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# Hydrodynamic Study of Lake Enriquillo in Dominican Republic

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## Abstract

This study presents an analysis of the hydrochemical characteristics of Lake Enriquillo in the southwestern region of the Dominican Republic. This lake is hypersaline and endorheic. The climatology of the region is influenced by the Caribbean Regulator Climate Centers (CRCCs). Due to the endorheic nature of the basin, evaporation plays an extremely important role in its dynamics [1]. During the study period, in November 2002, the water level of Lake Enriquillo was 42 m below sea level (BLS), and the salinity level was 104.2‰. By 2014, the water level of the lake rose to 29 m below sea level, and the salinity decreased to 23.4‰, as a result of the high cyclonic activity in the Caribbean region.

## Keywords

Hydrochemical Parameter, Endorheic Lake, Hypersaline, Lake Enriquillo

## 1. Introduction

During the Eocene period of the Tertiary Era, the block forming the Sierra de Neyba collided with the Central Cordillera, both formed by tectonism and volcanism [2]. The Sierra de Bahoruco also shifted toward the Sierra de Neyba, generating pressure and raising the seabed that gave birth to the Enriquillo basin [3]. During this process, the highest mountains of the Cordillera Central were eroded by torrential rains, and their masses shifted following numerous landslides, thereby forming the valleys of San Juan, Azua, and Neyba. Sediments carried by the Rio Yaque del Sur (RYS) were deposited in what today forms the Bay of Neyba and Lake Enriquillo (LE) [4]. During this process, the waters that collected in the basin of LE during rainy periods were poured into the sea. When the outlet to the sea was blocked by the sediments and the amount of water collected surpassed the rate of evaporation within the basin, salts began to concentrate within the lake, reaching a salinity level of up to 105‰ [5]. Previously, the lake was reported to be located at 44 m below sea level (BSL).

The area currently occupied by LE formed part of the seabed for a long time. Even so, currently, its waters are not remnants of seawater but rather were trapped by tectonism [6] or the sedimentation dynamics of the region. The water and physical-chemical properties of the lake are linked to specific characteristics of the geology of the region, which also leads to the storage of water in this basin during rainy periods. Measurements from 2011-2014 showed that the salinity ranged from 18‰ - 34‰, while the water level increased from 36 to 29 m below sea level (BSL) due to high levels of rainfall in the region. As mentioned, the composition of salts in the lake indicates that the waters of LE are not remnants of a confined sea reservoir [7] [8]. Although LE was assumed to have a salinity level higher or equal to that of the sea upon reaching an equal level, only at about 31 m BSL does its salinity match that of the sea.

## 2. Study Area

Lago Enriquillo, Dominican Republic, (18˚31.7N, 71˚42.91W) is a hypersaline lake of marine originis the largest depression in the Caribbean region, located in the southwestern portion of the Dominican Republic between the mountains of the Sierra de Neyba and the Sierra de Bahoruco (**Figure 1** and **Figure 2**). This lake is endorheic, with no outlet to the sea. In 2003, the basin had an area of


**Figure 1.** Map of the Caribbean Region and location of Lake Enriquillo and its watershed, Dominican Republic.

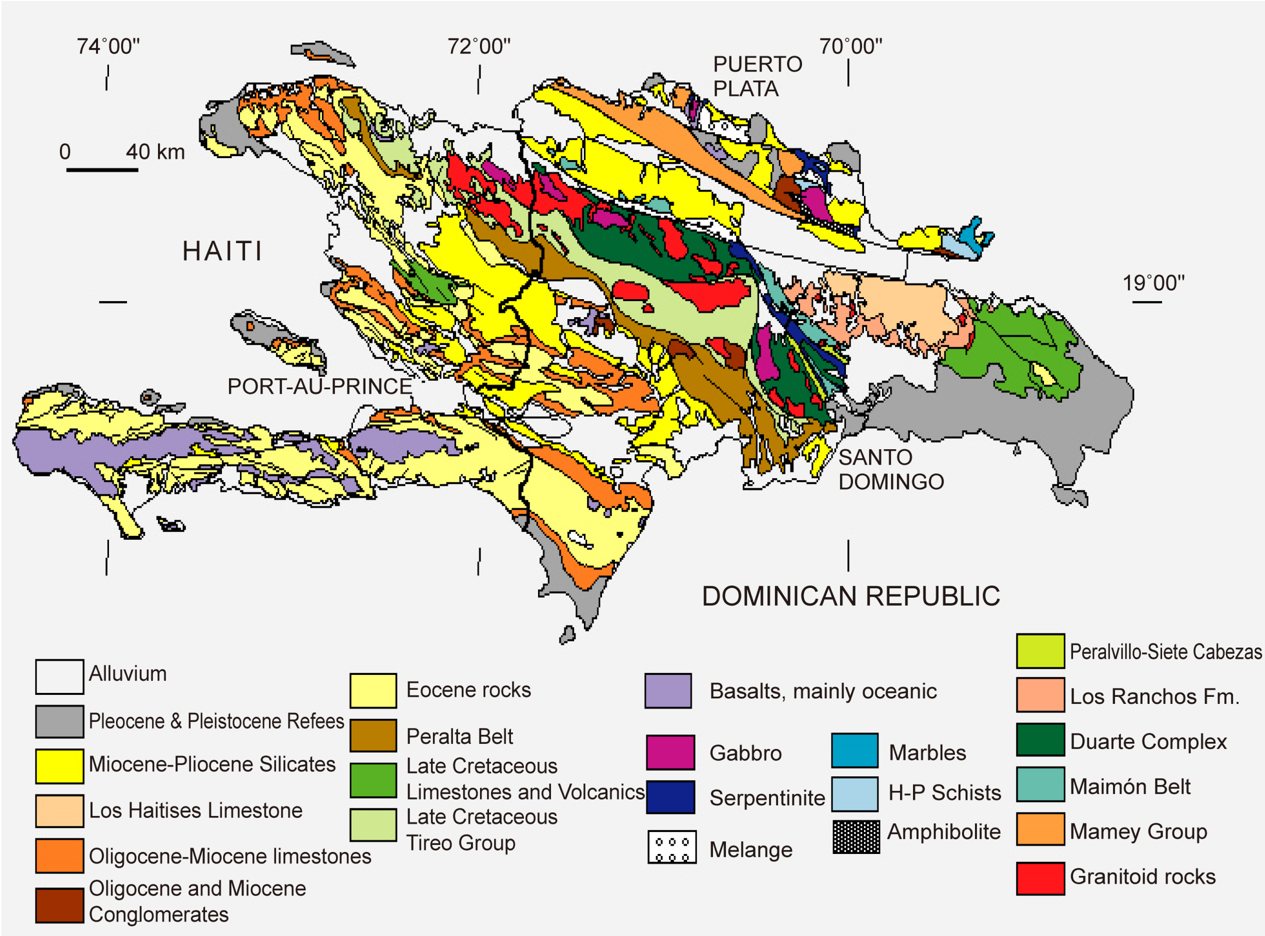


**Figure 2.** Geological Map of the Island of Hispaniola, Dominican Geological Survey. The Enriquillo-Plentain Garden fault lies south of Lake Enriquillo and continues towards Haiti. In the area of Port-au-Prince was located the epicenter of the earthquake of January 12, 2010 that destroyed the city Source Draper, Lewis and Gutierrez (1995).

3,048 $km^2$, and its salinity was 105‰ [9]. In addition, the lake occupied an area of 194.9 $km^2$, was located at 42 m BSL, had a maximum depth of 23 m (BSL), and contained a water volume of 1.14 $m^3$ in its reservoir [10].

Several geological faults intersect the LE basin. In addition, the basin contains several caverns in which portions of their roofs frequently collapse [11] following the small earthquakes that have occurred in the region. The main geological fault is the Enriquillo-Plantain Garden [12] [13], from which the Haiti earthquake of 2010 [14] was generated (**Figure 2**).

The LE basin has several tributary sub-basins, including Guayabal, Los Bolos, Penitente, Damas, Boca de Cachón, Azufrada La Zurza, Angostura, Barmesí, Río Panzo, Rio Barreno, Rio Blanco or Solié, Rio Penitente, Rincon Lagoon, and Limón Lagoon, which is part of the Yaque del Sur River Basin (RYS) that runs through the Cristóbal Channel. The water of the basin serves the aqueducts of the region and combines with that from other basins, including Las Barias and Las Marias, and from more than 700 small springs [15]. The largest amount of water originates from springs in basins formed by karst rocks [16]. The surface rivers are mostly dry during a large part of the year (**Figure 2**).

The neighboring Guayabal River basin is located on the southern slope of the Sierra de NeybaIndependencia province, with an area of 58 km$^2$. The length of the river bed of one of the main contributing branches is about 15.6 km (13.1 km from the Guayabal River and 2.5 km from La Cañada, La Codorniz), and this river flows into LE at the height of the municipality of Postrer Río (**Figure 2** and **Figure 3**).

The main cities located around LE are located within the provinces of Independencia and Bahoruco, with populations of 54,785 and 97,313 inhabitants, respectively. These provinces include the cities of Jimaní, La Descubierta, Neyba, Postrer Río, Duvergé, Boca de Cachón, Mella, Villa Jaragua, Los Ríos, El Limón, and Galván [17], which are mainly dedicated to agriculture, livestock, and fishing in LE [18].

Also, the RYS spills part of its waters into LE through the Cristóbal Channel. The RYS originates in the province of San Juan de la Maguana, with a population of 129,224 inhabitants. The population of this region is dedicated to the intense cultivation of agricultural products and to cattle ranching.

The LE basin corresponds with first driest region in the Dominican Republic due to the low levels of recorded annual rainfall [1] [19]. The elements that have the greatest influence on the region's hydrometeorology are evaporation in addition to temperature and precipitation between May and November. Even though the cyclonic season extends from June to November, peak precipitation in the region occurs during May. The rainfall regime is bimodal, with a peak in May and another in November. The arrival of cold fronts, as well as troughs, storms, and hurricanes impact the basin during the June-November cyclonic season. These elements also determine the variation in salinity, which ranged from approximately 105‰ to 23.4‰ during the 2003-2013 period [8] [9].

In addition, the rains are influenced by so-called Caribbean Regulators Climate Centers (CRCCs) the North Atlantic Oscillation (NAO), El Niño Southern

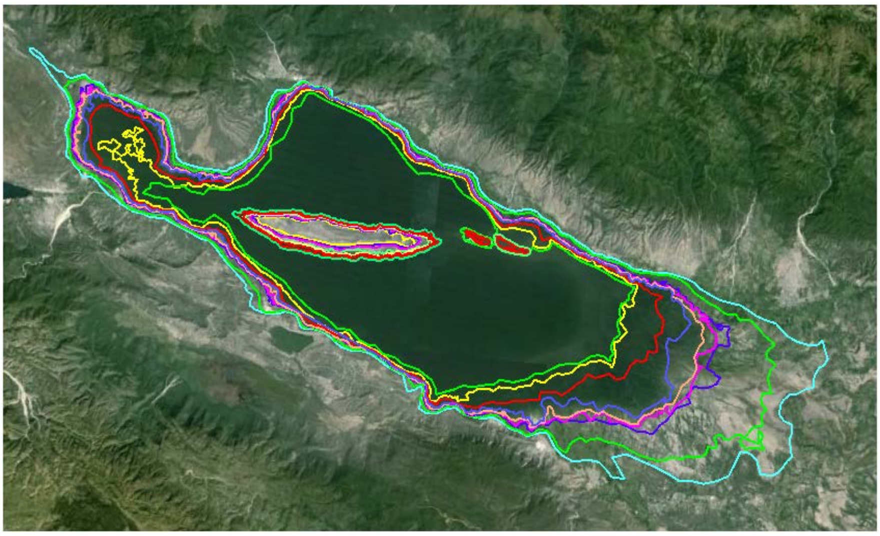

**Figure 3.** Contour of enriquillo lake level curves -42, -40, -36, -34, -33, -31, -29, -20 y -10 Below sea Level (BLS).

Oscillation (ENSO), trade winds, and Warm Water Pool North Atlantic, Multidecadal Oscillation, as well as the behavior of the Azores anticyclone. The presence of ENSO, [1]

The flora surrounding LE corresponds the different types of vegetation: dry forest, broadleaved woodlands, pine forests, wetlands and marine coastal areas cover an altitudinal succession ranging from 40 m BLS in Lake Enriquillo to 2,300 m above sea level in the Sierra de Bahoruco are affected by the climate and type of soil [20]. The fauna is mainly characterized by reptiles such as iguanas, snakes, and lizards as well as scorpions. Crocodiles, fish, crustaceans, and mollusks inhabit the waters of LE, and their abundance is dependent on the varying levels of salinity (**Table 1**). When conditions are favorable, several types of birds can be observed, including flamingos and various species of herons and seagulls [21].

The lake also encloses three islands located below sea level (BLS). Isla Cabritos is the most important of these, with an area of 27.6 $km^2$ and an elongated shape (**Figure 3**). The other two islands are Barbarita (also locally known as "Chiquita") and Islita. During long droughts, when the lake level drops, these islands, especially the last two, become peninsulas and can be reached by walking. Isla Cabritos contains the only hyperxerophytic dry forest that exists BSL in the Caribbean.

## 3. Equipment and Materials

Equipment: Uwitec Sampler, Sartorius Balance, Oven, Muffle, Filtering Equipment, Glassware, Multi-Parametric Sensor, and Sonar-GPS.

## 4. Methodology

The physical-chemical parameters were determined using a multiparametric probe. Several passes along the lake in a vessel were performed using a Sonar-GPS, and the depths and coordinates were recorded to create the bathymetry of the lake in the Surfer 10 software. Using data from the bottom of the lake obtained during sampling in addition to historical data, topographic data [22], and

**Table 1.** Averages values of salinity, conductivity, and total dissolved solids during 2011-2014 in Lake Enriquillo.

| Date | Salinity (‰) | Conductivity (mS/cm) | Total dissolved solids (g/l) | Level (m BSL) | Area ($km^2$) | Volume ($km^3$) |
|---|---|---|---|---|---|---|
| *Nov. 2002 | 104.2 | 146.8 | 152.1 | 42 | 194.9 | 1.04 |
| *Mar. 2003 | 103.4 | 145.9 | 150.7 | 41.5 | 198.6 | 1.14 |
| 28 Feb. 2011 | 30.4 | 46.5 | 30.1 | 30.0 | 375.4 | 4.60 |
| 28 Feb. 2012 | 26.1 | 40.6 | 20.3 | 29.5 | 385.3 | 4.99 |
| 13 May 2013 | 23.7 | 37.6 | 18.8 | 29.0 | 391.4 | 5.22 |
| 16 Dec. 2013 | 24.4 | 38.3 | 19.2 | 29.5 | 387 | 5.00 |
| 23 May 2014 | 23.4 | 36.8 | 18.5 | 29.0 | 393 | 5.25 |

Google maps and Okmap, the areas and volumes of the lake were determined for different periods in the Surfer 10 software.

These calculations were focused on the 2004-2013 period. In the 2004-2012 period, Lake Enriquillo received a large amount of sediments that were transported to the lake by the rains that accompanied numerous storms and hurricanes, therefore causing an alarming increase in the water level and flood zone. In the northwestern part (La Descubierta), the column of sediments was determined in several places to reach more than 60 cm, similar to the mouth of the Guayabal river. Also, through the Cristóbal Channel, waters from the RYS removed a large mass of sediment and deposited it in the western part of the lake. The bathymetry of 1994 [23] showed changes resulting from the contribution of sediments, thereby reducing the volume and shape of the lake cavity in comparison to before 2013.

## Results and Discussion

During the 1969-1979 period, the water level of Lake Enriquillo (LE) decreased each subsequent year yet recovered its water level with the passage of Hurricane David and storm Federico in August and September 1979, respectively [1]. Then, for the 1982-1998 period, the water level dropped to 44 m BSL but recovered about two meters following Hurricane George in September 1998. By 2003, the level of the lake was about 42 m BSL. The storm Odette and a series of extreme weather events at the beginning of the year led to an increase in the water level to 29 m BSL (See **Table 2**). During the 2003-2013 period, the water level increased even more to 13 m. In the area of "Los Borbollones", the physical-chemical parameters reached their highest values (February 2011), which was unexpected since this area represents the entry way of fresh water where the salt content would be expected to be lower. To the contrary, these waters contained a high salinity, indicating that they originated from areas experiencing significant salinization processes and drought. At that time, because of the high rainfall in

**Table 2.** Levels, areas and volumes occupied during 2004-2013 by Lake Enriquillo calculated using the Google applications, Surfer 10 and Okmap. * Includes Islita and Barbarita (1,127 km$^2$ and 1,427 km$^2$).

| Level (BSL) (m) | Areas km$^2$ | | | Volume km$^3$ | |
|---|---|---|---|---|---|
| | Cabrito Island | Lake | Mirror | Lake | Date |
| 42 | 24.088 | 243.267 | *216.625 | 1.037 | 2004 |
| 40 | 21.691 | 276.894 | 255.203 | 2.033 | 2007 |
| 36 | 18.772 | 314.714 | 295.942 | 3.674 | 2008 |
| 34 | 16.765 | 344.766 | 328.001 | 3.891 | 2009 |
| 33 | 15.400 | 353.470 | 338.070 | 4.223 | 2010 |
| 31 | 13.118 | 375.388 | 362.270 | 4.599 | 2011 |
| 30 | 11.748 | 385.255 | 373.507 | 4.923 | 2012 |
| 29 | 10.602 | 391.121 | 380.519 | 5.221 | 2013 |

the basin, the rivers and water sources that fed and drained into LE had a very high salt content.

At the beginning of 2011, the physical-chemical parameters were variable from one area to another and also between the surface and the bottom of the lake, as the volume of water entering the lake was also variable and mixed to a large extent with hypersaline water [8] [24]. By 2012, the values of salinity and conductivity throughout the lake were more homogeneous. The mixture of water stored during the years 1979-2003 and the rainfall between 2003-2011 had mostly mixed, so we could infer that by 2013 the level of the lake would begin to fall, as indeed happened. For the 2013-2016 period, the decrease in meteorological events in the basin caused the water level to descend by 3.44 m. So, we can confirm that the changes in water level experienced by Lake Enriquillo are a consequence of changes in rainfall throughout its basin and no other factors.

The background of LE is irregular due to its origin. At the time of analysis, this water body was not considered a lagoon. In addition, the waters that fed LE originated from different places and had distinct characteristics. Some waters were loaded with sulfur, while others contained calcium carbonate or were of good quality and low in salts.

Variations in the physical and chemical parameters of LE are determined by changes in rainfall and the geomorphological characteristics of the basin rocks. The salts in the water of the lake are characteristically different than those of the sea [5], further confirming that the waters are not of marine origin. Rather, this basin represents a reservoir of water funneled from the mountain ranges of Neyba and Bahoruco. The levels of sodium, magnesium, and chlorine also differ and are lower than those of the sea. However, sulfur is more concentrated in the lake than in the sea because several springs that feed the reservoir contain sulfur water (La Descubierta and Duvergé).

In **Figure 4** it is presented as a result of the differences in depth and bathymetric slope, Lake Enriquillo typically experiences a greater surface growth in its western and eastern zone than in the north and south, the points taken as references for this bathymetry are shown in **Figure 5**. This result is similar to that presented in article [25].

## 5. Conclusions

In Lake Enriquillo (LE), the level and the physical-chemical parameters of the water equally respond to changes in the pluviometry of the surrounding basin. The LE basin is framed by the southern slope of the Sierra de Neyba and the northern slope of the Sierra de Bahoruco in the Dominican Republic and is somewhat influenced by the RYS and Cristobal channel. As this zone is one of the driest in the country, the level of evaporation is higher than the amount of precipitation that occurs, causing the levels of Enriquillo Lake to fluctuate. In addition, these fluctuations are influenced by the Caribbean Regulator Climate Centers (CRCCs), as the replenishment of the water level is dependent on storms and hurricanes, to corroborate this assertion [25] finds that the frequency of

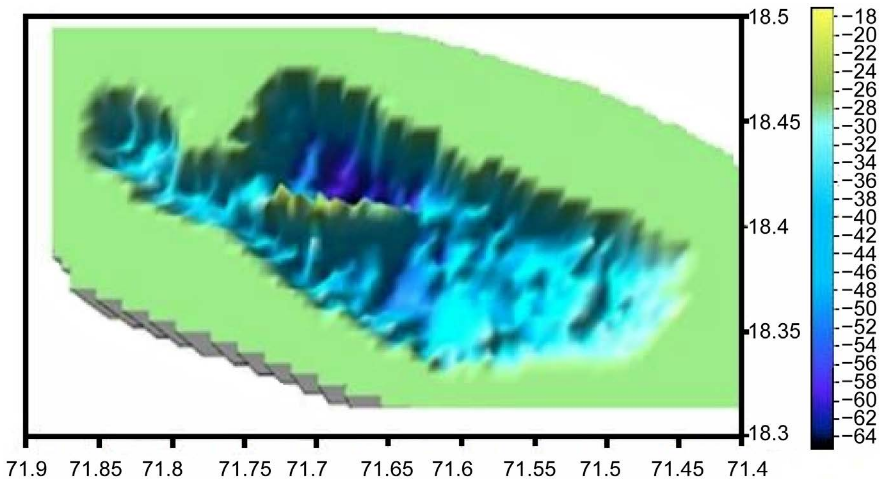


Figure 4. Bathymetry of Enriquillo Lake in 2013, the maximum level reached is 29 m BSL. The maximum depth is of 65 m BSL located to the north. In 2003, the level was 42 m BSL, representing a change of 13 m over a period of 10 years. The coordinates are north latitude and west longitude.


Figure 5. Sampling locations during the 2011-2013 period.

storms in Southern Hispaniola in the last 63 years shows a similar trend with the last decade characterized by the exits of the moderate El Niño and the beginning of the periods of La Niña that generally coincide with the increase of the hurricane and the activity of the storm.

The characteristics of the waters entering the lake do not correspond to those of sea water, either concentrated or diluted, as they have a distinct composition. The high salinity reached by Enriquillo Lake during its formation is evidence of how salts have concentrated from sources other than the sea [26]. The salt contents result from the contribution and the dilution of the karst rocks that largely constitute the basin and from the salt mines of the basin, and these dynamics are exacerbated by the high rate of evaporation in the region.

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## References

[1] Méndez-Tejeda, R., Rosado, G., Rivas, D.V., Montilla, T., Hernández, S., Ortiz, A. and Santos, F. (2016) Climate Variability and Its Effects on the Increased Level of Lake Enriquillo in the Dominican Republic, 2000-2013. *Applied Ecology and Environmental Sciences*, **4**, 26-36.

[2] Bowin, C. (1966) Caribbean Gravity Field and Plate Tectonics. The Geological Society of America, Inc., Library of Congress, Catalog Card No. 76-16261.

[3] Van den Berghe, B. (1983) Evolution sédimentaire et structurale depuis le paléocène du secteur "Massif de la Selle-Bahoruco-Nord de la ride de Beata" dans l'orogène nord-Caraibe. Université Pierre et Marie Curie, Paris, France, 205.

[4] Díaz De Neira, J.A. and Solé Pont, F.J. (2002) Precisiones estratigráficas sobre el Neógeno de la cuenca de Azua (República Dominicana) [Stratigraphic Precisions about the Neogene of the Azua basin (Dominican Republic)]. Depto. de Geología. Informes y Proyectos S.A. (INYPSA). C/Velazquez, 60. 28011 Madrid. *Acta Geologica Hispanica*, **37**, 163-181.

[5] Margalef, R. (1985) Limnología del Lago Enriquillo. Rep. Dominicana.

[6] Mann, P., Burke, K. and Matumoto, T. (1984) Neotectonics of Hispañiola: Plate motion, Sedimentation, and Seismicity at a Restraining Bend. *Earth and Planetary Science Letters*, **70**, 311-324.

[7] Greer, L. and Swart, P.K. (2006) Decadal Cyclicity of Regional Mid-Holocene Precipitation: Evidence from Dominican Coral Proxies. *Paleoceanography*, **21**, PA2020, https://doi.org/10.1029/2005PA001166

[8] Rosado, G., Méndez-Tejeda, R., Rivas, V.D. and Infante, I.M. (2016) Physicochemical Analysis of Lake Enriquillo in Dominican Republic. *Open Science Journal*, **1**, 1-13. https://osjournal.org/ojs/index.php/OSJ/article/view/638/44

[9] Buck, D.G., Brenner, M., Hodell, D.A., Curits, J.H., Martin, J.B. and Pagani, M. (2005) Physical and Chemical Properties of Hypersaline Lago Enriquillo, Dominican Republic. *Verhandlungen des Internationalen Verein Limnologie*, **29**, 725-731.

[10] Mann, P., Taylor, F.W., Burke, K. and Kulstad, R. (1984) Subaerially Exposed Holocene Coral Reef, Enriquillo Valley, Dominican Republic. *Geological Society of America Bulletin*, **95**, 1084-1092. https://doi.org/10.1130/0016-7606(1984)95<1084:SEHCRE>2.0.CO;2

[11] Araguás-Araguás, L., Michelen, C. and Febrillet, J. (1993) Estudio de la dinámica del Lago Enriquillo: informe de avance. Internat. Atomic Energy Agency, Vienna, Austria, ProjectDOM/8/006.

[12] Bionini, W.E., Hargraves, R.B. and Shagan, R. (1984) The Caribean-South American Plata Boundary and Regional Tectonic. Geological Society of America, Memoir 162, USA.

[13] Dolan, J., Mann, P., De Zoeten, R., Heubeck, C. and Shiroma, J. (1991) Sedimentologic, Stratigraphic and Tectonic Synthesis of Eocene-Miocene Sedimentary Basins, Hispañiola and Puerto Rico. In: *Geologic and Tectonic Development of the North America-Caribbean Plate boundary in Hispañiola*, Geological Society of America Special Paper, 262.

[14] Bird, J.M. (1980) Plate Tectonics. 2nd Edition, American Geophysical Union, Washington DC, 986 p.

[15] Ing. Antonio Cocco Quezada (2013) La oscilacion natural del Lago Enriquillo (ONLE). Un evento hidrometeorológico que responde a la variabilidad climática de la República Dominicana. http://www.acqweather.com/LA%20ONLE%20Final.pdf

[16] Stemann, T.A. and Johnson, K.G. (1992) Coral Assemblages, Biofacies, and Ecological Zones in the Mid Holocene Reef Deposits of the Enriquillo Valley, Dominican Republic. *Lethaia*, **25**, 231-241. https://doi.org/10.1111/j.1502-3931.1992.tb01391.x

[17] Hernaiz-Huerta, P.P. (2004) Mapa Geológico de la Hoja a E. 1:50.000 nº 5871-I (La Descubierta) y Memoria correspondiente. Proyecto de Cartografía Geotemática de la República Dominicana. Programa SYSMIN. Dirección General de Minería, Santo Domingo.

[18] National Bureau of Statistics, Dominican Republic (2010). http://ghdx.healthdata.org/organizations/national-statistics-office-dominican-republic

[19] ONAMET (2013). http://www.onamet.gov.do/

[20] Ducoudray, F. (2006) La Naturaleza Dominicana. Tomo 2. Región Sur. Colección Centenario. Grupo León Jimenes. Editora Corripio. ISBN de la obra completa 9945-422-05-7, Santo Domingo, Rep. Dominicana.

[21] Marcano, E. (1987) Flórula de la Isla Cabritos. Universidad Autónoma de Santo Domingo, Rep. Dominicana.

[22] Wallace, M.H. (1947) A Review of the Stratigraphy of the Enriquillo Basin, Dominican Republic. Unpublished Reports, Dominican Seaboard Oil Company, 12.

[23] INDRHI (1994). http://www.indrhi.gob.do/

[24] Brenner, M. and Binford, M.W. (1988) A Sedimentary Record of Human Disturbance from Lake Miragoane, Haiti. *Journal of Paleolimnology*, **1**, 85-97. https://doi.org/10.1007/BF00196066

[25] Wright, V.D., Hornbach, M.J., Mchugh, C. and Mann, P. (2015) Factors Contributing to the 2005-Present, Rapid Rise in Lake Levels, Dominican Republic and Haiti (Hispaniola). *Natural Resources*, **6**, 465-481. https://doi.org/10.4236/nr.2015.68045

[26] Comarazamy, D.E., González, J.E., Moshary, F. and Plasecki, M. (2015) On the Hydrometeorological Changes of a Tropical Water Basin in the Caribbean and Its Sensitivity to Midterm Changes in Regional Climate. *Journal of Hydrometeorology*, **16**, 997-1013. https://doi.org/10.1175/JHM-D-14-0083.1