1998) found a range of 22.0 to 33.5^{o}C, under this point also the three aguadas mentioned above are within these values. It is possible that these high values correspond to some chemical reaction of the CO_2. In particular, in the Heliport, this aguada is recovering from an extreme extraction, thus the water surface level was shallow and probably it conserved a major temperature and a major atmospheric CO_2 transfer.

Hardness is associated to the presence of CO_3 providing medium to soft values (95.3-204 mg/L). This is very clear since the minimum value of 95.3 mg/L was observed in Zoh-Laguna that is an aguada within the population, and La Ceiba with 204 is a natural site surrounded by unaltered conditions, thus there is a major contribution to dissolve karst rocks. As a consequence, the same behaviour was observed at the alkalinity with the lower value of 69.4 mg/L in Zoh-Laguna and major value of 204 mg/L in La Ceiba. It is interesting that although with low values 7.8-27.2 mg/L, the acidity is major in the Heliport with 42.7 mg/L. This value could be also associated to the shallow surface water in a pond filled with vegetation. Thus with low oxygen, certain bacteria is activated and convert the vegetation carbohydrates into acid, which increases the acidity.

Oxygen values were less than 3 mgO_2/L (<40%) that according to Alcocer et al. (1998) is not far to the observed by Pearse et al. (1936) of <50%DO. For Alcocer et al. (1998) this lower concentration is associated to biological (respiration and microbial oxidation of organic matter) and chemical oxidation of the groundwater. In this case La Misteriosa has the higher value with 2.94 mg/l (40.6%) of DO and also it has aquatic macrophytes, which increases DO concentrations in the aguada as pointed by Alcocer et al. (1998). Oxygen is related to the potential redox (Eh) that regulates the behaviour of many chemical and organic compounds through oxidation and reduction in water bodies. Thus as DO increases there is a major probability to have a chemical change and an increase of solutes, and Eh is expected to be low. It was observed in La Misteriosa with a high DO but low Eh (2.14mV). However, El Refugio presented a value for DO of 2.56 mg/L (36.3%) and high value of Eh with 261mV, this implies an environment favouring oxidative reactions. Although it was considered El Refugio as an unaltered aguada, it is highly probable that a high amount of organic matter enter to the system. This input could come from the decomposition of organic matter by microorganisms in the soil releasing CO_2.

Schmitter-Soto et al. (2002) noticed that the organic and inorganic matter (OM) enters in the cenotes during the rainy season by soil lixiviation, the weathering of logs, leaves and transport of animal carcasses, and anthropogenic sewage. Values obtained for COD (inorganic matter) were between 33 and 63 mg/L that is relatively low and could imply a medium organic matter (Biological Oxygen Demand in 5 days) concentration. Finally, sulphates and Chlorides are very low with maximum values of 0.048 and 0.019 mg/L, respectively, corresponding to fresh-water with low solids concentrations. Total Dissolved Solids (TDS) have values of 66-180mg/L being the lowest in Zoh-Laguna (altered) and the highest in La Ceiba (unaltered).

4.3 Metals

Heavy metals presence in nature usually is not dangerous for the environment because they are present only in very small quantities. Heavy metals are pollutants in the environment only if these are present in large quantities. Table 3 indicates the values of heavy metals found in the aguadas tested.

Table 3. Metals observed in the nine aguadas obtained by the ICP.

Element	LD (mg/L)	La Ceiba	Corosal	La Misteriosa	Ramonal	Bonfil	Heliport	Refugio	Flores Magon	Zoh-Laguna
Al	0.004	0.128	0.063	0.048	0.023		0.018		0.012	
Ba	0.002	0.144	0.154	0.228	0.05	0.143	0.146	0.026	0.05	0.016
Ca	0.01	107.353	58.413	115.455	393.202	406.353	356.179	413.486	410.473	352.823
Cd	0.001	0.026	0.05	0.023	0.043	0.065	0.045	0.015		0.023
Cu	0.005	0.046	0.027	0.019	0.022	0.01	0.015	0.007	0.008	0.009
Fe	0.001	0.242	0.079	0.021	0.076	0.051	0.033			0.022
K	0.01	8.082	10.856	2.157	8.421	11.597	14.304	6.39	5.292	4.124
Mg	0.01	6.104	5.543	4.367	2.094	3.956	4.836	2.253	2.469	1.805
Mn	0.001	0.087	0.079	0.115	0.093	0.078	0.048	0.035	0.005	0.013
Na	0.01	4.106	4.55	16.648	22.381	8.367	12.669	4.903	5.083	11.967
Sr	0.014	0.074	0.042	0.207	0.228	0.245	0.4	0.077	0.234	0.174

Limits are expressed in mg/L, except where otherwise indicated

The major amounts above the detected limits permitted by the NOM-127-SSA1-1994 were for Ca, Na, K and Mg. These elements were also observed by Schmitter-Soto et al. (2002). In this case, the natural influence by rock washing or erosion in the subsurface and surface has an effect on production systems due to the presence of carbonates, sodium, calcium, magnesium and potassium by the clay-limestone soil. Besides these elements, also all aguadas have high concentrations of: Cd, Mn, Cu, Fe, Al, Ba and Sr. In La Ceiba some traces of arsenic 0.019 mg/L<0.005 mg/L from the NOM) and vanadium 0.041 mg/L>0.001 mg/L form NOM were detected. For Sr a concentration <0.5 mg/L was related to the natural soil sources at the Yucatan Peninsula that explain the 0.4mg/L in the Heliport aguada. Something similar could be expected for the rest of the detected heavy metals. As it was observed by Bárány-Kevei et al. (2005) that found in a karstic forest area in Hungary the presence of zinc, cobalt, cadmium, copper, nickel and chromium contained in the soils, and this metal content could be associated to the duality between clay and loamy soils.

5. Conclusions

Results show that the RBC could be divided into three areas according to several factors being one of them the soil type. Thus, it was observed a similitude between La Ceiba, Corosal and La Misteriosa at the South, and Zoh-Laguna, El Refugio and Flores Magon at the North-Centre part of the RCB, and Ramonal, Bonfil and Heliport in the pyramids area at the west of the RBC. Water quality demonstrated that almost all the aguadas meet the permitted limits of NOM-127-SSA1-1994 for microorganisms and physico-chemical compounds. Also the coliforms and physico-chemical compounds values obtained agree with the findings from other authors for these types of water bodies in the Peninsula de Yucatan. The natural influence by rock washing or erosion in the subsurface and surface has a direct effect on the ecosystem due to the presence of carbonates, sodium, calcium, magnesium and potassium. For heavy metals, from the 29 elements that can be detected using the ICP, only 13 were observed and from these As and V were only detected in La Ceiba aguada. The rest of 11 elements were detected for all the aguadas and presented values above the one permitted by the NOM-127-SSA1-1994. Thus, it is important to define the origin of them in the aguadas, since it is very probable that these type of elements had been present by the karstic rock nature. So, it is highly possible that they are present by rock weathering, biodegradation in soils, atmospheric deposition, but also by anthropogenic activities.

Authors consider that the determination of pollutants in the aguadas need to establish the origin of the sample and to identify sources of pollution. Natural and anthropogenic origins could generate pollution when elements and compounds overpass the established permitted limits. For example, deforestation around bodies of water, transforming jungle into agricultural area, has been crucial since it creates a climatic transition zone affecting the water characteristics and conditions. Direct effects such as the erosion which drags nutrients and soil materials into the water bodies are also considered. Looking at water erosion, carbonates are conveyed due to karst topography forms contain limestones, which are mainly composed of calcium carbonate and clay that is also dissolved by water containing carbon dioxide. Also, in these karstic areas, tree roots generates residues also producing organic acids changing pH, and other compounds. Finally, even if human activities are pressing the ecosystem, its resilience capability helps to recover the resource maintaining some water quality for drinking and direct use. However, if the tendency of destruction continue, short-term water goals and targets will be not sufficient for the conservation and sustainable use of biodiversity and ecosystems. Thus, in order to regulate human relationship with nature activities, it is necessary to predict the consequences of changes in the drivers for biodiversity, ecosystem functions, and ecosystem services.

Acknowledgements

The elaboration of this work was possible thanks to the sponsorship of the projects No. 1345 and 2335 within the Program "Research of the International Collaboration Fund" of the Instituto de Ingeniería, UNAM. Authors appreciate the support provided by director Adalberto Zuñiga, the staff and inhabitants of the Calakmul Biosphere Reserve.

References

Abdallah, M.A.M. &Abdallah, A.M.A. (2008). Biomonitoring study of heavy metals in biota and sediments in the South Eastern Coast of Mediterranean Sea, Egypt.

Environmental Monitoring and Assessment, 146: 139-145. doi:10.1007/s10661-007-0066-8

Alcocer, J., A. Lugo, L. E. Marín & E. Escobar, (1998). Hydrochemistry of waters from five cenotes and evaluation of their suitability for drinking-water supplies, north-eastern Yucatan, Mexico. *Hydrogeol. J*. 6: 293–301. doi:10.1007/s100400050152

Bárány-Kevei I., E. Szoke & R. Kaszala (2005) Research on heavy metal contamination in the Aggtelek karst area in Hungary, Geophysical Research Abstracts, 7, 02685, 2005. SRef-ID: 1607-7962/gra/EGU05-A-02685

Domínguez, M. R. & William, J. F. (1996). Calakmul, México: Aguadas, bajos, y asentamientos en el Petén Campechano en IX Simposio de Investigaciones Arqueológicas en Guatemala, 1995, editado por J.P. Laporte y H. Escobedo, pp. 147-173. Museo Nacional de Arqueología y Etnología, Guatemala (digital version)

García Gil, G., Palacio Prieto J.L. & Ortiz Pérez M.A. (2002) Reconocimiento geomorfológico e hidrográfico de la Reserva de la Biosfera Calakmul, México, Investigaciones Geográficas (Mx), 48, 7-23. ISSN: 0188-4611

Herrera-Silveira JA, Comín FA, López S, & Sánchez I (1997) Limnological characterization of aquatic ecosystems in Yucatan Peninsula (SE Mexico). Verh. Int. Verein Limnol. 26: 1348-1351.

INE (1999). Programa de Manejo de la Reserva de la Biosfera Calakmul, Instituto Nacional de Ecología. México, D. F. 272 p.

Martorell V., M. D. Galindo-Riano, M. García-Vargas, M. D. Granado-Castro. (2009) Bioavailability of heavy metals monitoring water, sediments and fish species from a polluted estuary, *Journal of Hazardous Materials*, 162, 823–836. doi:10.1016/j.jhazmat.2008.05.106

MEA (2005b). Ecosystems and Human Well-Being: Synthesis. (Millennium Ecosystem Assessment). Washington DC, Island Press

MEA (2005a). Ecosystems and Human Well-Being: Wetlands and Water Synthesis. (Millennium Ecosystem Assessment).Washington DC, World Resources Institute (WRI)

Merck Millipore^{R} (2011). Swab and Samplers Test Kits Quality control as easy as 1, 2, 3, Millipore Corporation, USA

Nham T. (2010). Monitoring Heavy Metals by ICP-OES for Compliance with RoHS and WEEE Directives Agilent Technologies Inc., USA

DOF (2014). NMX-AA-131/2-SCFI-2014 análisis de agua-medición de metales por espectrometría de plasma acoplado inductivamente (ICP), en aguas naturales, residuales y residuales tratadas-método de prueba-parte 2-aplicación de la espectrometría de masas con plasma acoplado inductivamente (ICP-MS)-medición de 67 elementos. DOF: 25 July, 2014

DOF (2000). Norma Oficial Mexicana NOM-127-SSA1-1994, "Salud ambiental, agua para uso y consumo humano-límites permisibles de calidad y tratamientos a que debe someterse el agua para su potabilización". DOF, Web Page consulted in April 2016 [http://www.salud.gob.mx/unidades/cdi/nom/127ssa14.html]

Pearse A.S., Creaser E.P. & Hall F.G. (1936). The cenotes of Yucatan. A zoological and hydrographic survey. Carnegie Institution of Washington, Washington DC.

Thomas R. (2004). Practical Guide to ICP-MS, MarcelDekker Inc.

UN, 2010 ONU, 2010. UN-Water Statement on Water Quality, World Water Day, March 22, 2010 Página Web Consultada en Septiembre 2013 [http://www.unwater.org]

Schmitter-Soto J.J., F.A. Comin, E. Escobar-Briones, J. Herrera-Silveira, J. Alcocer, E. Suarez-Morales, M. Elias-Gutierrez, V. Diaz-Arce, L.E.Marin & B. Steinich (2002). Hydrogeochemical and biological characteristics of cenotes in the Yucatan Peninsula (SE Mexico) in J. Alcocer & S.S.S. Sarma (eds), Advances in Mexican Limnology: Basic and Applied Aspects. *Hydrobiologia* 467: 215-228. doi:10.1023/A:1014923217206

UNEP (2010). Annual Report. A year in Review, United Nations Environment Programme ISBN: 978-92-807-3149-1

UNESCO, 2012. The United Nations World Water Development Report 4: Managing Water under Uncertainty and Risk (Vol. 1), Knowledge Base (Vol. 2) and Facing the Challenges (Vol. 3). Published by the United Nations Educational, Scientific and Cultural Organization

van der Kamp G (1995) The hydrogeology of springs in relation to the biodiversity of spring fauna: a review. *J Kansas Ent Soc,* 68:4–17

Ward WC, Weidie AE, & Back W (1985) Geology and hydrogeology of the Yucatan and Quaternary geology of northeastern Yucatan Peninsula. *New Orleans Geological Society*, New Orleans, 160 pp