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# BATHYMETRIC STUDY OF WADI EL-RAYAN LAKES, EGYPT

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## Abstract

Bathymetry is a technique of measuring depths to determine the morphometry of water bodies. The derivation of bathymetry from the surveys is one of the basic researches of the aquatic environment, which has several practical implications to on the lake environment and it's monitoring. Wadi El-Rayan, as Ramsar site, is a very important wetland, in Egypt, as a reservoir for agricultural drainage water, fisheries and tourism. The Lakes are man-made basins in the Fayoum depression. Wadi El-Rayan Lakes are two reservoirs (upper Lake and Lower Lake), at different elevations. The Upper Lake is classified as open basin, while the Lower Lake is a closed basin, with no significant obvious water outflow. During recent decades, human impact on Wadi El-Rayan Lakes has increased due to intensification of agriculture and fish farming. Analyses of bathyemtric plans from 1996, 2010 and 2016 showed, the differences between morphometric parameters of the Upper Lake were generally small, while the Lower Lake changes are obvious at the three periods. The small fluctuate, in the features of Upper Lake is due to the water balance between the water inflow and water. The Lower Lake has faced extreme water loss through last twenty years is due to the agricultural lands and fish farms extended in the depression. The Upper Lake is rich in Lakeshores macrophyets, while decline the water plants in the Lower Lake. With low water levels, in the Lower Lake, the future continuity of the Lake system is in jeopardy.

**Keywords**: Wadi El-Rayan Lakes, bathymetry, morphometry.

## 1. INTRODUCTION

Bathymetry is the science of measuring the underwater depth of any water body; in order to produce a map that shows the water body depth as a function of geographical coordinates (latitudes and longitudes). This corresponds to topographic maps, which symbolize the altitude of Earth's surface at different geographic points (Jawaka and Luisa, 2015).

The study of a lake basin features is known as lake morphology. This type of study is a key element to proceed for a professional lake

management scheme. Lake management professionals can get wide views about how a lake functions by studying its morphometric characteristics. The determination of the shape and the structure of a lake basin leads to a good prediction on how human-induced events may affect water levels in that system (Anon, 2001). Therefore, knowledge of lake volume and depth are highly important in water resources management, in addition to biogeochemical and limnological research (Sobek et al, 2011).

### 1.1. Study site

Wadi El-Rayan (figure 1) is a natural depression in the western desert of Egypt (Khalifa and El-Khateeb, 2011). This depression was declared a Protected Area by Prime Ministerial Decree 943/1989 (Mohamed and Sabae, 2015), and as a wetland area of the Ramsar site (EEAA, 2012). The Protected Area is considered a paleontological site of international importance due to the presence of unique fossils of some of the earliest forms of whale discovered to date (Azzazi, 2009). Furthermore, the area comprises large desert areas that contain a variety of landscapes and formations (Khalifa and El-Khateeb, 2011). Wadi El-Rayan depression is important for migrating reed warblers (Ozarowska et al. 2011). Its total area is 1759 km² and is classified by the Egyptian Environmental Affairs Agency as a managed Protected Area for the conservation of wild species and the sustainable utilization of natural resources.

Wadi El-Rayan significance surpasses the local boundaries of the country, as the lake provides one of the oases for the migratory birds wintering from the Northern Hemisphere. Also ntionally the lake is extremely important, its importance is related to some factors, as a receptor for agricultural drainage water, fish and tourism. According to EEAA (2012), the Lakes present a significant wetland environment in the western desert with its biological diversity. Wadi El-Rayan Lakes play a fundamental role in the life cycles of the diverse species in these waters bodies, including 29 fish species, 164 bird species, 24 mammal species, 14 reptile species and 38 plant species.

Wadi El-Rayan wetland is considered to be one of the most recent man-made lakes. In the seventies of the last century (1973), Wadi El-Rayan depression was connected to the agricultural drainage system of Fayoum Governorate- through El-Wadi Drain- in an effort to decrease the accumulation of excess drainage water in Lake Qarun and to protect the nearby agricultural land from inundation (Konsowa and Abd Ellah, 2002). In 1973 a 9 km canal and an 8 km tunnel were constructed to connect the western side of the Fayuom depression and Wadi El-Rayan depression aimed at drainage water transport (Gophen, 2008). Nowadays, Wadi El-

Rayan Lakes are two reservoirs (northern, called upper Lake and southern, called Lower Lake), at different elevations.

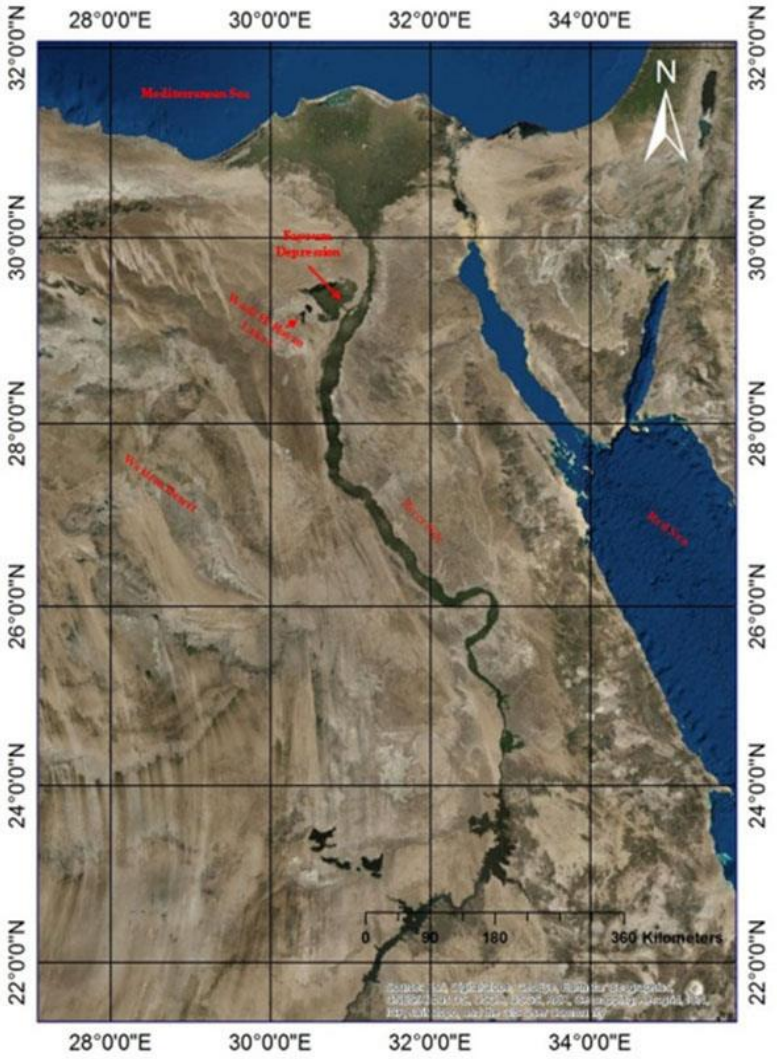


**Figure 1. Wadi El-Rayan Lakes location**

The Upper Lake receives frequent effluent of agricultural draining water and wastewater from El-Wadi Drain, with highly monthly fluctuations and slightly annually changes. The Lower Lake began forming in 1980 from water flowding from the Upper Lake (Afefe et al, 2016). In the nineties of the last century, a pumping station (power; $2m^3/s$) was created on the north-western coast of Upper Lake, near connected channel. The aim of the project was to pump a lot of water from Upper Lake, through underground pipeline, running towards the west, to newly reclaimed land in the far

northwest of Lower Wadi El-Rayan Lake. However, this pumping station is not consistently operating all time (Abdou, 2006).

The Wadi El-Rayan climate is typically Saharan, hot and dry with scanty winter rain; annual average rate is 10.1 mm (Azzazi, 2009). According to the bio-climatic provinces of Egypt, the area is one of the most arid places in the world; the area is hyper-arid with mild winters and hot summers (Abbas et al, 2016). The air temperatures (12.5- 28.2 Celsius) and surface water temperatures (14.8- 28.2 Celsius) are low in winter and high in summer (Beltagi et al, 2015). As Wadi El-Rayan Lake is located below 42 m altitude, the air pressure is relatively high (1009.0 mb in summer - 1018.6 mb in winter); resulting in small water amplitudes. The dominant wind direction is from the North, varying from North-West to North-East (Azzazi, 2009). The wind shows great monthly variability, being 2.1 m/s in December and 5.4 m/s in June. The relative humidity, too, varies between 36.8% in June and 57.7% in November. The potential evaporation rate is extremely high throughout the year. The monthly evaporation of Wadi El-Rayan Lake ranges between 1.72 (in December) and 6.97 mm/day (in June); with an average of 4.65 mm/day (Abd Ellah, 2009). In recent years Wadi El-Rayan Lakes have suffered from many problems affecting all aspects of their ecosystem (Azzazi, 2009; Sayed and Abdel-Satar, 2009; Khalifa and El-Khateeb, 2011; Mohamed and Sabae, 2015; Afefe et al, 2016). One of the problems in the Lakes is the decrease in their depths and consequently changes in their bathymetry and-morphometry. The main objectives of the present paper are to; study the temporal and spatial water depths variations in available data of 1996, 2010 and 2016 years, estimate water surface area and volume, and also forecast of the water area those Lakes. Where, the knowledge of the bathymetry and morphometry for a lake has become a key factor for the lakes development and management.

## 2. METHODOLOGY

A bathymetric survey was conducted on Wadi El-Rayan Lakes. The survey program was commenced in July 1996, December 2010 and February 2016. Lake's Bathymetry has become attractive using Global Positioning Systems (GPS) and portable sonar sounders mounted on small boats. The GPS device (Magellan NAV 5000 PRO, Garmen 76 and Garmen 78) was used to determine the positions; records the location coordinates (Latitudes & Longitudes). The water depth was determined using Portable Eco-sounder device (Lowrance Sonar-X-25 and Navman, fish 4500). The depth record density or measurement grid distance is a function of the variation of the Lakes bathymetry. As a rule, high variations in depth

require high record densities. They contain Longitude and Latitude reads along water depth reads. Data is supplied by the bathymetry survey to cover two distinct data classes; the Lakes shoreline data, water plants, islands and their depth reads. The sounder uses a beam frequency transductor of 50 kHz to measure the distance from sensor to lake's bottom with an accuracy of 10 cm.

## 3. RESULTS

The morphometric features of 1996 bathymetric map were nearly similar to those estimates 2010 -and 2016 years (figures, 2). The Upper Lake, oval shaped, was completely filled with water and was surrounded by dense aquatic plants in all shoreline. The Upper Lake is contained 2 very small rocky islets, located in most northern area, which are usually appearance. In 1996 year, the Upper Lake was occupied an area between $30^0$ 25' 52" and $30^0$ 31' 14" E longitudes, and $29^0$ 11' 29" and $29^0$ 17' 15" N Latitudes. It was represented basin as 10.8 km length, maximum width of 8.5 km, surface area of 49.12 million $m^2$ and water storage of 500.7 million $m^3$. In 2010 year, the Upper Lake was separated between $30^0$ 25' 52" and $30^0$ 31' 15" E longitudes, and $29^0$ 11' 29" and $29^0$ 17' 16" N Latitudes. It was extends along 10.9 km length, maximum width of 8.5 km, surface area of 49.14 million $m^2$ and water storage of 539.2 million $m^3$. In 2016 year, the Upper Lake was situated between $30^0$ 25' 52" and $30^0$ 31' 14" E longitudes, and $29^0$ 11' 29" and $29^0$ 17' 15" N Latitudes. It was separated along 10.7 km length, maximum width of 8.5 km, surface area of 49.13 million $m^2$ and water storage of 513.4 million $m^3$.

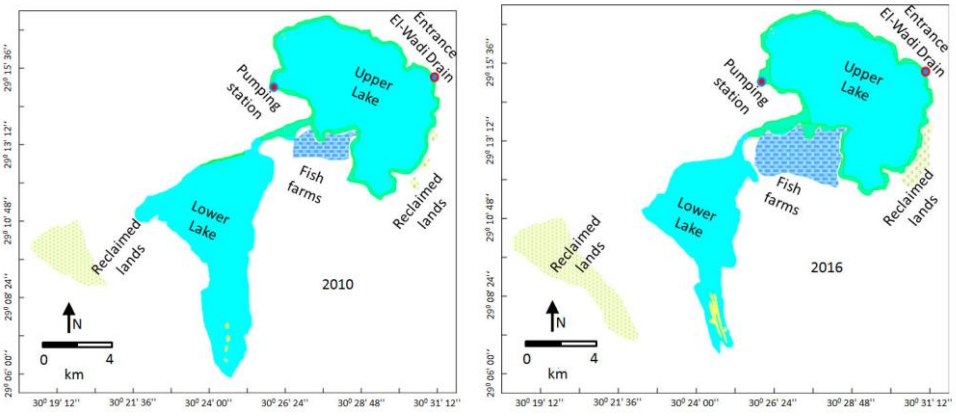


**Figure 2. The variations in features Wadi El-Rayan Lakes; 1996, 2010 and 2016**

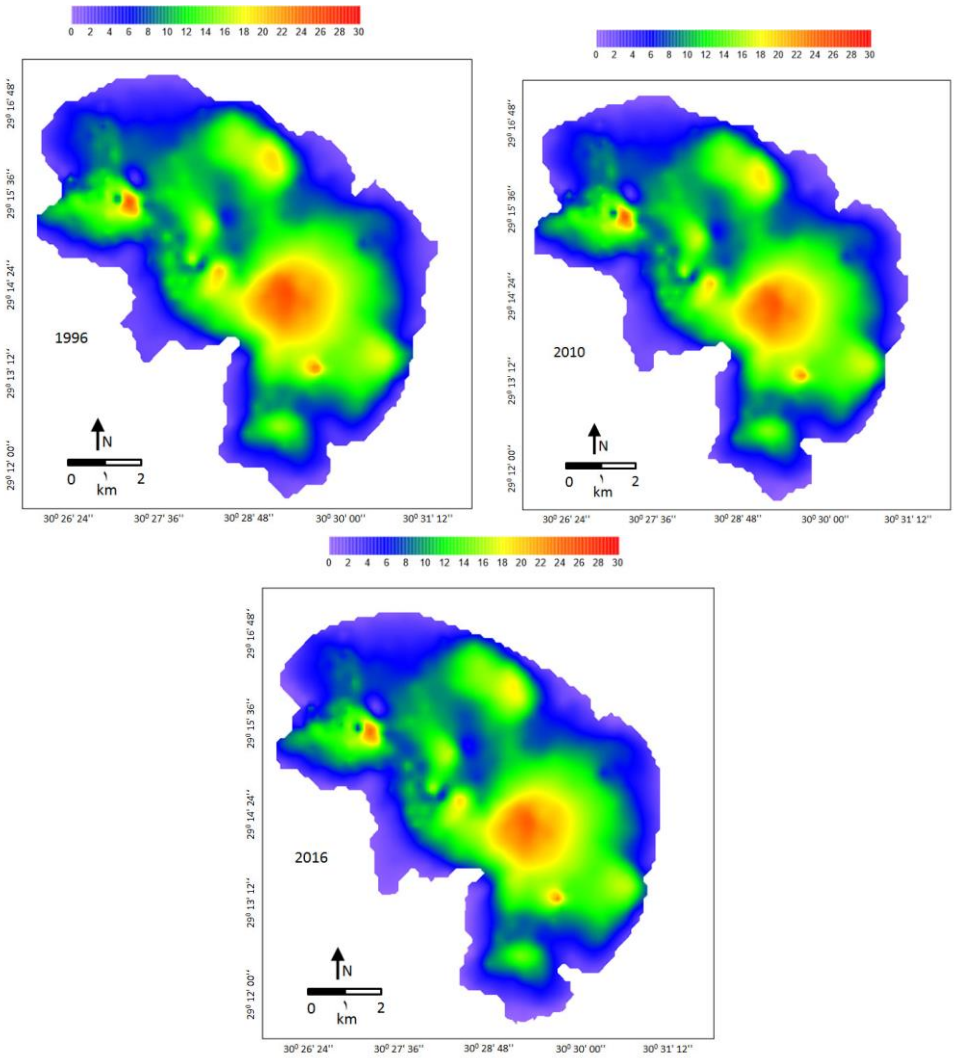


**Figure 3. Bathymetric chart of the Upper Lake; 1996, 2010 and 2016**

The morphometric features from the 1996 bathymetric map were completely changed to those occurs 2010 -and also 2016 years. The Lower Lake has pear ship, separate along the north–south direction. The Lower Lake is open water changes with time. Until 1996, the Lower Lake was contained patches of aquatic plants was not contained sandy islets; most of those plants cover the northern and eastern Lake's shoreline. For 2010 year, the aquatic plants area was decreases and sandy islands were appeared at the southern area. By 2016 year the aquatic plant was decline and these sandy islands was extended in their area. In 1996 year, the lower Lake was located between $30^0$ 21' 06" and $30^0$ 26' 13" E longitudes, and $29^0$ 05' 46" and $29^0$

12' 56" N Latitudes. It was represented basin as 13.3 km length, maximum width of 7.8 km, surface area of 48.73 million $m^2$ and water storage of 662.8 million $m^3$. In 2010 year, the Lower Lake was separated between $30^0$ 21' 38" and $30^0$ 26' 03" E longitudes, and $29^0$ 05' 53" and $29^0$ 12' 49" N Latitudes. It was extends along 12.8 km length, maximum width of 6.7 km, surface area of 39.18 million $m^2$ and water storage of 475.0 million $m^3$. In 2016 year, the Upper Lake was situated between $30^0$ 22' 18" and $30^0$ 25' 38" E longitudes, and $29^0$ 06' 04" and $29^0$ 12' 45" N Latitudes. It was separated along 11.2 km length, maximum width of 5.1 km, surface area of 32.54 million $m^2$ and water storage of 406.8 million $m^3$.

Regarding to bathymetric chart of Upper Lake (figures, 3), the Lake are classified as deep water with no regular bottom topography. The lower water depths observe near the shoreline especially at northern region of the Upper Lake. The higher depths occur near the central zone of the Lake. Mathematically, both ratio of water surface area- and water volume of the Upper Lake are divided through the three surveys (1996, 2010 and 2016) as shown in figures (4). The lower ratios of surface area are measured above 20 m depths, while the higher ratios of surface area are appeared in layer between 5-10 m depths. On the other hand, the lower ratios of water volume are measured below 5 m depths, while the higher ratios of surface area are occurred in layer between 10-15 m depths.

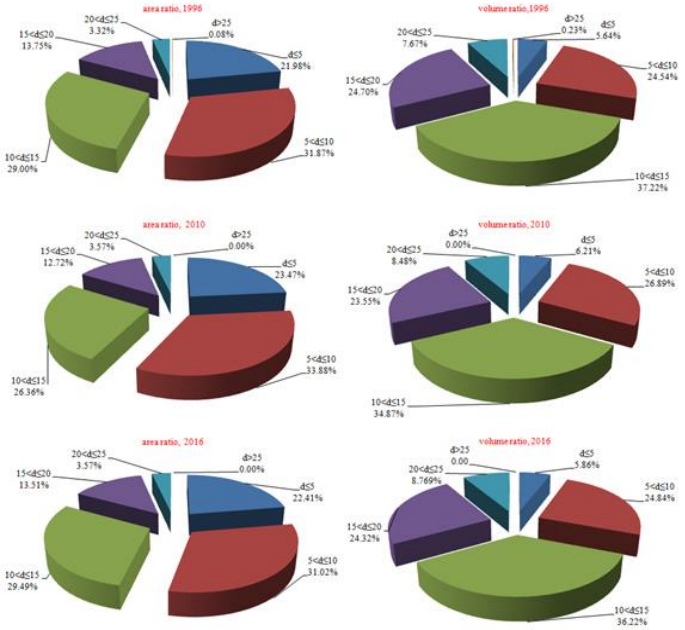


**Figure 4. The percentage both water surface area and water volume of the Upper Lake; 1996, 2010 and 2016**

Concerning the bathymetric map of Lower Lake (figures, 5), the Lake are classified as deep water with no regular bottom topography. The lower water depths show near the shoreline especially at southern region of the Lake. The higher depths exist near northern area of the Lower Lake. Mathematically, both ratio of water surface area- and water volume of the Lower Lake are divided through the three surveys (1996, 2010 and 2016) as shown in figures (6).

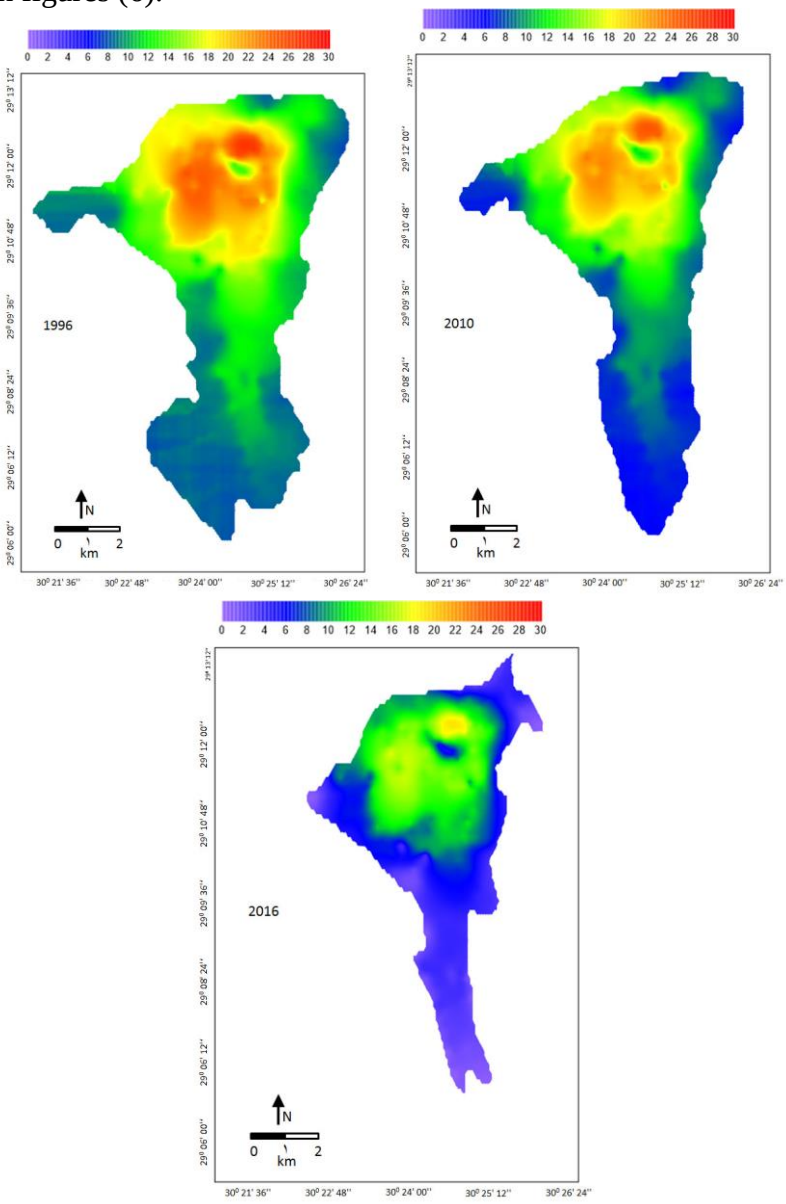


**Figure 5. Bathymetric chart of the Lower Lake; 1996, 2010 and 2016**

The lower ratios of surface area and also water volume are measured in layer above 20 m depths, while the higher ratios are appeared in layer between 10-15 m depths. Figure (7) shows the history, the present and the predict variations in surface area of the Lower Lake. The variations in surface area water were obvious, and can be divided into four periods.

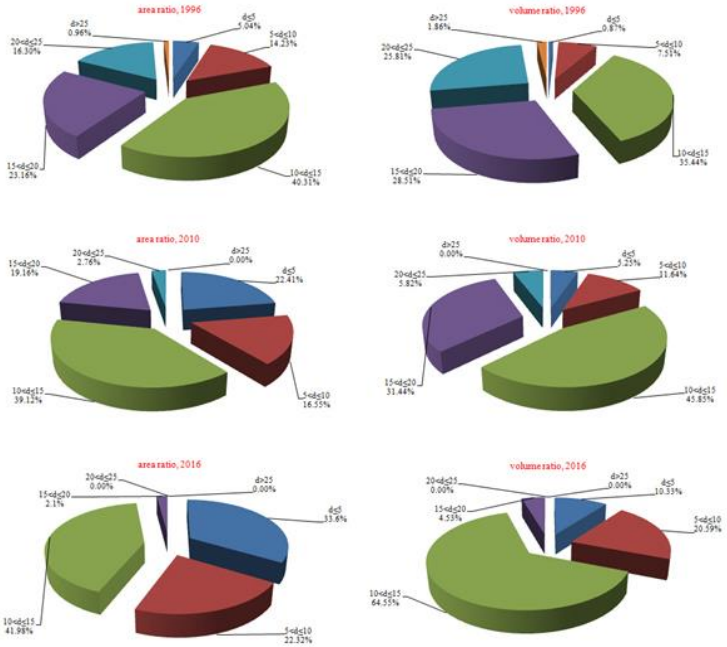


**Figure 6. The percentage both water surface area and water volume of the Lower Lake; 1996, 2010 and 2016**

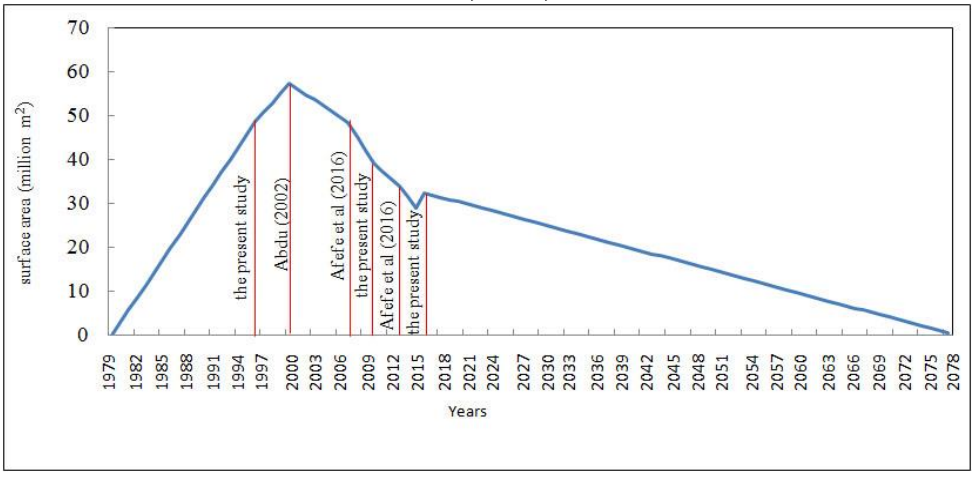


**Figure 7. The surface area of the Lower Lake in the past, the present, and the future**

## 4. DISCUSSION

The area of Wadi El-Rayan is an important valuable protected area in Egypt, especially for ecotourism sector as the most visited protected area (Hassan, 2005). The environmental changes is one of the major problems we face in the twenty-first century which is of vital importance to human existence and development, Wadi El-Rayan Lakes exposed continuously to environmental changes (Abou El-Geit et al, 2013). Many changes have taken place in the Wadi El-Rayan area since its formation in 1973. Significant effects started to be highly observed in last years with the vast human activities including agricultural land reclamation and fish farming (Abdel Hameed et al, 2007).

The study of a lake basin features is a key element to proceed for a professional lake management scheme. Lake management professionals can get clearer views about how a lake functions by studying its morphometric characteristics. Depths, surface area and volume are principal parameters of the Lakes, impacting on their physical, chemical, and biological properties. Morphometrical features that strongly impacts the water retention time and, therefore, on the extent to which in-lake processes such as nutrient dynamics, primary production, organic matter mineralization, or sedimentation can affect the chemical composition of the water (Sobek et al, 2011). Studying the Lakes morphometry can also help to examine both present and future status of the Lakes in a realistic manner (Anon, 2001).

Wadi El-Rayan depression occupies the southwest area of Fayoum, and is separated from it by a limestone ridge. An artificial tunnel used to transfer drainage water from Fayoum to Wadi El-Rayan depression, has formed the two lakes of Wadi El-Rayan. The Lakes occupy the middle section of the depression with the upper lake at 14 m below the sea level and the lower one at 36 m below the sea level.

Bathymetry is a technique of measuring depths to determine the morphometry of water bodies. The derivation of bathymetry from the surveys is one of the basic researches of the aquatic environment, which has several practical implications to the lake environment and it's monitoring (Jawaka and Luisa, 2015). As closed basins fluctuate in level to a much greater degree than the open basins, the differences between morphometric parameters of the Upper Lake were generally small, while the Lower Lake changes are obvious at the three periods (1996, 2010 and 2016). Surface area ($\pm 1.15 \times 10^3 m^2$ annual fluctuate) and storage volume ($\pm 635 \times 10^3 m^3$ annual fluctuate) in the Upper Lake have been slightly fluctuating. The small fluctuate, in the three features of Upper Lake, is due to the water balance between the water gain (inflow via El-Wadi Drain) and water loss

(outflow through the connected channel, evaporation process, a pumping station, extract water to agricultural land reclamation and fish farming). Hence the Upper Lake is classified as open basin, sometime it is represented as water pathway basin. About 210 million $m^3$/year ±1% of drainage water reaches the Upper Lake annually (EASRT, 2015). The surplus water from the Upper Lake floods to the Lower one via the shallow connecting channel (Abd Ellah, 1999). The present results are in accordance with the results of Abdou (2006).

The Lower Lake has faced extreme water loss through last twenty years, surface area ($810x10^3m^2$ annual decreases) and storage volume ($12.80 x10^6m^3$ annual decreases), due to overuse and mismanagement. During 1996, About 127 million $m^3$/year water reached the Lower Lake through the connected channel (Abd Ellah, 1999). This amount of the water consequently decreased with time to 35.2 million $m^3$/year in 2014 (EASRT, 2015). Over the last years, the agricultural lands and fish farms extended in the depression. Such large agricultural area consumes a large amount of water for irrigation, mostly pumped from the upper lake through pipelines (Afefe et al, 2016). Because the Lower Lake is a closed basin with no significant water outflow, the only way water leaves the Lake is through evaporation process. Therefore, the decrease in its water depths, consequently surface area and water volume, is either by increased evaporation or a decrease in water coming into the Lake. The rate of water inflow is currently less than the total rate of water use and lost by evaporation (Abd Ellah, 2009; Mohamed and Sabae, 2015). The activities include large-scale land reclamation schemes, rapidly expanding aquaculture, as well as human settlements in highly sensitive areas are the reason (Abdel Hameed et al, 2007). The results of the current study are in accordance with the results of Abdou (2002) and Afefe et al (2016) in regards to the effect of the agricultural activities. They concluded that, from 2000 to 2013, the Lower Lake perimeter has decreased with a clear loss from 57.5 million $m^2$ to 34.1 million $m^2$. Abdelhaleem et al (2013) state that, the currently agriculture lands in Wadi El-Rayan depression are 16.8 million $m^2$ in addition to an area of 3.8 million $m^2$ of fish farms. Moreover, the target is to reclaim 16.8 million $m^2$ of new lands and add an area of 5.9 million $m^2$ fish farms, depended on the water of the Wadi El-Rayan Lakes.

The waterfall is a place, which connects the Upper and Lower lakes together through a narrow shallow canal. This canal reaches the northeastern edge of the Lower Wadi El-Rayan where a waterfall is formed. With any decrease in the water discharges to the Lower Lake, the height of this water fall is reduced and the area around turns to be densely covered by vegetation and marsh plants (photo, 1).


**Photo 1. Wadi El-Rayan fall; 1996, 2010 and 2016**

The Upper Lake water is brackish, and it is considered as open basin, its salinity is roughly constant (less than 2 ‰) spite the fact that its salinity showed slight fluctuation with time (Shama et al, 2011). As a result, the Upper Lake is rich in vegetation and is more productive. The main vegetation bordering the shallow shorelines are the commonreed *Phragmites australis* (bous, hagna or ghab), which vary from dense, almost impenetrable thickets to thin rows lining the Lakeshores (Stêpniewska and Ozarowska, 2012).

The salinity increase in this ecosystem results in environmental problems particularly for the second lake. Salinity of the Lower Lake (closed basin) examined a progressive increase over time from 2.41‰ in 1984-1985 to 14.3 ‰ in 2010, and 16.5‰ in 2015 (Saleh et al, 1988; EASRT, 2015). Abd Ellah and Konsowa (2002) referred that its salinity is rising at a rate of about 0.3 ‰/ year. The reason for such increase is the dramatic decrease of the water level throughout time. These increasing in water salinity lead to decline the water plants in the Lower Lake. In this respect, the high vegetations in Upper Lake shorelines, resulting in more nutrients entering the Upper Lake than in the Lower Lake which is surrounded by low macrophyets (Bahi El Din, 2011).

According to the available date of the Lower Lake morphometry, the variations in surface area water of the Lake are obvious, and can be divided into three periods. The First period, from 1980 to 2000, the increasing in surface area of the Lower Lake is obtained (2.74 $x10^6 m^2$/year). The Second period, from 2000 to 2016, the Lake's area is decreased by $1.56x10^6 m^2$/year. The last period, predicted period, the Lake's field will be decreasing by $0.52x10^6 m^2$/year till decline in 2078. This prediction in annually Lower Lake surface area is may be inaccurate. The reasons are the rare public information in variations of the Lake morphometry and quickly human impact on Wadi El-Rayan Lakes, due to intensification of agriculture and fish farming.

The problem with low water area in the Lower Lake continues with alarming declines in the levels and the future of the lake system in the Lower Lake is in jeopardy. New islands have appeared in the Lower Lake, with vegetation taking hold. Lake's water surface area is among the most important parameters needed for water balance analysis. Periodical measurement of this parameter directly by conventional topography almost seems impossible since it is costly and time consuming (Ahmadi et al, 2015). Knowledge of the shape and structure of a lake basin, sometimes predict how human-induced events may impact on water levels in that system (Lawniczak et al, 2011). This is important because changes in water levels can affect the water quality of the lake including the amount of aquatic plants growing in the water, types and abundance of fish species, and water clarity. It can even play a role in determining the zoological structure around the water body, *e.g.* types of birds and wildlife (Anon, 2001). After four years of Ramsar convention stating emphasized protection of Wadi El-Rayan Lakes, the Lower Lake is on the edge of extinction, a significant portion of the Lake surface area has become salt marsh, and the lake is transforming to a desert. According to UNDP (2010), the key problems of declining lake levels are; eco-tourism infrastructure investments are lost or compromised, vegetation has died, pollution and other compounds have increased in concentration and waterfalls has declined.

## 5. CONCLUSION

Periodical measurement of water morphometry directly by conventional bathymetry almost seems impossible since it is costly and time consuming. The depth, surface area and volume of a lake are key elements that greatly impact on a wide array of its physical, chemical, and biological properties. Knowledge of the shape and structure of a lake basin, sometimes predict how human-induced events may impact on water levels in that system. Wadi El-Rayan Lakes are exposed continuously to environmental changes. The differences between morphometric parameters of the Upper Lake were generally small. Practically strong changes have been observed in Lower Lake. The area of the Lower Lake decreased dramatically in the last years as direct result of the general decline in the level of water. The Upper Lake is rich in Lakeshores macrophyets, while decline the water plants in the Lower Lake. With low water levels, in the Lower Lake, puts the future of the lake system in jeopardy.

## 6. ACKNOWLEDGEMENT

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