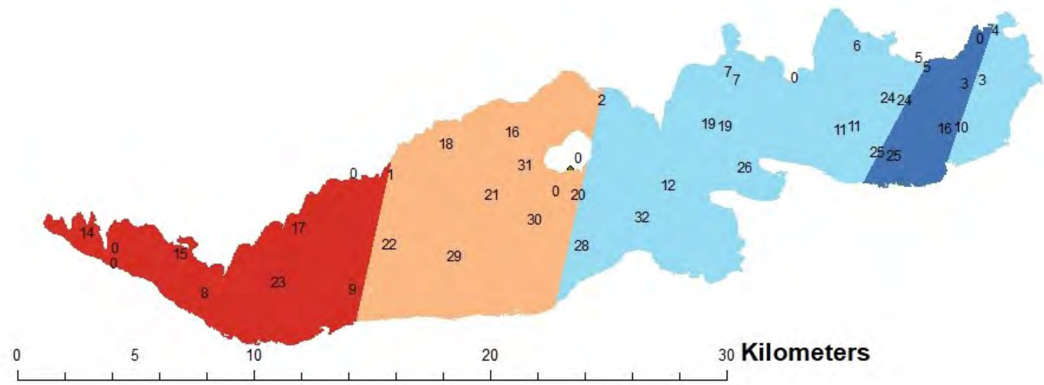
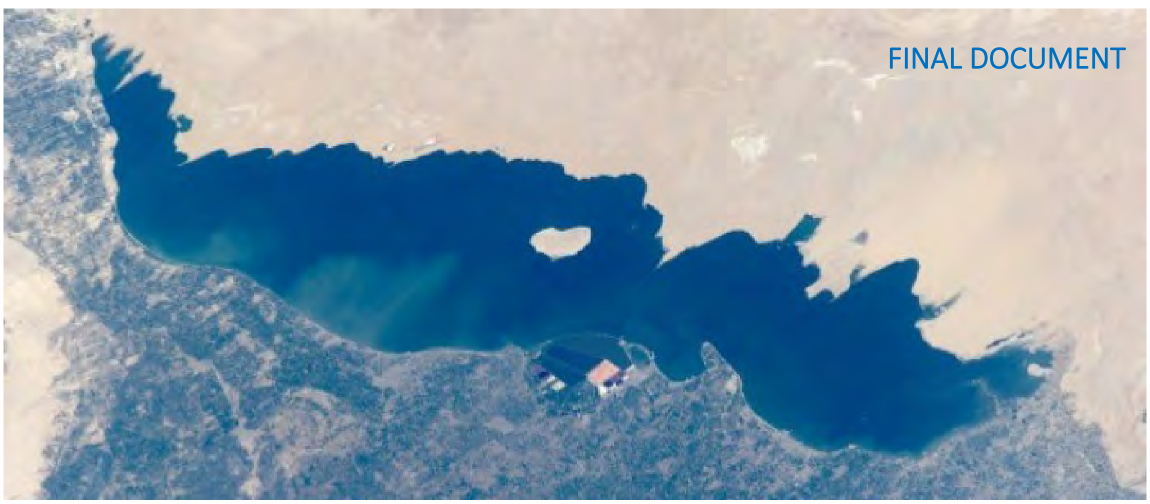


LAKE QARUN ECOSYSTEM RESTORATION



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ABBREVIATIONS

Administration and Institutional System	**AIS**
Billion Cubic Meters	**BCM**
Catch per unit effort	**CPUE**
Commission on Sustainable Development	**CSD**
Convention on Wetlands	**RAMSAR**
Degree of Contamination	**DC**
Division for Sustainable Development Goals	**DSDG**
Ecological Risk	**ER**
Egyptian Environmental Affairs Agency	**EEAA**
Egyptian Environmental Policy Program	**EEPP**
Egyptian Minerals and Salts Co.	**EMISAL**
Electric Conductivity	**EC**
General Authority for Fisheries Resources Development	**GAFRD**
Giga Watt per hour	**GWh**
Important Bird Area	**IBA**
International Union for Conservation of Nature	**IUCN**
Million Cubic Meters	**MCM**
Million years ago,	**M.y.a.**
Ministry of Irrigation and Water Resources	**MIWR**
National Institute for Oceanography and Fisheries	**NIOF**
Natural Resource System	**NRS**
Nature Conservation Sector	**NCS**
Part Per Million	**PPM**
Protected Area	**PA**
Qaroun Protected Area	**QPA**
Socio-economic system	**SES**
Strength Weakness Opportunity Threat	**SWOT**
Sustainable Development Goals	**SDGs**
Traditional ecological knowledge	**TEK**
United Nations	**UN**
United Nations Department of Economic and Social Affairs	**UNDESA**
Water Resources System	**WRS**

Preface

The International Union for Conservation of Nature –Regional Office for West Asia (IUCN-ROWA) is executing the Project "Effective Management of Wadi El-Rayan and Lake Qarun Protected Areas in Egypt". The project is implemented in partnership with the Egyptian Environmental Affairs Agency (EEAA) and with the support of the Global Environment Facility (GEF) and United Nations Environment Programme (UN Environment). The project aims to strengthen the overall management effectiveness of Wadi El-Rayan and Lake Qarun protected areas (PAs) to safeguard biodiversity by addressing a range of threats. It seeks to enable community involvement, capacity building and gender equality as the principle means toward improving effectiveness. The project mainly focuses on two PAs, Wadi El Rayan and Lake Qarun, which are located within the Fayoum Governorate.

Lake Qarun Protected Area requires several interventions during this project including updating the management plan and developing a restoration plan as part of the first component of the project which involves strengthening management capacities of targeted. Restoration comprises the rehabilitation of degraded ecosystems and individual species to enhance biodiversity conservation, ecosystem services, improve visitation, and enhance human well-being. This activity comes as an extension to updating of the LQPA management plan.

This report includes a proposed restoration plan for Lake Qarun developed by the project through a consultancy agreement with Centre for Environment and Development for the Arab Region and Europe (CEDARE) in close coordination with The Egyptian Environment Affairs Agency EEAAA and IUCN ROWA.

CHAPTER 1

1. INTRODUCTION

1.1 BACKGROUND

Because most Egyptian cities and villages are located around the Nile River, Mediterranean, and Red Sea coastlines, living near water is an important part of Egyptian culture. Conserving and improving this finite resource is a fundamental goal for Egyptian society's progress. Lakes in Egypt are unique in that a diverse range of wild and urban environment surrounds them [2].

The majority of civilizations occur along rivers, coasts, and lakes. Waterfront refers to any property that is close to a body of water, whether it is a river, stream, ocean, or lake. This demonstrates that any connection to water is deemed waterfront. There is nothing quite like water for relaxation. Aside from coastal tourism, there are a number of lakes and wetlands around the world that can be visited for recreation. In terms of ecosystem importance, lakes and their surrounding watersheds have a special place in the lives of both humans and wildlife. "Storage tanks" for freshwater, such as lakes, are vital. Most of the liquid surface freshwater is stored in lakes and reservoirs. Despite their importance, many lakes around the world are in jeopardy [11].

The waterfront has long served as a transportation mean and commercial hub, as well as a focal point in many communities. The waterfront's character and functions have undergone numerous transformations. Even while they all go through the same stages of growth; each waterfront has its own personality [11].

Because waterfronts contribute to the city's and downtown districts' images, initiatives to rejuvenate them began in the latter half of the twentieth century. Water is a draw for visitors, and associated amenities act as a spur for inner-city revitalization. The globe is now recognizing the value of waterfronts and is taking steps to improve them. Public interest in waterfront rehabilitation has grown as a result of urban regeneration schemes. In addition, waterfront revitalization is a response to changing dynamics in waterfront users, functions, and requirements [11]. Egypt, like most developing countries, is confronted with a slew of environmental issues because of its rapid population expansion, which has more than doubled in the last 40 years [2].

The first agricultural society in Egypt's Nile Valley, one of the earliest societies developed and related to nature, reflected the relationship between man and nature since the start of history. This community has been impacting and shaping nature for millennia, resulting in one of history's greatest civilizations. This relationship has continued in the valley to form towns, villages, countries, and many communities, with water and greenery being two of the most important aspects in these societies [11].

Cities and villages in Egypt have been faced with the pressing task of halting the ongoing loss of agricultural land caused by urban growth. Because of their informal nature, these settlements are not depicted in details on traditional maps, and data is not available. Cities and villages in Egypt have been faced with the pressing task of halting the ongoing loss of agricultural land caused by urban growth [2].

This unique relationship has recently faced a number of obstacles and problems because of social, cultural, and urban developments, which may have an impact on the natural environment, where it began with migration from rural to urban regions and the collapse of the old agricultural idea. As a result, Egypt's urban population could rise from 40% in 2010 to 60% in 2030, posing a threat to the agricultural environment. Faced with major obstacles such as rural communities' changing traditions and a lack of scientific advancement, these communities may be able to endure and expand [11].

Environmental issues are gaining traction around the world. These concerns involve not only updating the rules and regulations that govern sustainable development, but the financial incentives for incorporating sustainable development concepts. The news media began to promote environmental concerns across Egypt, and because of this increased public awareness, substantial legislation was enacted, empowering planners to incorporate ecological values [2]. The environmental awareness of both tourists and tourism businesses has improved over the last two decades, and as a result, concepts of sustainable ecotourism and other types of "new tourism" have arisen [11].

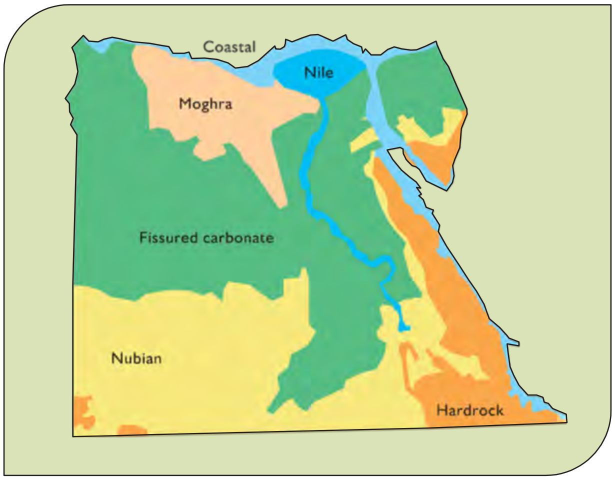
Farmers, fishermen, and Bedouins coexist in Egyptian lakes, creating a social and environmental combination. These numerous tribes and cultures coexist in the vicinity of Egyptian lakes, giving these locations a distinct character. Accommodations, quickly rising populations, unemployment, a lack of education, and a lack of environmental awareness are all issues that villages near lakes face. The study examines the issue of these communities living near Egyptian lakes, as well as the development of strategies and environmental performance of these urban settlements in light of contemporary issues [11].

Lakes are extremely delicate habitats where the balance of climatic circumstances, hydrological settings, and human pressure determine their status. In arid areas, this balance is especially precarious. Egypt has a vast number of inland lakes, with Lake Nasser being the largest freshwater lake and the saline Lake Qaroun in Fayoum being the largest saltwater lake [2].

The public's need for rejuvenation has grown because of greater awareness of the natural environment and the preservation of ecosystems and resources. People are getting more interested in outdoor recreation, and waterfront parks are one of the most popular spots for such activities. A smart waterfront development takes into account diversity, community engagement, safety and security, as well as the environment and long-term sustainability. Because of the diversity of economic, social, and environmental benefits, waterfront development can be a desirable location [11].

1.2 EGYPT WATER RESOURCES

The Water Resources System (WRS) in Egypt combines the natural resource system (NRS) with socio-economic and institutional systems. The natural system comprising of the Nile river, lakes, groundwater aquifers (Nile Aquifer, Nubian Sandstone Aquifer, Fissured carbonate aquifer, Moghra aquifer, Coastal aquifer and Hardrock aquifer) and its related infrastructure; it includes both quantity and quality aspects of the water. The socio-economic system (SES), the water uses and water related human activities; a demand that will continue to increase under pressure of a growing population. The Administration and Institutional system (AIS), the system of administration, legislation and regulation including the authorities are responsible for the management of WRS and the implementation of laws and regulations [15].



Map 1 Water resources of Egypt

The total conventional resources of fresh water are about 59.8 BCM per year [21]. It includes Egypt's share of Nile water (55.5 BCM), deep non-renewable groundwater (2.6 BCM per year), and rainwater and torrential rains (1.6 BCM per year), in addition to desalination of brackish and semi-saline waters (0.3 BCM per year) [14] (Map 1).

1.2.1. Conventional resources

Nile

The Nile River accounts for most of Egypt's surface water. It stems from the Ethiopian plateau, which represents 85% of the river's revenue at Aswan, and the plateau of the tropical lakes and southern Sudan, which represents about 15% of the river's revenue.

The Nile's annual natural revenue averages around 84 BCM, with Egypt and Sudan accounting for 74 BCM and evaporative losses accounting for 10 BCM. The High Dam has a live storage capacity of 90 BCM. The High Dam was built in Egypt to profit from the whole revenue of the river, due to the large variation in annual revenue and the sequence of droughts and floods; Egypt was able to deal with both severe and rare floods with complete efficiency because of this. The High Dam, the Aswan Reservoir, and a series of seven major barrages along the Nile to the Mediterranean manage the Nile's waters. Due to Egypt's sensitivity to the Nile River as a primary source of water, any future increase or decrease of water entering the High Dam must be carefully evaluated and analyzed. This could necessitate a revision in the High Dam's operating rules and the provision of additional storage capacity [14].

Underground Water

The Nubian sandy aquifer of the Western Sahara is considered one of the largest in North Africa. The quantities of groundwater, including the oases of Dakhla, Kharga, Farafra, East Oweinat and Darb Al-Arbaeen, are large, but the economically exploitable volume of them is limited. The annual withdrawal amounts of groundwater in the Western Desert and oases are about 3.75 BCM to ensure sustainability. Currently, only about 1.75 BCM are exploited (Ministry of Water Resources and Irrigation, 2010). As for the Nubian aquifer in the Eastern Desert, its potential is relatively limited and needs detailed studies to find out the possibility of exploiting it. In Sinai, groundwater is found in three reservoirs: shallow, medium and deep, in addition to the deep Nubian sandstone reservoir. The total deep groundwater used in Egypt is about 2.4 BCM per year [21].

Rainfall and floods water

Rainfall rates on the northwest coast range from 192 millimeters in Alexandria to 102 millimeters in Salloum and increase as we head east until they reach about 300 millimeters in Rafah. The rain decreases rapidly the further south we go from the coast. Part of it seeps into the coastal aquifers. Floods in arid and semi-arid regions are common. The waters of these torrents are utilized by building dams and underground reservoirs to collect the water and use it later. The rainwater and torrential rains on the coasts of the Red Sea and Sinai are among the most important sources of fresh water for the tribes. They use it for drinking and agriculture, and the total exploited amounts of rainwater are estimated at about 1.6 BCM annually [21].

Desalination

Desalination will be one of the most important tools for managing water resources in Egypt in the future. Egypt is located in an appropriate geographical location, as it is bordered by the Red Sea along its borders to the east and the Mediterranean Sea along its borders to the north. However, the high cost of desalination remains an obstacle to expansion in that direction. With the increasing demand for water in coastal areas, the number of desalination plants in Egypt has increased progressively over the past years, with the total capacity of desalination units reaching about 0.3 BCM annually [21].

1.2.2. Non-Conventional Resources

Non-conventional water resources include water used from the shallow aquifer in the valley and the delta. The use of this stock is about 6.5 BCM per year, which is within the limits of the safe withdrawal, which is estimated at about 8.4 BCM per year (Ministry of Water Resources and Irrigation, 2010). In addition, to the reuse of agricultural drainage water, which use is estimated at 15 BCM annually. This quantity includes what is reused from Lower Egypt water, it also includes another amount that is reused from drains directly by farmers, in addition to the return from Lower, Upper Egypt drains directly to the Nile and its two branches, and the quantities of sewage reused in Fayoum. It should be noted here that all the sewage networks in the valley drain their water to the agricultural drainage networks, and then to the Nile River. In the delta, most of the sewage goes to drains and from there to the northern lakes [21].

1.2.3. Water Uses

Water use is increasing in Egypt because of population growth and increased demand for water for different sectors. The agriculture, drinking water and industry sectors are the largest users and consumers of water, in addition to the electricity and navigation sectors, and part of the water resources are consumed for tourism, entertainment and fisheries purposes.

Agriculture

The share of agriculture as the largest consumer and user of water is about 85%. It may reach 93% of the total actual water consumption, as the actual consumption of agriculture is 40.4 BCM per year (for evaporation and transpiration), while the use allocated to agriculture is about 68.5 BCM annually including all losses; starting from the distribution of water for the main canals to the level of the field.

Drinking Water

The coverage rate of drinking water, at the level of the Republic, reaches nearly 100% (96%), and surface water represents the main source of drinking water, while underground resources represent about 15% of the total, in addition to the use of seawater desalination in some coastal areas along the coasts. The quantities of water released to the drinking and domestic consumption sectors are estimated at about 9.9 BCM annually [21].

Industry

The water needs for the industrial sector are estimated at about 2.4 BCM annually, not including cooling water for power plants. The actual consumption is 0.85 BCM; That is, with an efficiency of up to 35% [21].

Navigation

The navigation sector is a water user, not a consumer. The Nile River is used as a navigational course, in addition to the Riahat and some major canals. The construction of the High Dam has improved navigation conditions throughout the year due to the regularity of the water behavior, allowing for an adequate water depth in summer and winter. Since the mid-eighties and with the increase in water demand, water disposal has been reduced during the winter season, which has led to a reduction in water levels in a period of minimal needs. This has been accompanied by difficulty in water navigation; this necessitated the development and modernization of navigational channels, and the use of modern technological means to regulate the movement of navigational units.

Power

The total hydroelectric power generated annually from industrial works on the Nile River is estimated at 14.632 GWh. It represents about 8% of the total energy generated in Egypt, which is estimated at 182,000 gigawatt-hours per year.

Aquacultures

Fish farms have spread in Egypt due to their high financial returns, with fish cages spread in the Nile River in its two branches. There is an area of about 300,000 feddans of fish farms on the northern canals, banks and lakes (Ministry of Water Resources and Irrigation, 2010), of which 50,000 are in Kafr El-Sheikh Governorate and the rest are in the control of El-Salam Canal in Port Said and North Sinai governorates, as well as fish farms in Sharkia Governorate. Aquaculture is currently the largest source of fish supply in Egypt, accounting for about 75% of the country's total fish production. Today, aquaculture production in Egypt is the largest in Africa, with a volume of one million tons per year. With the exception of a very limited number of isolated cases, most aquaculture activities are located in the Nile Delta. Aquaculture uses a variety of systems with varying levels of technology. The high rate of return on investment in aquaculture has attracted a large number of small to medium level investors, who have more scientific background than the traditional farmers.

1.2.4. Water Balance in Egypt

Table (1) shows the water balance according to the current situation, where the total conventional water resources amount to 59.8 BCM annually, 74% of which are consumed as drinking water, in addition to industrial and agricultural sectors. As for the rest of the resources, it is consumed in evaporation from the network, the ecological balance and the drainage of the sea and northern lakes. The total water use is 81.3 BCM annually. Thus, it becomes clear that there is a deficit between the total resources and uses estimated at about 21.5 BCM annually, which is provided by reusing agricultural, sanitary and industrial wastewater and the water of the shallow aquifer in the valley and the delta [14].

Table 1 Current water balance of Egypt [21]

Water Resource	Quantity (BCM)	Uses	Quantity (BCM)
Conventional			
Nile	55.5	Agriculture	68.5
Deep Aquifer	2.4	Drinking	9.9
Rainfall and floods	1.6	Industry	2.4
Desalination	0.3	Others	0.5
Non-Conventional			
Surface Aquifer	6.5		
Domestic & Agriculture water reuse	15		
Total	81.3		81.3

1.3 LAKES

1.3.1. Introduction

The Nile Valley was home to one of the world's ancient cultures. The many achievements of the ancient Egyptians included the quarrying, surveying and construction techniques that facilitated the building of monumental pyramids, temples, and obelisks; a system of mathematics, a practical and effective system of medicine, irrigation systems and agricultural production techniques, the first known ships Egyptian faience and glass technology, new forms of literature, and the earliest known peace treaty [11]. Egypt now has one of the most developed and varied economies in the Middle East, with tourism, agricultural, industry, and service sectors producing at about equal levels [11].

Water covers 6% of Egypt's land area and is separated into three types: seas (Mediterranean and Red Seas), lakes, and the Nile River. Waterfront developments are crucial in the tourism industry, fishing, agriculture, and urban life. The population of coastal cities accounts for half of Egypt's population. In Egypt, water front projects are typically employed in the tourism industry, such as al Guna resort at the Red Sea, Marina and Marasy at the Mediterranean, and river Nile beaches in touristic cities such as Cairo, Aswan, and Luxor [11].

Inland lakes abound in Egypt, with the freshwater Lake Nasser and the salty Lake Qaroun in Fayoum being the largest. Several densely populated economic centers, including Alexandria, Damietta, Hurgada, Port Said, Suez, and Sharm El Sheikh, are located along the coast. Lakes are extremely delicate habitats where the balance of climatic circumstances, hydrological settings, and human pressure determines their status. In arid areas, this balance is especially precarious.

Egypt's lakes are unique in that they feature a variety of ecosystems, including desert, water, and green areas, as well as protected areas, which are protected by national law and international conventions. For the northern Lakes, parts of Lake Manzala and Lake Bardawil are protected within Ashtom Al-Gamil and Zaranik Protected areas; Burullus Lake is representing a protected area. For inland lakes; Khor Al-Allaqi is included within Wadi Al-Allaqi protected area; Lakes of Wadi El-Rayan are included in Wadi El-Rayyan Protected Area; Lake Qaroun is included in Qaroun Lake Protected Area.

1.3.2. Values and Importance of the Lakes [11]

Lakes, both natural and man-made, provide a wide range of important benefits, including water resources, agriculture, tourism, and fisheries, all of which help to support human livelihoods and economic activity. Bacteria, fungi, algae, plants, plankton, mollusks, crustaceans, insects, fish, amphibians, reptiles, birds, and mammals all use lakes as a habitat. They are home to a great number of endangered and unique species (species that exist nowhere else in the world). For their water, food, and way of life, most human populations that surround lakes rely largely on Lake Biodiversity and natural lake processes. For protein, much of the world's poorest populations rely on freshwater biodiversity.

Lakes are extremely delicate habitats where the balance of climatic circumstances, hydrological settings, and human pressure determine their status. In arid areas, this balance is especially precarious. In terms of shape, climate, culture, traditions, and so on, the majority of lake and wetland sites are vastly diverse. Nonetheless, they share a number of parallels in terms of their characteristics, development prospects, and challenges, especially those posed by tourism [11].

Lakes also provide buffering capacities against hydrologic and temperature variations, and receptor roles for inflowing materials accumulated over their basins as unique wetland features. Small or large, saline or fresh, ancient or new, they are among the most beautiful and picturesque features of international landscape, providing with great aesthetic and spiritual values. On the other hand, they are among the most sensitive ecosystems on the planet, susceptible to a variety of pressures resulting from human activities and a lack of understanding [11].

In Africa, lack of water is a key obstacle to growth. Despite having abundant water resources, such as big rivers and lakes, Africa is the second driest continent in the world, after Australia. Due to climate variability, increased water demand, and inadequate management of existing resources, over 300 million people in Africa are currently experiencing water shortages. Water consumption is currently inefficient; around 70% of diverted water is utilized for irrigated agriculture, but few developments have been constructed with long-term water management in mind. Furthermore, the majority of Africa's surface water is found in Trans boundary waterways, complicating management. The quality of the water is also a big concern. Almost half of Africans are infected with one or more of the six primary water-borne illnesses [11].

Although available water is a limited and precious resource, it is frequently managed as if it were still plentiful. In arid, semi-arid, and dry sub-humid locations, climate change will exacerbate water stress. Water stress or scarcity would affect nearly half of Africa's projected population of 1.45 billion people by 2025. Water policy must address this growing scarcity by ensuring that: (a) water is used efficiently; (b) watersheds are conserved; and (c) financing is available for additional investment. Water scarcity is a major contributor to environmental insecurity, and climate change will exacerbate the problem. The availability of water for growing populations congregating in urban conglomerations and megacities, which are forming mostly along Africa's coasts, major rivers, and lakes, is an especially ignored occurrence. As a result, achieving integrated management of rivers, coastal, and marine resources, which support bigger segments of Africa's people, is critical [11].

1.3.3. Sustainable Development and Lakes

Understanding the ideas of sustainable development and local community requirements, as well as the combination of development, conservation, and involvement, are essential components of sustainable development planning: development of urban life; natural resource conservation; and involvement of local communities.

Traditional landscape policy instruments are limited by conflicts between ecological and socioeconomic variables, which frequently ignore the multi-functionality of urban landscapes. For these reasons, landscape policymakers in some cities have realized that urban open space requires more than just a top-down approach to public landscape protection, but also active landscape management and development [2].

Egyptian cities and villages face the task of integrating rapidly growing populations into cities and providing them with land, infrastructure, and shelter while ensuring environmental sustainability and boosting economic growth in the new millennium. To bridge the gap between population expansion and limited resources, it is necessary to develop creative strategies for increasing quality of life and getting new economic resources. A significant difficulty for waterfront rehabilitation is integrating public sector goals for sustainable regeneration with private sector "know how" on efficient, cost-effective development procedures [11].

The UN Conference on Environment and Development in 1992 recognized the importance of indicators in supporting countries in making informed decisions regarding sustainable development. Sustainable development, on the other hand, remains a dynamic process due to rising humanitarian demands and shifting economic and social situations.

Planners and designers should create measurement and analytic methods to keep up with these changes. The Egyptian Environmental Policy Program (EEPP) program includes three sources of indicators for sustainable development. Commission on Sustainable Development Indicators (CSD) This set of indicators is assessed and updated on a regular basis, and members from the Egyptian Environmental Affairs Agency (EEAA) have attended expert meetings to this end. Egypt participates in two regional frameworks aimed at accomplishing long-term development goals (the Mediterranean Action Plan and the Arab League).

1.3.4. Lakes in Egypt

Various cultures arose from the blending of farmers', fishermen's, and Bedouins' lives. Different cultures coexist in the area surrounding these lakes, giving this location a unique character. Egypt's Mediterranean coastal shoreline has five big lakes, accounting for nearly a quarter of the Mediterranean region's total wetlands [11].

With their fishing, tourism, and agriculture, Egyptian lakes are a valuable economic resource. Lakes are located near important towns such as Alexandria, Damietta, Fayoum, and Aswan. Water is the most important element in the development of Egyptian urban communities. It comes in both fresh and salty forms and can be divided into six coastal lakes in the north along the Mediterranean Sea, four of which are in the Delta region (Manzala, Burullus, Idku, Mariout); and two lakes in the east of the Suez Canal (Malahet Port Fouad and Bardawil), and three internal lakes (Qaroun – Wadi El-Rayan - Nasser).

In Egypt, lakes represent a major source of fishing supplies, making them a valuable economic resource. Because fish is a vital source of protein, successive administrations have made considerable efforts to ensure the provision of food for the continuous increase in population through fisheries development. According to Egyptian government estimates, more than 5 million Egyptians call the lakes home. Diversified industrial and tourism operations that rely on Egypt's lakes, such as Lake Nasser, are also considered a source of electric power generation.

Qaroun Lake is one of the world's oldest natural lakes. It is an inland closed basin located in the northwestern portion of the Fayoum governorate. Lake Qaroun marks an important period in Egyptian history, when the country's potential economic resources were based on its fertile terrain for agriculture and abundant fish supplies.

1.4 CHALLENGES FACING WATER RESOURCES MANAGEMENT IN EGYPT

Egypt faces many water-related challenges due to its geographical location and its dependence on the Nile River as a main source of water. Population growth is one of the most important of these challenges, which leads to increased needs for all sectors. The following is a review of the most important water challenges [14].

1.4.1 Limited water resources: By reviewing the current water situation, it becomes clear that there is a limit to the extent of the possibility of increasing water resources. Given the Nile water and the possibility of increasing revenue by attracting losses, we find that the implementation of the first phase of the Jonglei Canal will increase the revenue reaching the High Dam within 4 billion meters cubic meters per year, and the project is still stalled. As for the other waste attraction projects, they are long-term projects, and it is difficult to predict the timing of their implementation and the extent of the increase in revenue reaching the High Dam. As for deep groundwater, the potential of groundwater reservoirs does not exceed 2 BCM annually and requires high investments. The shallow reservoir in the valley and delta is not an additional resource. With regard to rainwater, a slight increase can be achieved through rain and flood harvesting projects. As for desalination, its economic cost and its energy sources make the possibility of achieving an increase through it limited.

1.4.2 Obstacles to implementing projects to reduce water losses: The Ministry of Irrigation and water resources (MIWR) is implementing a large number of projects to rehabilitate and line canals to reduce water transport and distribution losses at the irrigation water level; in addition to projects to reuse wastewater that exceeds the actual consumption of different crops in order to maximize use efficiency of the total water budget. The challenge facing these projects is to overcome many obstacles during implementation, as this requires converting the main canals to new ones that penetrate large areas of agricultural land owned by a large number of individuals, in addition to the high costs.

1.4.3 Pollution of waterways: The main course of the Nile River has the ability to self-purify, as the rates of agricultural pollution increase in the Damietta and Rosetta branches as we head north as a result of sanitary and agricultural drainage. As a result of the high level of pollution in many agricultural banks, the Ministry of Irrigation and Water Resources has suspended the implementation of a number of agricultural drainage water reuse projects. In addition to limited water and pollution, there are many other problems and challenges such as:

1.4.4 Increasing population: thus, increasing the demand for water (the water per capita decreased to 570 cubic meters per year in 2018, and is expected to decrease to 390 cubic meters in 2050).

1.4.5 Possible effects of climate change: Some studies have shown that the impact of climate change on the quantities of incoming water is not clear, e.g., the amount of change in behavior at the entrance to Lake Nasser may increase with an average of 14.3% or decrease with an average of 11.8%, which effects crop composition as well as food security.

1.4.6 The establishment of dams on the sources of the Nile: The negative impact of this is reflected on the upcoming actions of the High Dam during the filling and storage process, as well as the impact of the operating rules on the water flows of Egypt. Some studies have shown that the construction of the Grand Ethiopian Renaissance Dam will lead to a decrease in the upcoming actions of the High Dam if it is filled within 6 years.

1.4.7 Unfair distribution of water among beneficiaries: The persistence of water deficit and the deterioration of water quality have negatively affected the equality of water distribution over the previous years. It can be emphasized that there are still many obstacles facing the current environment at the national and governorate levels.

The process of evaluating the equality of water distribution in the different sectors depends only on quantity but has never been assessed on the basis of its accessibility - quality level - affordability, because there are a number of users in rural areas who have access to sufficient quantities of clean drinking water but are making efforts to travel great distances to get it. On the other hand, there are a large number in rural areas that do not have sanitation services either. The phenomenon of leakage in drinking water networks also leads to the possibility of mixing water with pollutants from agriculture, industry and sewage.

1.4.8 Achieving self-sufficiency in strategic crops: Despite the population increase, it is necessary to provide water for self-sufficiency in some strategic crops.

1.4.9 Lack of appropriate financial resources: To implement the plans and programs emanating from the previously and currently established water strategies and policies, this requires many financial resources.

1.5 PAST AND CURRENT WATER STRATEGIES, PLANS AND POLICIES

The water policies that have been followed in the management of water resources in Egypt over the past decades are divided into 2 groups of policies. The first one depends on the development method, in which the focus was on the relative abundance of water resources and an attempt to add other resources (from 1975 to 1980). The second group of methods depended on the approach of allocation between Sectors (from 1986 to 1990). The policies, starting in the new century, were based on the integrated water resources management approach [15]. The water policies in Egypt include the following:

- Resource development policies such as Nile water, groundwater, rain and floodwater harvesting, reuse of agricultural drainage water and desalination.
- Rationalization policies in agricultural and industrial sectors and household consumption.

- Policies for completing and rehabilitating the national structure of the water system.
- Pollution control policies.
- Policies of adaptation to climate changes.
- Institutional and legislative development policies.
- Policies to raise awareness and community participation.

Table (2) explains Progress in the Fayoum Water Resources Plan 2012-2017 as an illustrative example

Table 2 Progress in the Fayoum Water Resources Plan 2012-2017 as an illustrative example [14]

Action	Indicator	Baseline 2012	Targeted 2017	Actual 2017	Notes
1- Improving drinking water services & reducing loss	No. water gauges	-	-	-	NA
	Loss (%)	33	20	30	Weak
	Drinking water rural coverage (%)	95	100	95	No progress
2- Maintaining canals and drains 3 times/year	Canal lengths (km)	1398	1398	1398	100% progress
	Drain lengths (km)	1063	1063	1063	100% progress
3- Applying modern irrigation technologies in new areas	Area (feddans)	45000	45000	45000	100% progress
4- Expanding the reuse of agriculture wastewater, and focus on intermediate uses	Volume (BCM/year)	0.6	0.7	0.8	200% progress
5- Reduce industrial pollution on water courses	No. Factories need treatment	-	-	40	NA
	Units to treat	-	-	24	NA

The National Water Resource Plan for Egypt: Water for The Future, 2017

This plan describes how Egypt will safeguard its water resources in the future, both with respect to its quantity and quality. It also explains how it will use these resources in the best way from socio-economic and environmental points of view. The time horizon of the plan is the year 2017 [15].

Egypt is confronted with numerous water-related issues. Egypt's predicted population rise from 63 million in 2000 to 83 million in 2017 (time of preparing national plan), as well as the associated water demand for public water supply and economic activity, particularly agriculture, is the first and most significant concern. The second task is to enhance environmental quality, as population growth and associated industrial and agricultural activities have resulted in a significant deterioration of water resource quality, notably in the Nile Delta. The third challenge arose from the previous two, and it can only be addressed by improving water management institutional settings, including aspects of cooperation, decentralization, and privatization (participatory approach in planning, development, and management, as well as the inclusion of coast recovery aspects) [15]. The plan set up policy objectives as follows:

- The supply for drinking water for domestic uses and provision of sanitation services according to the standards on a cost recovery basis taking into account the right on basic requirements of all people.
- The supply of water for industrial purposes and the provision of sewage treatment facilities on a cost-recovery basis.
- The supply of water for irrigation based on a participatory approach and cost recovery of operation and maintenance.
- The protection of water system from pollution, based on a polluter-pays principle and the restoration of water systems, in particular the ecological valuable areas.

1.6 EGYPT VISION 2030

The most downstream country in the Nile Basin is Egypt, which is extremely dependent on the River Nile. This makes co-operation with other Nile Basin countries indispensable. The country hardly has any other fresh water resources. Rainfall is very rare, except for a very small strip along the Mediterranean coast. Fossil groundwater is available in parts of the Eastern and Western Deserts and Sinai [15].

The 2030 Agenda for Sustainable Development, adopted by all United Nations Member States in 2015, provides 17 Sustainable Development Goals (SDGs), which are an urgent call for action by all countries - developed and developing - in a global partnership. They recognize that ending poverty and other deprivations must go hand-in-hand with strategies that improve health and education, reduce inequality, and spur economic growth – all while tackling climate change and working to preserve our oceans and forests.

Today, the Division for Sustainable Development Goals (DSDG) in the United Nations Department of Economic and Social Affairs (UNDESA) provides substantive support and capacity-building for the SDGs and their related thematic issues, including water, energy, climate, oceans, urbanization, transport, science and technology.

DSDG plays a key role in the evaluation of UN system wide implementation of the 2030 Agenda and on advocacy and outreach activities relating to the SDGs. In order to make the 2030 Agenda a reality, broad ownership of the SDGs must translate into a strong commitment by all stakeholders to implement the global goals. DSDG aims to help facilitate this engagement.

In this regard, Egypt's national agenda "Egypt Vision 2030" was launched in February 2016 that reflects the state's long-term strategic plan to achieve sustainable development principles and objectives in all areas. Egypt's Vision 2030 is based on the principles of 'comprehensive sustainable development' and 'balanced regional development'. The Vision 2030 reflects the three dimensions of sustainable development: economic, social, and environmental dimensions. Believing that the strategies are living documents, Egypt decided to update its sustainable development agenda at the beginning of 2018 with the participation of all stakeholders from development partners to keep pace with changes in the local, regional and global contexts.

The second version of Egypt's Vision 2030 was keen to make the vision an inspiring one that explains how the Egyptian contribution will serve the UN agenda, and how it will serve that global context. The updated vision focuses on addressing and overlap of all issues from the perspective of the three dimensions of sustainable development: environmental, economic and social dimensions. It is a comprehensive and coherent vision consisting of sectoral strategies for various government agencies. Egypt Vision 2030 focuses on improving the quality of life of the Egyptian citizens and improving their standard of living in various aspects of life by ensuring the consolidation of the principles of justice, social inclusion and the participation of all citizens in political and social life, in conjunction with high, inclusive and sustainable economic growth, enhancing investment in human beings, and building their creativity by promoting increased knowledge, innovation and scientific research in all areas.

Egypt's Vision 2030 gives significance for addressing the impacts of climate change through an integrated and sustainable ecosystem that enhances resilience and ability to face natural hazards. The vision also focuses on the governance of state institutions and society through administrative reform, consolidating transparency, support for monitoring and evaluation systems and empowerment of local administrations. All these objectives come within the framework of ensuring Egyptian peace and security and strengthening Egyptian leadership regionally and internationally Egypt's Vision 2030 (mped.gov.eg).

Objective No. 5 of the "Egypt's vision 2030" that is referred to by "Sustainable Environment" "INTEGRATED AND SUSTAINABLE ECOSYSTEM" states that: "Egypt seeks to preserve both development and the environment through the rational use of resources to preserve the rights of future generations to a safer and more efficient future. This can be achieved by addressing the impact of climate change, enhancing the resilience of ecosystems, countering natural hazards and disasters, increasing the use of renewable energy and adopting sustainable consumption and production patterns".

The SDG 6 "Clean water and sanitation" is a very crucial one that is carefully taken in consideration by the Egyptian Government. The national program "National project for the development of Egyptian Lakes" is launched by the Egyptian president and currently under implementation for the purpose of upgrading and developing all Egyptian lakes and restoring their previous condition.

CHAPTER 2

2. SITE DESCRIPTION

2.1 LAKE QAROUN IN THE FAR PAST

Around B.C. 450, Herodotus visited Egypt and reported seeing an artificially controlled lake covering the basin of the Fayoum depression, receiving water by an intake channel input from the Nile during the annual flood "Moeris." During droughts, the water stored in the large natural reservoir was released into the thirsty valley via an outlet canal. [5]

A large portion of the Fayoum depression resembled a natural lake in the days of the first Egyptian dynasties, rising and sinking with the river and with settlements of Egyptian fisher-folk along its edges. The lake region became a favorite royal residence for the 12th dynasty's kings, and it was probably a king of this dynasty, known in Herodotus as "Moeris", who built the great dam with powerful locks across the natural gap through which the river flowed into the depression, thus regulating the inflow and outflow and reuniting the inhabitants of the depression. [5]

The great lake was still there when the Ptolemies conquered Egypt; however, when the Greeks looked at the fair and fertile land on the other side of the barren hills that bounded the Nile, it appeared to them that it would be possible to dry up a large portion of the water in the depression and lay bare large tracts of new, good soil for colonisation. Under Ptolemy I and Ptolemy II, Greek engineering science took up the task, and in a few years, where there had been a sheet of water only a few years earlier; there were lengths of cornfields with new towns and villages. The water was reduced to less than half its previous size, laying only over the depression's northern and deepest parts, where it is still known as "Birket Qaroun; Qaroun Pond; Qaroun Lake". Due to the influence of evaporation on its reduced volume, Birket Qaroun became brackish and undrinkable. Fayoum is an Arabic transliteration of its Egyptian (Coptic) name, which means "lake" [5].

The general impression gathered from this is that “Lake Moeris was a large artificial sheet of water occupying the greater part of Fayoum, and serving as a reservoir for the surplus flood waters of the Nile” [5].

At Lahun, the Bahr Yusef, a branch of the Nile, separates from the main river and enters the Fayoum channel. The water is then channeled in all directions, irrigating the entire province until finally falling into Birket Qaroun. In their historical follow-up to Lake Qaroun, Tomson & Gardner (1929) came to a conclusion that “any hope of a true solution of the problem must rest on a consideration of all of the three main aspects – namely, geological, archaeological, and irrigation engineering” [5].

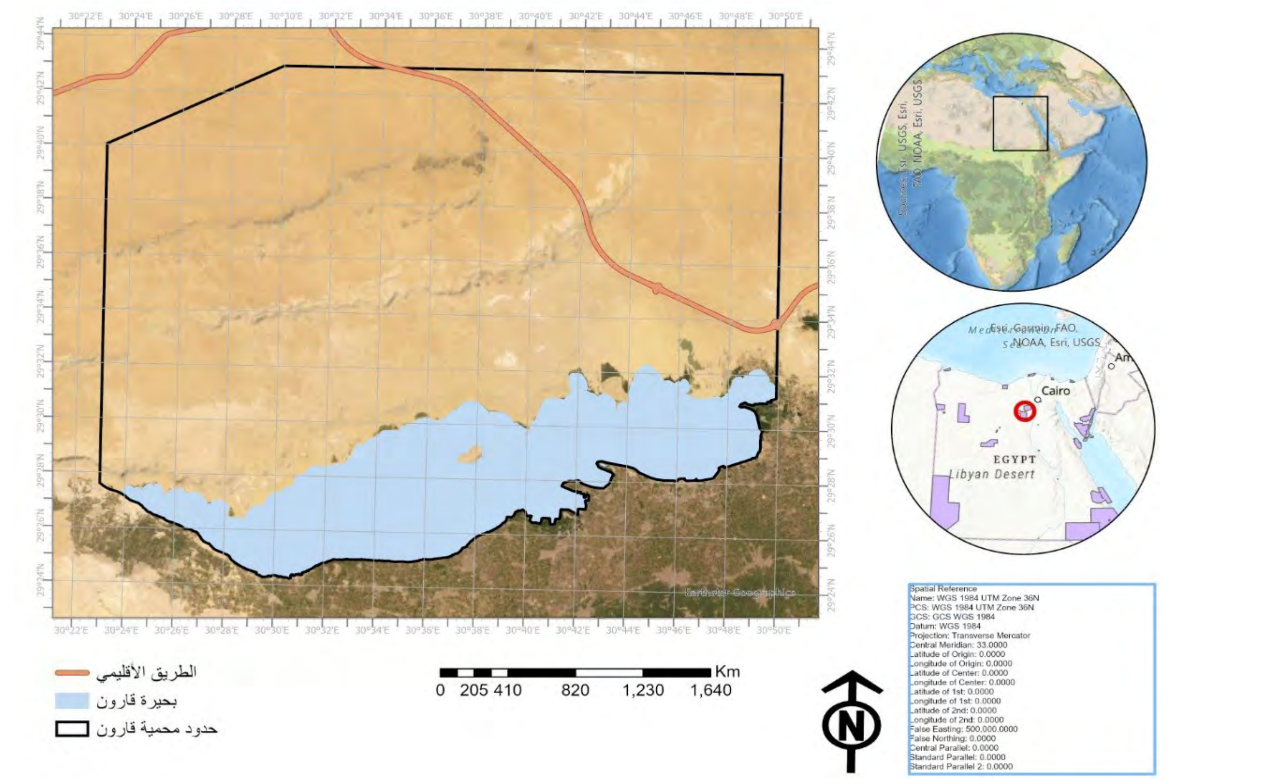
The Government has no influence on the rain or snow, which falls on Beauce or Brie, but in Egypt the government, has direct influence on the extent of the inundation, which takes their place [7].

2.2 THE PROTECTED AREA

Prime Minister Decree No. 943 allocated the lands of Qaroun protected area in 1989, with an area of 1,340 square kilometers. The decision was amended by Prime Minister Decree No. 3155 in 2019 to exclude the southern strip of the coast of the lake from the boundaries of the former area to become 1298 square kilometers.

The Qaroun Protected Area (QPA) lies 80 kilometers southwest of Cairo, on 29° 30 N and 30° 40 E. Its territory is partially included in both the Fayoum and Giza Governorates: approximately 29.5 percent of the PA territory falls within the Giza Governorate administrative boundaries, while the remaining 70.5 percent falls within the Fayoum Governorate administrative boundaries [20].

The protected area is divided into two parts: inland water and land (Map 2). Lake Qaroun, the remnant of the ancient Lake "Moeris", previously supplied by a waterway branching from the Nile and now receiving agricultural drainage water from much of the land in the Fayoum Governorate through a multitude of drainage canals, represents the inland water component. The lake, which is estimated to be roughly 250 km^2 in size, is Egypt's third largest and an important wetland for resident water birds and other migratory species. Gezeret El Qarn El Zahbi (Qarn Island) is a small island in the midst of Lake Qaroun that covers an area of about 1.5 km^2. It is regarded one of the most gorgeous and important islands in the lake as an attraction site for resident and migratory birds [20].



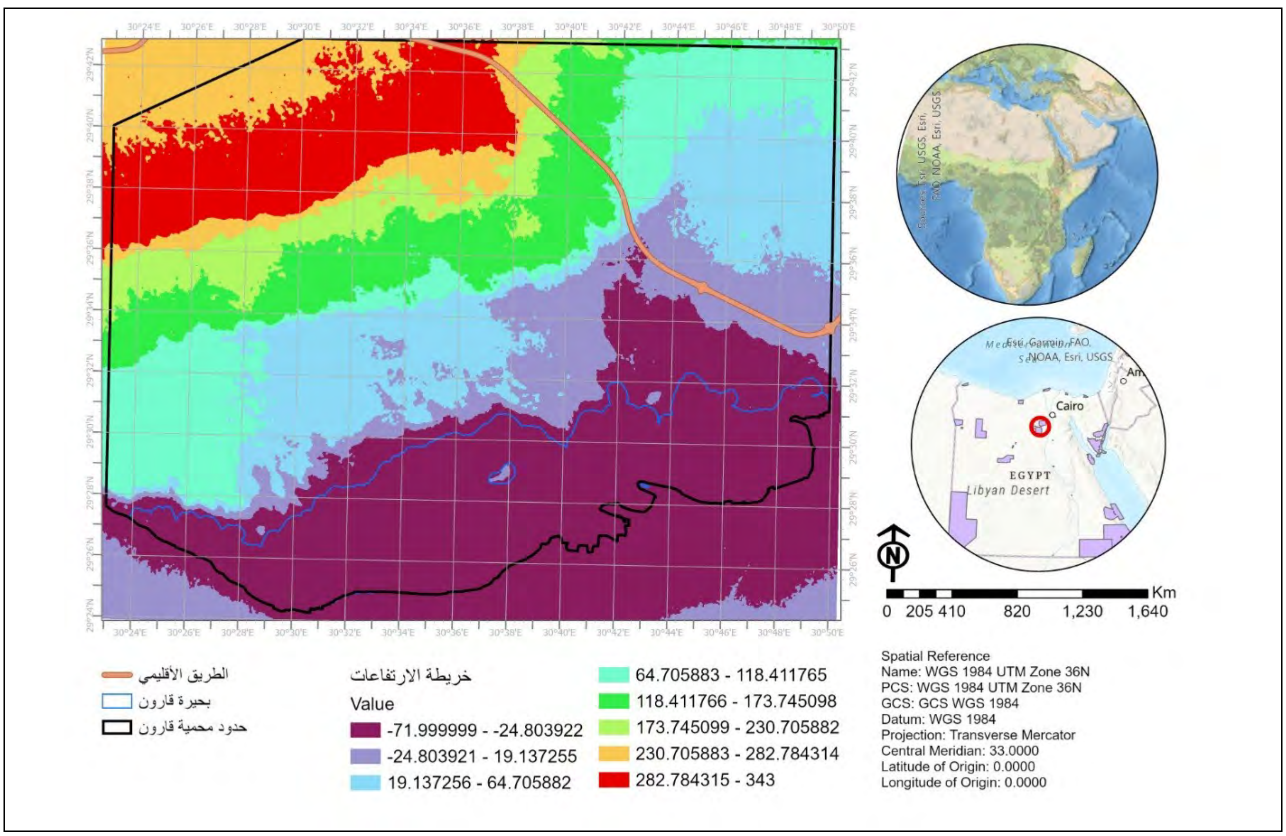
Map 2 The location and borders of Lake Qaroun protected area

2.2.1. Physical Settings

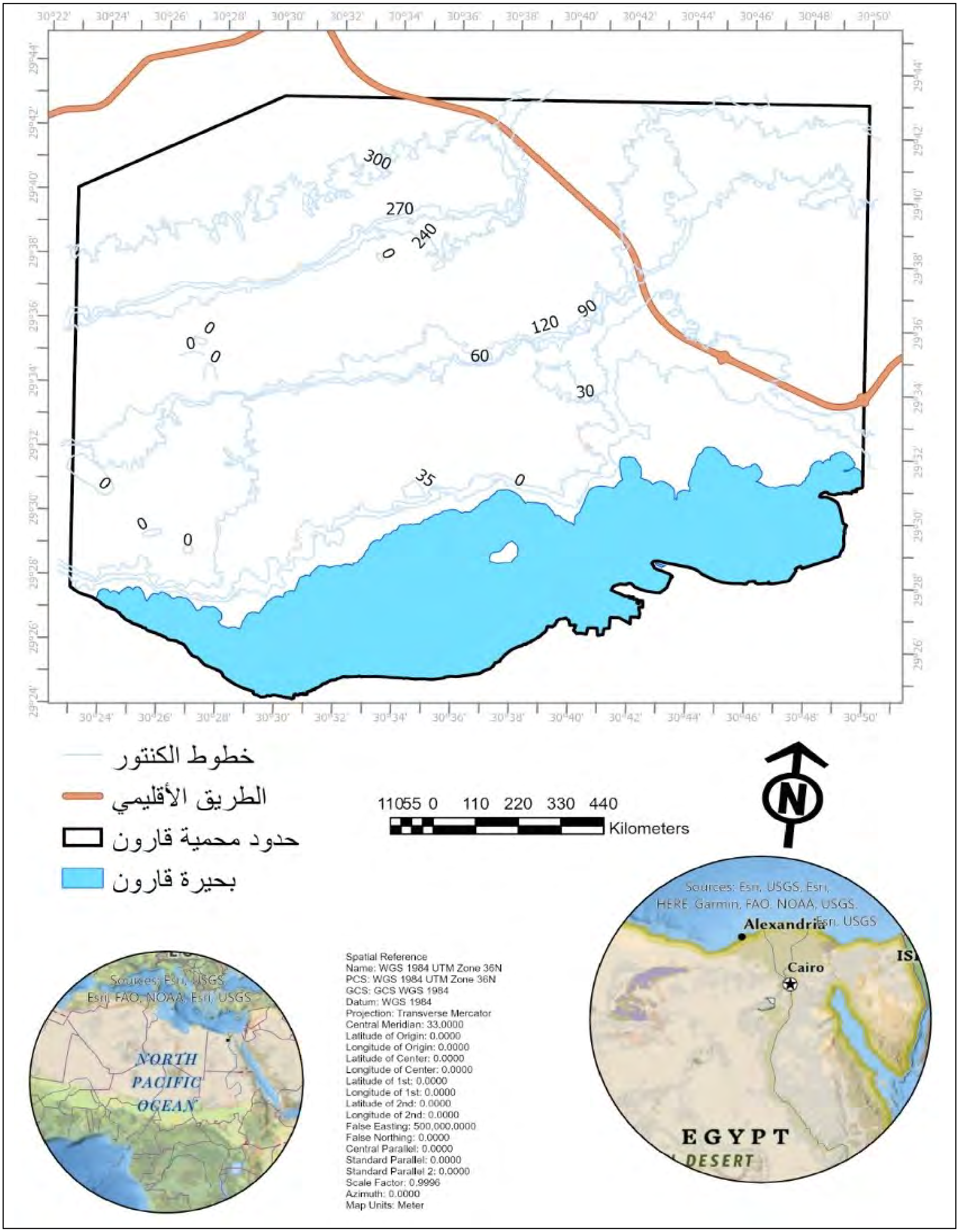
Except on the southeastern side, where Hawara channel, through which the major irrigation canal of Bahr Yousef flows, cuts it, the Fayoum depression is surrounded on other sides by hills or escarpments. Sloping plains continue northward and upward from the lake's shoreline, reaching sea level around 7 kilometers from the beach. Further north, the topography becomes rougher and rockier, with a succession of benches and escarpments that extend up to around 300 meters above sea level. The Eocene Qasr El-Sagha and Jebel Qatrani formations are among these escarpments [17].

Geomorphology

A section of Fayoum's depression and its northern boundary is covered by Qaroun Lake. The Fayoum depression is one of Egypt's primary depressions, carved in the Eocene limestone plateau that stretches over this area of the country and marked by the existence of Lake Qaroun. The depression, which is surrounded on all sides by scarps and a sloping plateau, produces an internal drainage system that is fed by water entering the depression through canals connecting it to the Nile River. From the south, the Fayoum depression's floor dips northwesterly to Lake Qaroun, with Lake Qaroun occupying the basin's deepest northwestern section, where the surface water that enters the depression drains is gathered. The only way water leaves the Lake is through evaporation [17] (Map 3&4).



Map 3 Elevation map for Qaroun Lake and surrounding areas



Map 4 The contour map for Lake Qaroun and surrounding areas

Geology

The Fayoum depression and nearby areas are largely covered by Tertiary and Quaternary age sedimentary layers, which are structurally impacted by the northwestern dip of the massive Arabo-Nubian massif. Sedimentary rocks from the Middle Eocene, Late Eocene, Oligocene, Early Miocene, Pliocene, Pleistocene, and Holocene eras occupy the area around Lake Qaroun. Basalt sheets are the only igneous rocks present in the area. A distinguishing trait is the consistency of many beds over large areas. Furthermore, the Fayoum area's sediments thin down in the south and southwest directions [17].

A sharp rises 350 meters above sea level in a succession of steps over the lake Qaroun shore north of the lake, following a gently ascending pattern. The cliff is made out of limestone and clays, with sand, clays, and small carbonates on top, and a 30 m thick basalt sheet covering the scarp summit. In terms of geological features, this area is the most intriguing for visitors, as erosive occurrences and rock exposures have resulted in numerous stunning geological formations [18].

The age and origin of the Fayoum depression are still unknown, and the relative roles of water and wind erosion have been a source of debate in the past. Except for the occurrences of Oligocene basaltic flows, the rocks exposed in the QPA area are sedimentary in origin and range in age from Middle Eocene to recent. From bottom to top, the chrono-stratigraphic succession of the rock units exposed in QPA is as follows:

The Middle Eocene rocks form the oldest exposed beds, crop out at the scarps around the depression, and partly formed its floor (45 million years ago). These include the Gehannam Formation, which consists of gypsiferous shale, marl, limestone, and sandstone, as well as strata consisting of firm, snow-white, extremely fossiliferous limestone with shale and marl intercalations. The maximum thickness of the Gehannam Formation is 60 meters [18].

The Upper Eocene rocks (39 M.y.a.) are exposed to the north of Lake Qaroun. The exposed Upper Eocene rocks are distinguished into two formations from base to top [18]:

A. Birket Qaroun Formation: is composed of fine to medium-grained, fairly hard, and extremely fossiliferous yellowish grey sandstones that transition to yellowish to brownish grey, calcareous sandstones before being capped with greyish yellow, fossiliferous limestone. The Birket Qaroun Formation is well developed in many regions, notably the desert stretch separating El-Fayoum from the Nile Valley, the area surrounding the northern frontier of cultivation and Lake Qaroun, and the Garret Gahannam hill mass on the west side of Fayoum. This unit has a thickness of around 50 m.

B. Qasr El-Sagha Formation: Approximately 200 meters of cross-bedded sand, sand mud, and carbonaceous shale make up the Qasr El-Sagha Formation. The rocks were deposited in a subsiding basin with a W-SW to E-NE orientation that was limited to the north by high hills. The Qasr El-Sagha Formation is divided into four members, which are listed below in order of appearance:

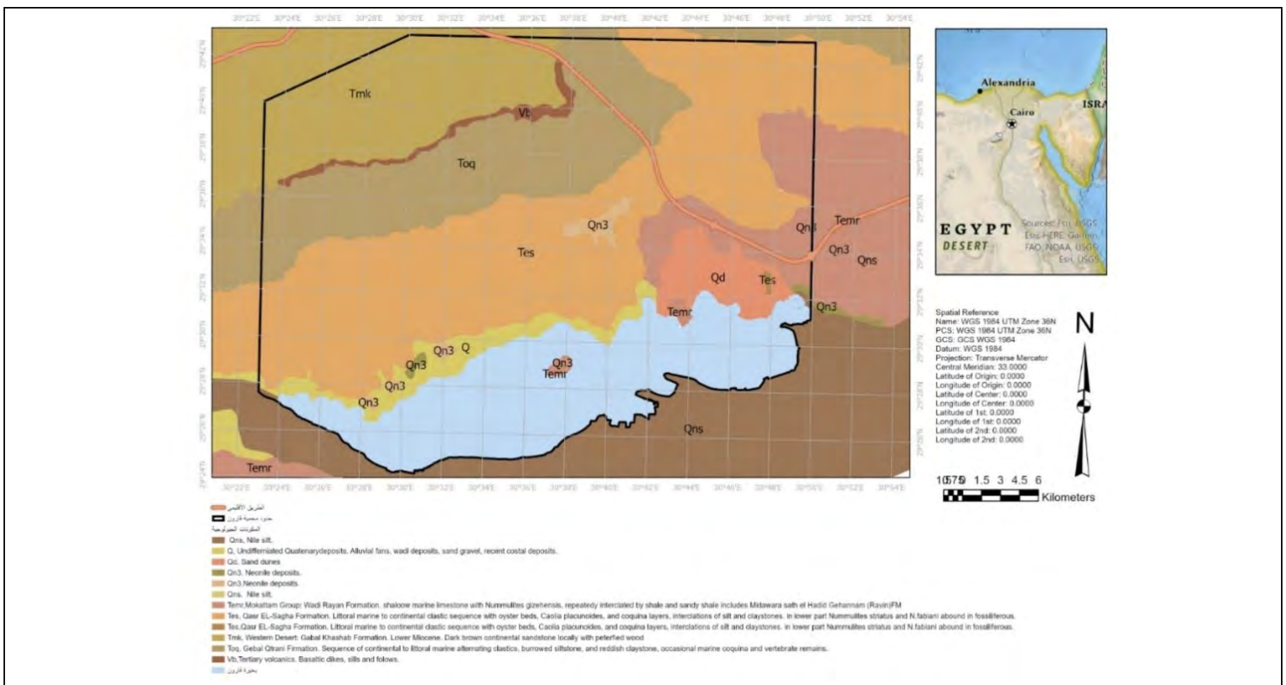
1. Dir Abu Lifa Member represents the upper 77 m of Qasr El-Sagha Formation. It is distinguished from the overlying Qatrani Formation in the absence of variegated beds and gravels and in its greater proportion of limestone and shale.

2. The Temple Member attains thickness of 123 m and consists primarily of thin glauconitic to limonitic arenaceous limestones and fine quartz sandstones that are inter-bedded with thicker, generally laminated sandy mudstones and carbonaceous mudstones. Gypsum is abundant in this member.

3. Harab Member is 30-40 m thick and consists of gypsiferous and carbonaceous laminated clay stone and siltstone. Its type locality is the Minqar El-Abyad section. It forms broad featureless plains and separate the Umm Rigl member below from the Temple member above.

4. Umm Rigl member is a 30-65 m interval at the base of Qasr El-Sagha Formation, its type locality is Garet Umm Rigl in the Qaroun lake escarpment north of the lake. This member is of special interest as it contains Zeuglodon and other vertebrate remains in beds.

Oligocene (35 M.y.a.): Jebel Qatrani is the type locality for the Oligocene Qatrani Formation, which is made up of a fluvio-marine series of variegated alluvial rocks, fine to coarse sandstone, granule and pebbly conglomerate, sandy mudstone, carbonaceous mudstone, and limestone, all of which are strongly burrowed and root-bearing, fluvial, point bar, and flood clastics. The vertebrate fauna that flourished in this area during the late Eocene and early Oligocene periods is abundantly fossilized in this deposit (Map 5). The Qatrani Formation is divided into two sections: an upper sequence (previously known as the upper fossil wood zone) and a lower sequence (formerly known as the lower fossil wood zone) (formerly termed lower fossil wood zone). A persistent 4-10 m thick layer of barite sandstone separates these two phases [18].



Map 5 Geological map for Lake Qaroun and surrounding areas

Paleontology

Fauna fossils: In terms of fossils, Fayoum depression has a one-of-a-kind heritage, particularly in vertebrates and, above all, mammals. The fossil deposits in Jebel Qatrani escarpment, in instance, are so extensive that modern scientists have dubbed it "Africa's best-known Paleogene site". Since the discovery of Eocene shark teeth and cetacean bones on the Gezerit El Qarn island in Qaroun Lake, as well as other specimens from Qasr El-Sagha that were diagnosed as a new species of archaic whale *Zeuglodon osiris* by German geologist Schweinfurth, this part of the world has been known as a repository of Paleogene vertebrates and has attracted the attention of scientists from all over the world. There's also a good chance that there's still a lot of fossils to be found in the area. [19].

In fact, the northern escarpment of the Fayoum depression, particularly the Jebel Qatrani area, provides by far the most comprehensive view of endemic African fauna before the Miocene faunal interchanges resulted in a major influx of other groups, such as the many rodent families, artiodactyls, perissodactyls, and fissipeds that are common in modern Africa [19].

Mammals are the most important fossil group discovered at the site, which included a mix of endemic and major immigrant groups from Eurasia, some of which have since become extinct or have greatly diminished in diversity. The Fayoum fossils can be divided into four faunal assemblages, each of which is stratigraphically unique. Each of these mammalian assemblages can be compared to the communities of current mammals [19].

There are twenty-eight orders of placental mammals known to exist in the world today, twelve of them can be found in Qatrani area, which is most renowned for its incredible primate species. The earliest primates from Africa have been discovered in three fossil-bearing layers of Jebel Qatrani Formation, and several hundred anthropoidean specimens have been collected from the upper sequence, but the Family Parapithecidae, which includes monkey-like primates about the size of modern squirrel monkeys, is the most striking [19].

Simons and his team's important finding of *Aegyptopithecus zeuxis* in 1965 was a significant step forward in our knowledge of primate evolution. Quarries I and M in the upper series yielded a virtually entire cranium, many jaws, and various bones (about 33 MY ago). *Aegyptopithecus* is the Qatrani primate that most closely resembles later (advanced) taxa. Quarry L-41 has produced materials ranging from small Insectivores to a *Palaeomastodon* humerus over one meter in length, making it the most important site to date [19].

The Qaroun reptiles, like the mammals, include several taxa that are currently unknown in Africa. The fish and birds of Qatrani, on the other hand, are remarkably similar to those of current tropical Africa. The Upper Eocene Qasr El-Sagha Formation has massive reptiles. Chelonians (turtles) are the most common and diversified reptiles in Fayoum, with at least 14 genera. In Qatrani, crocodiles and snakes from the Oligocene epoch were discovered. A large number of siluroid catfish and lungfish, similar to those seen in modern Sub-Saharan Africa's rivers and wetlands, are present. The bird fauna of Qatrani is extraordinarily rich and provides the best-known Paleogene record of this Class in Africa, despite the fact that fossil birds are rare due to their delicate nature. Herons, jacanas, rails, storks, and fish eagles are among the fossil birds found in Jebal Qatrani stratigraphic layers [19].

Invertebrate fossils abound in the formations discussed above. Mollusca (e.g., *Carolina placunoides*, a species found in the Qasr El-Sagha formation's basalt layers, Gastropoda, and Cephalopoda), Crustaceans, and Foraminifera are among them. The abundance of ichnofossils in the area is also a notable feature. Large communal nests and passageways of social insects like termites and ants, living burrows of diverse invertebrates, pellet-filled tunnels of worms, and vertebrate burrows and excavations can all be found in the area, with significant ichnofossil concentrations [19].

Flora fossils: Jebel Qatrani area is as rich in fossil plants as it is in fossil animals. Angiosperms, pteridophytes, and algae are among the fossil plants discovered. Stems, leaves, fruits, seeds, pollen grains, roots, rhizoliths, thalloid, and unicellular algae are among the plant relics. In terms of the fossil flora, it's worth noting that all identified plant remnants have just been partially analyzed, and it's probable that future research may disclose even more fascinating facts [19].

Over 40 monocots, dicots, and pteridophytes, as well as over 160 algae species, may be found in Jebel Qatrani. This area's rich, diverse, and well-preserved palaeoflora (together with a richness of discovered fossil fauna) adds to making it one of the world's most important fossil sites. Furthermore, the good quality of the revealed plant remains indicates that the presence of fossil fungi and fossil bryophytes (which will be the first in Egypt) is not at all surprising, given the preservation circumstances in the paleoenvironment [19].

2.2.2. Biological & Biodiversity Settings

Fayoum Depression is a local biodiversity hotspot, which is indicated by the presence of several extinct species of African origin not documented elsewhere in Egypt (e.g. *Dasypeltis scabra* and Cape Wolf Snake *Lycophidion capanse*); Also, the endemic *Sylvia melanocephala norrisae*, a subspecies of Sardinian warbler, is also present. All these cases refer to a biogeographical history of Fayoum depression and its relative isolation for long periods. Due to rapid environmental changes, these species have disappeared and are presumed to be extinct (e.g. *D. Scabra*, which is still rarely documented). Most of the large mammals that inhabit the area are now gone, except for the Jackal *Canis aureus*, which still survives. [20]

Birds

Since Qaroun Lake is considered an Important Bird Area (IBA) for its importance to waterfowl, especially in winter, it was designated as a RAMSAR site in 2012 by RAMSAR convention with Wadi El-Rayan Protected Area. In the winter, Lake Qaroun hosts large numbers of waterfowl. Large-headed and black-necked follicles (*Podiceps cristatus* and *P. nigricollis*, respectively) are particularly abundant in this region. There are also large numbers of *Anas crecca*, *Aythya fuligula* and *Fulica atra*. At least ten species of waterfowl are known to breed in the area, most notably *Bubulcus ibis*, *Vanellus spinosus*, *Charadrius alexandrinus*, *Sterna albifrons* and Slender-billed Gull *Larus genei*. *Larus genei* birds began breeding in Lake Qaroun in the early 1990s. Currently, there are an estimated 1,200 pairs nesting on the Golden Horn Island, one of the largest colonies in the world, making it the most important biodiversity site in the Lake Qaroun region [20].

The species that live in agricultural areas on the southern shores of Lake Qaroun include birds typical of the Nile Valley, such as: Little Green Bee Eater *Merops orientalis*, Common Bulbul *Pycnonotus barbatus*, Crested Lark *Galerida cristata*, *Burhinus senegalensis* and *Coucal Centropus*.

Desert and semi-desert habitats support smaller species richness including notably the hoopoe, *Alaemon alaudipes*, Raven *Corvus ruficollis*, the brown-necked crow, and small numbers of Egyptian Nightjar and *Caprimulgus aegyptius* on the desert margins.

A local endemic species of the Sardinian species *Sylvia melanocephala norrisae* inhabited the vegetation, which was present along the shores of Lake Qaroun in the past when it was fresh water. These species are now extinct as a result of the rapid environmental changes that occurred during the last century, which led to the loss of their habitat [20].

Mammals

Today's desert mammals are dominated by rodents, mainly the small gerbillus and *Jaculus jaculus*. The Egyptian *Gazella dorcas* and *G. leptocerous* white deer used to live in the desert habitats of this area but both were locally exterminated during the last century.

In agricultural areas, both the Red Fox *Vulpes vulpes* and the Egyptian Jackal *Canis aureus* are still common. Other mammal species in the area are typical of the Nile Valley, including the Egyptian mongoose *Herpestes ichneumon* and the Nile Rat *Arvicanthis niloticus*. [20]

Flora

The natural vegetation cover is very sparse in desert habitats, largely confined to some valleys in Jebel Qatrani area range or to sand dune formations near the northern shores of the lake. The vegetation near the lake consists of the species *Tamarix sp*. and *Sueda aegyptiaca* and *Alhagi graecorum*. At higher altitudes, *Calligonum commosum* predominates.

In the cultivated areas, some wild plants grow in the vicinity of the farm where a wide variety of herbs and wetland plants are present, such as the reeds *Phragmites australis*, *Typha domingensis* and *Cyperus rigidus*. The neighboring lands are dominated by the plants *Tamarix niloticus*, *Desmostachya bipinnata* and *Alhagi graecorum*. [20]

Reptiles & Amphibians

In desert regions, *Acanthodactylus scutellatus* is the most common diurnal lizard, while *Stenodactylus sthenodactylus* is a common nocturnal gecko. The snake *Psammophis aegyptius* is common in rocky areas. In cultivated areas, *Sclerophrys regularis* and *Ptychadena mascareniensis* are common amphibians, while *Psammophis sibilans* is a common diurnal snake. [20]

2.2.3. Critical Ecosystems of Special Importance

Jebel Qatrani

The Jebel Qatrani fossil site is the only site that includes two major periods of Paleogene fossils: the late Eocene (37-33.9) million years ago, and the early Oligocene (33.9-28.5) million years ago. The Eocene and Oligocene rocks in Jebel Qatrani area are among the richest in fossils among all the sites. A few fossil species are very limited especially some primates, and some species of two-toed mammals are very abundant in Jebel Qatrani area. The Jebel Qatrani site has the best preservation conditions for Eocene/Oligocene animals and plants and the largest collections of fossils (more than 385,000 mammalian jaws, 11,500 skulls and 46,000 mammalian bones), and the fossil record in the region contains 12 orders of placental mammals out of the 28 existing today [20].

Jebel Qatrani site has the largest known petrified wood area with more than 1,126 pieces of wood (to date) and 22 plant species. This Petrified Forest covers the largest area of petrified wood in the world and covers an area of about 30 square kilometers.

The site of Jebel Qatrani provides evidence of the migration of animals from Africa to Australia and Asia through the emergence of the genus *Varanus*; its fossils come from the late Eocene and early freshwater deposits discovered at the site. The discovery of these fossils and their scientific definition indicate that the genus *Varanus* originated in Africa, before spreading to Australia and Asia [20].

Golden Horn Island

A desert island located in Lake Qaroun. It is an important site for birds (especially for nesting skinny gulls). It has geological importance, and contains many species of reptiles. The island is currently one of the largest gulls nesting, laying and hatching colonies in the world, with over 12,000 pairs of gulls nesting. The island is located in the middle of Lake Qaroun and covers an area of about 1.5 square kilometers, and is of paramount importance in the conservation of waterfowl, as it provides protection from potential terrestrial predators [20].

2.3 SOCIO-ECONOMIC SETTINGS

Qaroun Protected Area is located within the administrative boundaries of the governorates of Fayoum and Giza. Most of the areas of the Qaroun PA, especially those in which human activities are concentrated, are all located within Fayoum Governorate. Despite the fact that most of the area of the reserve is not inhabited, human uses are intensive in some sites, especially in the east and south of the lake. One of the more recent manifestations is the increasing encroachment of human presence, especially in agriculture, on the perimeter of the lake, especially in the southeast part. In 2019, the southern coastal strip of the protected area, which was loaded with agricultural activities, fish farming, private property and activities, was excluded from the borders of the area, and thus some villages were completely excluded with their accompanying activities, with a population of about 20,000 people [20].

Agriculture

Agriculture is the most important activity in Fayoum Governorate, where the availability of fertile land and abundant water from the Nile is taken as advantage. The cultivation of various crops is widespread, including fruits, vegetables, date palms and olives, as well as medicinal and aromatic plants. There are also many other rural occupations such as raising livestock or beekeeping. Fishing is practiced in particular in the waters of Lake Qaroun and Wadi El-Rayan. Agricultural activities are spread on the southern coast of Lake Qaroun and on the eastern side of it.

Industry

Industry still plays a less important role in the economy of Fayoum Governorate, and there are many small industrial establishments dedicated to various products, including canning and packaging of foodstuffs, ceramic factories, and the manufacture of some intermediate chemicals such as alum. Industrial activities are mostly concentrated in the industrial zone of the city of Kom Oshim. Commercial extraction of minerals and other non-renewable natural resources is also practiced in several areas, where there are some quarries for extracting basalt at the far northern edge of the protected area; It is currently on its way to ending its activities, and there are no longer any new permits from the administration of the PA to extract non-renewable natural resources.

Quarrying

The quarrying activities in Qaroun PA until recently represented one of the most important extractive activities of the non-renewable natural resources in the region. Where there were activities to extract basalt, clay, sand and gravel for industrial uses and building materials. Given the geological characteristics of the area, mining has in fact been an important activity since Pharaonic times: the archaeological sites of Jebel Qatrani, for example, illustrates the role of basalt quarries in the time of the pharaohs. In addition to the old quarries, there are also modern basalt quarries in that area, which are all but one activity in the far north of the PA, which will stop once its contractual period expires, as these activities represented one of the main threats to its natural and cultural heritage.

Fisheries

There are about 605 registered fishing boats in the entire lake, in addition to many unregistered boats; each boat employs about six people, meaning that each boat supported about six families until 2014. After 2014, the fish stocks began to decline rapidly [17].

Qaroun Lake is one of the important sources of fish production in Egypt in general and Fayoum Governorate in particular. The fish production of Qaroun Lake was about 878 tons in 2016, and 832 tons in 2018, representing about 2.85% and 2.4% respectively of the total fish production from the inland lakes, and about 0.55% of the total Egyptian lakes' fisheries. [25, 26, 27]

A study of the socioeconomic aspects of Fayoum, represented by Qaroun and Wadi El-Rayan, was conducted in 2017-2018. Interviews were conducted with fishermen who spent two nights fishing in the lake with the rest of the boat they are working on; it was discovered that their per capita share of mullet was approximately half a kilogram. When asked about the reasons for the decline in fish production, they blamed it on lake water pollution. They also demonstrated how the tongue-eating parasite Isopod infested the fish's mouth. They claimed that this parasite (locally known as a fish weevil) causes fish to lose weight dramatically and bites humans if handled. They also reported that this parasite had accompanied the General Authority for Fish Resources Development's process of releasing fry, and it first appeared in 2014 with another type of jelly fish that was in large quantities but suddenly disappeared. The study reported that the fishermen and their families no longer practice fishing activities in any part of the lake, as it was observed during the field visit; only one fishing boat was noticed in the lake and all the boats had been abandoned on the shore. The majority of the fishermen had left to fish in other governorates such as Aswan (Lake Nasser), Hurghada, and Suez. Fishing used to be a common occupation in Abu Nima, but now it is rare, as almost everyone in the area works or wants to work in the plumbing or tourism industry [17].

According to personal interviews with many women, some of them peel shrimp on board trucks from Damietta and some of them may participate in fishing activities, but this is rare these days. Another female-dominated profession that was once common is shrimp peeling, as it was proven through personal interviews with many women [17].

"Fisheries have been in decline since 1990" said Sheikh of Fishermen (previous head of the cooperative), adding that 2014 saw a rapid and significant reduction in fish stocks. Al-Bats, Al-Wadi, and Dayer Al-Berka drain all have sewage pollution that drains directly into the lake without any treatment. There has been a reduction in water flow into the lake as a result of the governor's decision to discontinue rice cultivation in 2008 [17].

Fish seed was released regularly by Egypt's Fish Resources Development Authority, however after the events of 2011, the authority stopped doing its routine work. The director of the authority in Fayoum was interviewed, and he explained that the minimal discharge of fish seed was due to the limited budget available. Sheikh of the fisherman has cleverly noted that even though the rest of the northern lakes in Egypt receive untreated sewage, there is still fish to be found there. Also, he remarked about the increasing salinity of the lake, which resulted in the extinction of many freshwater species that cannot sustain high salt levels [17].

Inland Water Research Institute scientists at the National Institute for Oceanography and Fisheries NIOF, Center for Marine Sciences and Fisheries (Shakshouk Station) reported that the Isopod parasite was a major factor for low fish stocks in the lake because it was introduced during the larval release process. As a result of this, the Public Authority for Fish Resources Development took over the role of scientifically supervising the procedures of releasing and adapting fry. In agreement with the fishermen's groups, the amount of fish seed diminishes each year, and that the process of adapting to the transferred seed is not taking place in a timely manner [17].

Interviews were also conducted with 16 restaurant owners (in Shakshok) to find out where they get their fish from. The study found that they used to get their fish from the lake, but now buy it from the nearby aquaculture farms. Because there are no wastewater treatment plants in the entire area, pollution from sewage and agriculture is a major issue, and all of the tourist facilities on Lake shoreline dump raw effluent directly into it.

Since the fish populations have declined, the majority of the original fishermen have migrated away from the area, as they have no other job experience than fishing, and they primarily fish at Lake Nasser in Aswan (1000 km away). In addition, some of them may return empty-handed.

A shift in the quantity of fish can be difficult to verify in practice because of pollution or materials introduced into the lake through drainage. However, it is extremely difficult to distinguish between natural and anthropogenic (human-caused) changes. The data can also be obscured by biological characteristics and variances like gender, age, and reproductive status, which can lead to a misunderstanding of the impact of contaminants on biota. The mobility of fish species complicates the determination of cause-and-effect links between biological forces and contaminants. Pollutants have no conclusive impact on fish stocks or aquatic life populations, according to the latest research. However, evidence in the scientific literature reveals that chemical contamination and nutrient inputs are practically lethal to fish and invertebrates, and some circumstantial evidence suggests that pollution, at least in part, may be responsible for several fish diseases.

Due to the fact that it is an illicit activity, there are fish farming operations in ponds that absorb drainage water before it reaches the lake and drain it on the lake in the eastern portion of the PA.

Salt Extraction

Egypt's EMISAL Company is solely responsible for the extraction of salts in the Qaroun Reserve. EMISAL was established in 1984 with capital of 76.25 LE, and its share capital was increased to LE 82.3 in 1989. As a result of the company's founding, Lake Qaroun has been protected from saltwater intrusion to some extent, in order to maintain the ecosystem and preserve the lake as a natural reserve. On top of the sodium chloride (vacuum) with a 35 thousand tons annual capacity, researchers are looking into the possibilities of generating other salts such as boron, bromine and potassium salts as well as sodium chloride (vacuum) [20]. The company's factories are located directly on the southern shore of Lake Qaroun in the area of Batna AbuKsah, near the village of Shakshouk, the center of Ibshaway, Fayoum Governorate. It has an economic, developmental and social return.

When the company's salt extraction activities expanded in 2013, an environmental impact assessment (EIA) was conducted to look at salinity levels in the lake and its history. Due to the amount of agricultural drainage of Fayoum Governorate, which is supplied to the lake, as well as evaporation, the salinity of Lake Qaroun in 1906 was approximately 10 g/l. It receives roughly 450 thousand cubic meters of agricultural drainage water annually, with a salt burden of about 700 thousand tons per year. Salt / yearly from 1992-2011, the company removed roughly 260 million cubic meters of water, containing approximately 12 million tons of salt, which resulted in the stability of the salinity of the lake.

The study found that the EMISAL Company's efforts to reduce the salinity of the lake had a significant impact on sustaining fishing chances, which are essential for most residents of the settlements spread along its southern shore. (In the presence of the company, it's the exact opposite of what's actually happening). Additionally, 60 (mag) nets are being placed by EMISAL surrounding the intake outlet from Lake to prevent fish fry from entering the ponds.

By 2013, more than 1,315 direct and indirect job possibilities had been created for individuals in the area. The company's workforce increased from 454 workers in 1995 to 626 workers by 2003, and reached 1315 workers by the end. In 2010, the enterprise is planned to employ 1,500 people, with the town of Shakshuk accounting for around 37% of the entire workforce [6].

The company submitted a study of proposed projects in 2013, which included a unit for the production of high purity sodium chloride, a unit for the production of medicinal salt, and the replacement and renewal of the packaging unit for the existing sodium chloride production plant.

2.4 LAKE QAROUN

Lake Qaroun is the only enclosed saline lake in Egypt. It is located in the western desert part of Fayoum depression and lies 83 km southwest of Cairo. The lake is located between longitudes of 30° 24` &30° 49` E and latitude of 29° 24` &29° 33` N. It is bordered from its northern side by the desert and by cultivated land from its south and southeastern sides. Qaroun Lake has an elongated rectangular shape with average dimensions 45 km length, 5.7 km width and 4.2 m depth in average. It is bounded from the south and east by the urban and cultivated areas and from the north and west by the unoccupied desert areas. The drainage in Fayoum depression is mainly by gravity. The drainage network consists of three main drains (El-Bats, El Mashroah and El-Wadi drains) and a number of small drains, which terminate into the lake. The lake is around 924 million cubic meters in size. Along the lake's southern and northern sides, there are multiple lagoons and bays, some of which have mud or salt flats of varied proportions. The only sizeable island in the lake, Al-Qarn El-Zahaby (Golden Horn), measures about 2 km^2 [17].

Climate

The climatic conditions in the area are typical of a desert environment. Rainfall is sporadic and rarely occurs in winter, especially on the deserts surrounding the cultivated land. The temperature generally shows a daily variation between 45^oC and 9^oC in summer and between 20^oC and 2^oC in winter. The humidity is higher in winter, reaching about 70% during February and decreases to 58% during the summer months. The evaporation rate reaches its maximum value of 13mm in June.

Lake Area and water level & Depth

The average area is about 240 km^2, the lake is not deep, with mean depth of 4.2m. Nearly, most of the lake’s area has a depth ranging between 5 to 8.5 meters. The water level of the lake changes between 43 to 45 meters below mean sea level. The maximum depth of lake is 8.5 meters to the west of El-Qarn Island and the eastern part is shallower with depth of about 3 meters [6].

Changes in evaporation rates and drainage input into the lake cause the lake area to fluctuate all year round from 1969 to 1989. It was found that the lake's mean level was -43.64 meters, with fluctuations of (+ or - 0.39) meters. It was discovered that the annual variance of lake levels fluctuates between -43 and -44 below mean sea levels. When it comes to these numbers, they vary wildly from January to March, March-June and June-November. Time and water levels also have a connection. There was no consideration given to the influence of time on the water level and the area in the prior investigations. Map (10) and table (3) show water levels with time of Lake Qaroun. Maps (6,7,8,9 & 10) show bathymetric and flood plain areas at water levels -44, -46 & -48m respectively [6]. Figure (11) shows the depth map for Lake Qaroun.

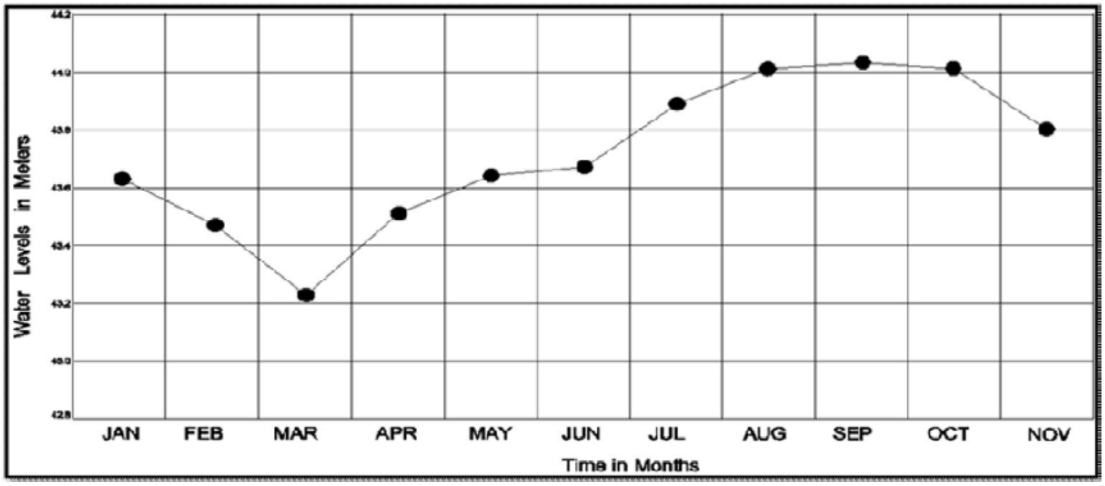
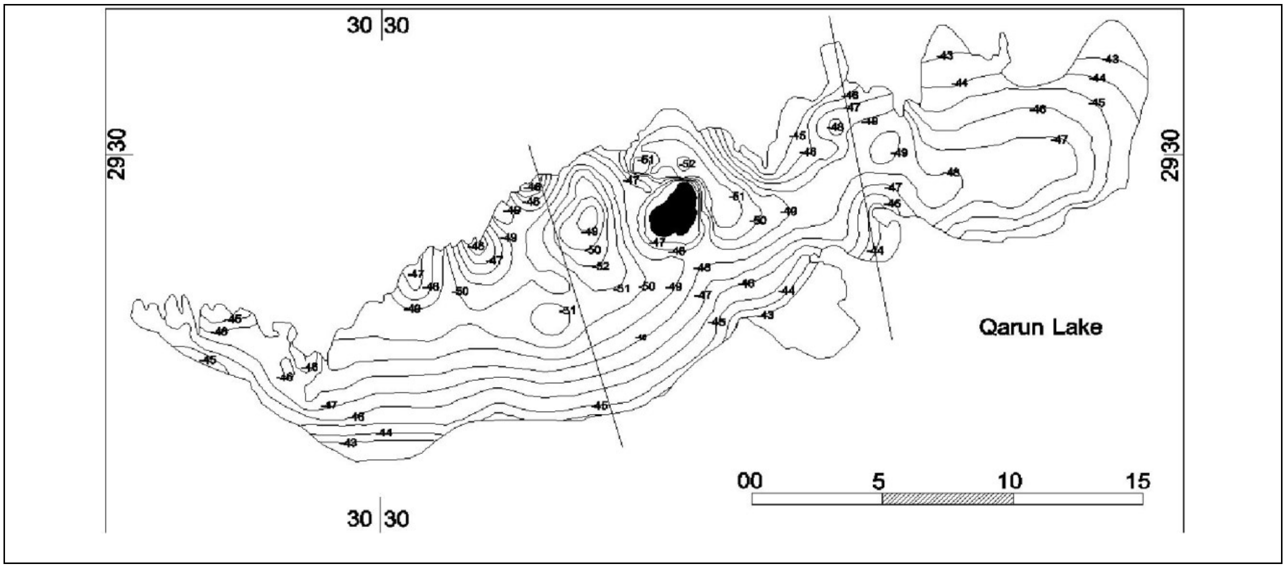


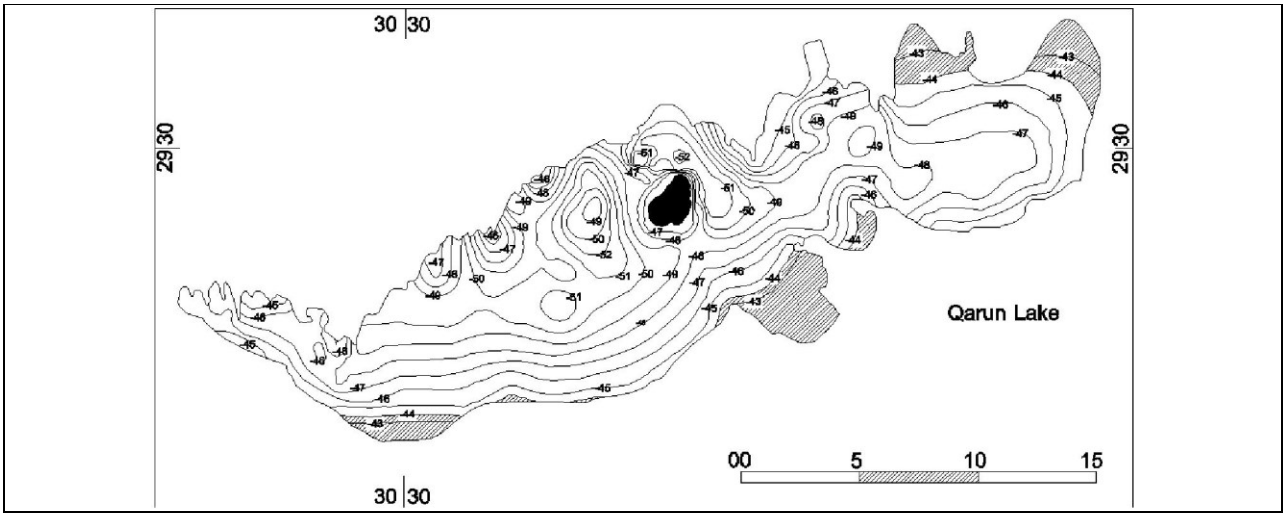
Figure 1 Water levels with time of Lake Qaroun [6]

Table 3 Water Levels with respect to time in months of Lake Qaroun

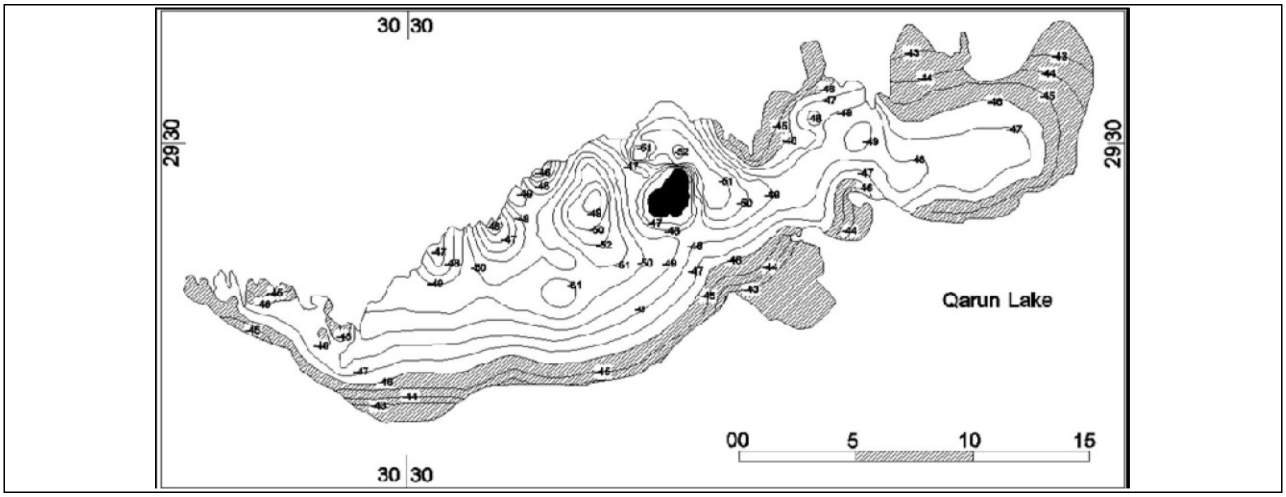
Month No.		WL_1	WL_2	WL_3	Measured WL	Difference	Error%	R^2
Jan	1	43.69			43.66	-0.03	-0.06	0.95
Feb	2	43.49			43.54	0.05	0.13	0.95
March	3	43.28			43.26	-0.03	-0.06	0.95
April	4		43.51		43.62	0.11	0.25	0.91
May	5		43.64		43.69	0.05	0.10	0.91
Jun	6		43.77		43.75	-0.02	-0.05	0.91
July	7		43.89		43.98	0.09	0.20	0.91
August	8		44.02		44.02	0.01	0.01	0.91
Sept.	9		44.14		44.07	-0.07	-0.17	0.91
October	10			43.97	44.03	0.06	0.13	0.93
Nov.	11			43.85	43.81	-0.04	-0.09	0.93
Dec.	12			43.72	43.73	0.01	0.02	0.93



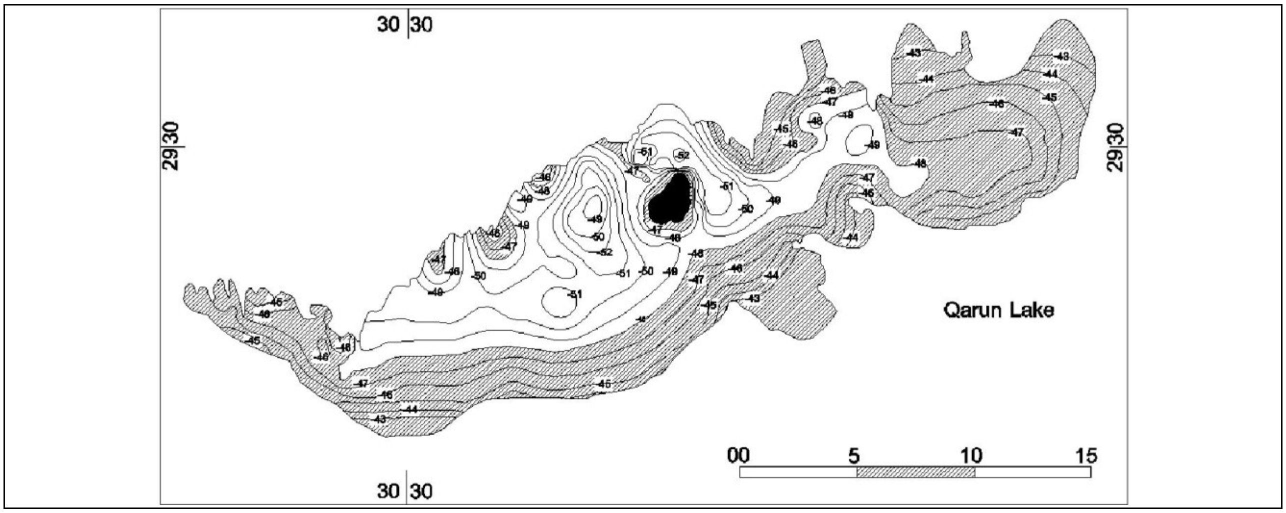
Map 6 Bathymetric map of Lake Qaroun



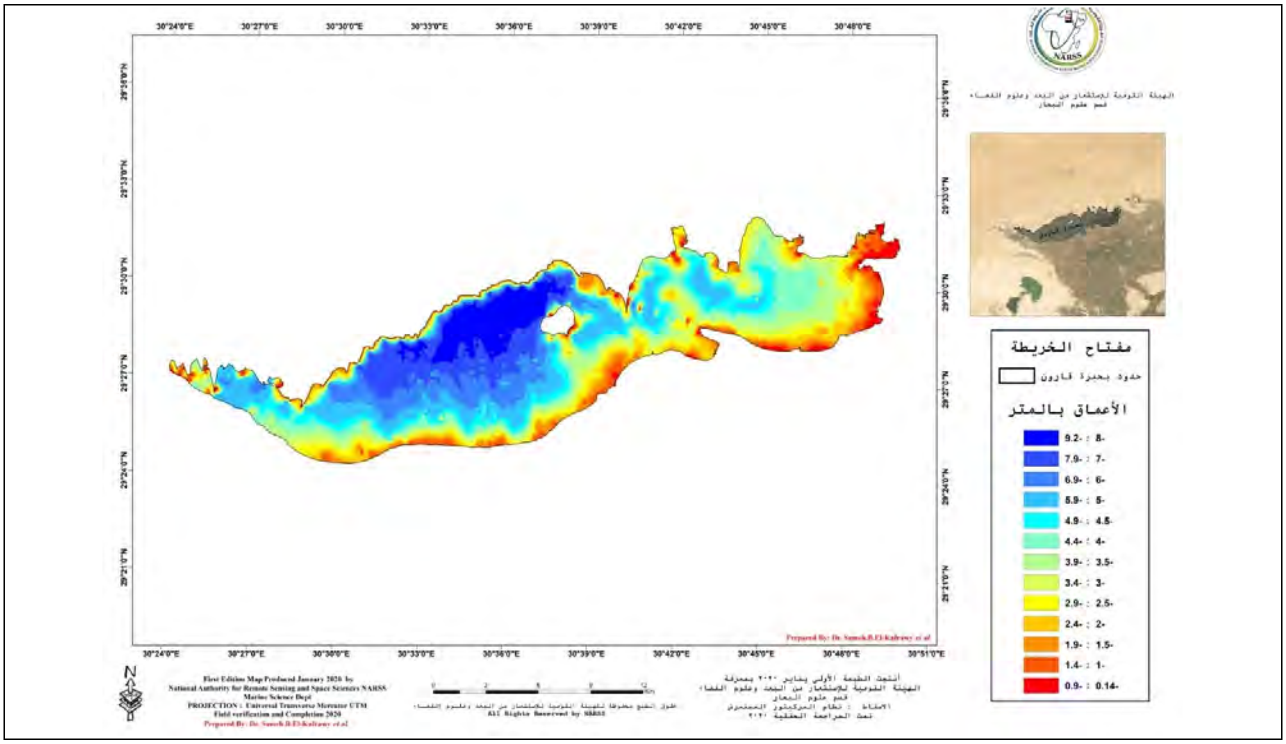
Map 7 Sketch shows flood plain areas at water level (-44)



Map 8 Flood plain areas at water level (-46)



Map 9 Flood plain areas at water level (-48)



Map 10 The depth of Lake Qaroun (2020), after [1]

<u>*Sediments*</u>

Sediments, as one of the water ecosystem components, act as a reservoir of heavy metals. Sediments reflect the environmental changes occurred in sedimentary basins and provide useful information about accumulation of heavy metals, reflecting the natural impacts. [6]

Water effluent to lake has different types of heavy metals mainly adsorbed on sediment particle. These heavy metals cause the deterioration of ecosystem. Sediments are important sinks for various pollutants like pesticides and heavy metals and also play a significant role in the remobilization of contaminants in aquatic systems under favorable conditions and in interactions between water and sediment. Oftentimes, mixtures of metals pollutants are present in the impacted sediments, which may result in severe contamination leading to destroying the entire aquatic life [6].

The deposition of the suspended sediment creatures causes the death of the benthic organisms. As a result, the number of living creatures in the dredging area decreases sharply. Moreover, the suspended solids in areas of fish spawning greatly decrease the successful spawning rate. Furthermore, sinking sediments bury the gravels, crushed stones and other similar irregular object on the bottom of the lake, which destroys the natural shelter for young fishes thus lowering their survival rates. While many heavy metals are nutrients at trace levels, Pb, Cd and Hg are non-essential and recognized as important industrial hazards, causing severe toxic effects in higher animals upon acute or chronic exposure. These three elements are highly persistent and in the bivalent form stable inorganic and organic complexes in biological systems [6].

Heavy Metals

Calculation of heavy metals revealed that the amounts of different heavy metals in tons for the eastern part of Lake Qaroun are (373350 Na, 87060 K, 518510 Ca, 131730 Mg, 295550 Fe, 4668290 Mn, 1709150 Zn, 170160 Cr, 14020 Cd, 757790 Ni, 33590 AS, 1322320 Cr, 400520 Cu, 172270 Pb, 468240 Zn, 39350 Sn, 77930 Mo, 1173310 V, and 211080 Co). The amounts of different heavy metals in tons for the middle part of Lake Qaroun are (475790 Na, 109550 K, 1072810 Ca, 236450 Mg, 222680 Fe, 4403780 Mn, 1599570 Zn,191720 Cr, 19010 Cd, 773660 Ni, 45500 AS, 1572410 Cr, 494480 Cu, 194620 Pb, 1046140 Zn, 46040 Sn, 67910 Mo, 3214890 V, and 4020 Co). The amounts of different heavy metals in tons for the western part of Lake Qaroun are (464390 Na, 120230 K, 704550 Ca, 184960 Mg, 171750 Fe, 2746900 Mn, 918330 Zn,167770 Cr, 12300 Cd, 482750 Ni, 31080 AS, 1679410 Cr, 531940 Cu, 152230 Pb, 686860 Zn, 34260 Sn, 99610 Mo, 1765000 V, and 155650 Co) [6].

Salinity

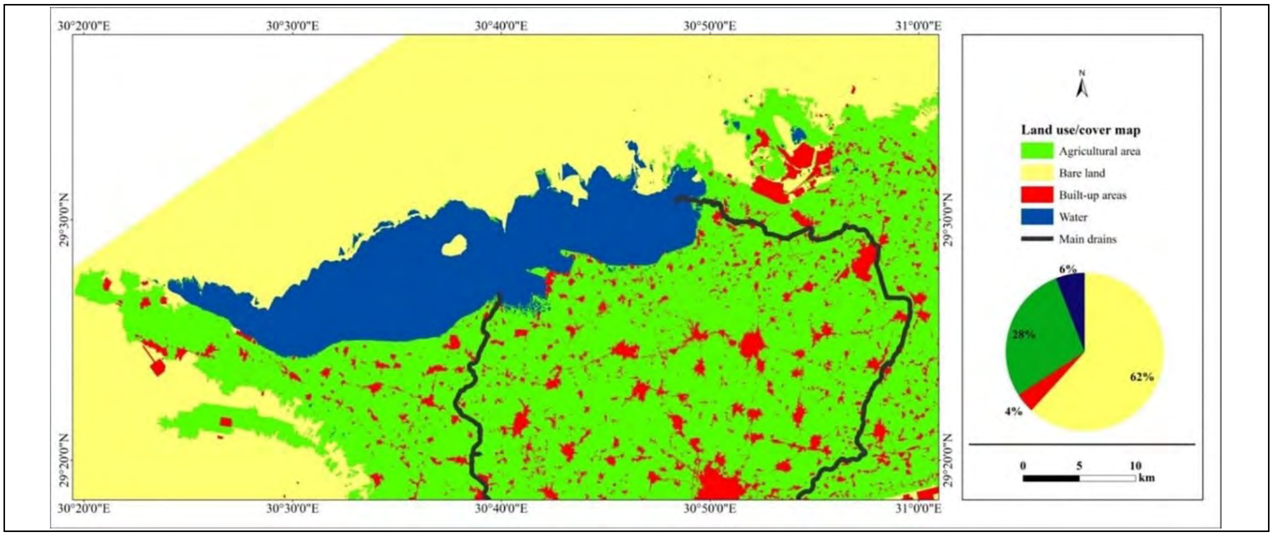
When it was first discovered in the 1890s, Lake Qaroun had a salinity of only 3.5 g/liter. By 1950, it had increased to 26 g/liter. In 1930s investigations noted that the Lake was changing from a fresh water to a saline water lake. Increased cultivation and irrigation have exacerbated the problem, and it has been anticipated that the lake will eventually turn dead [6].

El-Bats drain had the lowest levels of EC and associated salts in water, while their concentrations at their highest west of it. While the EC of water ranged from 10.30 to 54.10 mS/cm, with a mean value of 48.83, that of chloride and sulphate ions ranged from 3103 to 25763 mg/l and 2605 to 1864 mg/l, with mean values of 22344.67 mg/l and 15432.67 mg/l, respectively [1].

Land Use

Fayoum is bounded on the north by the western desert, according to a LULC map (61.77 percent, 3579.33 km^2). Except for the northern section, which has 1633.86 km^2 of agricultural land, the entire region is covered by agriculture (28.20 percent). The urbanized areas covered 235.94 km^2 (4.07%) of the total land area and were interconnected by a robust road network (Map 11) [1].

The average size of Qaroun Lake, according to the LULC map, is 240 km2. The two drains, El-Bats and El-Wadi, provide approximately 30% of the lake's drainage water. In the southern regions of the lake, a total of 12 secondary drains discharge into the lake. El-Bats drain is 50.9 kilometres long, and El-Wadi is 48.5 kilometers long. The annual drainage water volume is estimated to be over 700 million m^3 [1].



Map 11 Land use map around Qaroun Lake. [1]

CHAPTER 3

3. ECOLOGICAL RESTORATION OF LAKE QAROUN

3.1 RATIONALE

3.1.1 Definition

Ecological restoration: 'the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed' (SER, 2004). The term 'ecological restoration' can generally be taken as synonymous with 'ecosystem restoration' [28].

3.1.2 Concept

Restoration in and around Lake Qaroun protected area contributes to many societal goals and objectives associated with biodiversity conservation and human well-being.

Implementing restoration projects may assist in recovery of the lake, strengthening of landscape-scale ecosystem function or connectivity, improvement of visitor experience opportunities, and re-establishment or enhancement of various ecosystem services.

Because of its ability to increase resilience to climate change and provide ecosystem services, restoration can assist to climate change adaptation efforts. Carbon captured in ecosystems may help mitigate climate change, if the right restoration programs are done. Restoration is made more difficult by rapid climate change and other global developments, which underscores the necessity for adaptive management.

Restoration projects may need to work with stakeholders and partners inside and outside protected area boundaries to ensure successful restoration.

As a result of the world's most pressing conservation challenges in the 21st century, protected areas have shown to be an effective solution. Many factors contribute to the loss of species and ecosystem services such as habitat loss and degradation, resource overexploitation, climate change, invasive species, and pollution [28].

More emphasis is being paid to the restoration of terrestrial, marine, and freshwater ecosystems in order to reestablish ecosystem functioning and ecosystem services. As a management method, ecological restoration has the potential to help achieve broad societal goals, such as preserving a healthy planet and giving vital benefits to humans. If successful, it could help to repair the ecological harm that has been done, revive economic opportunities, revitalize cultural traditions, and improve ecological and social resilience to environmental change.

When an ecosystem undergoes a deliberate intervention, it begins to recover in terms of structure (species composition), soil and water property values (nutrient cycling, energy flow), as well as exchanges with surrounding landscapes and seascapes (e.g., productivity, energy flow, and nutrient cycling) through restoration actions.

Ecological restoration will frequently incorporate or build on attempts to 'remediate' or 'rehabilitate' ecosystems (e.g., eliminate chemical contaminants) (e.g., recover functions and services). Ecological restoration, on the other hand, has a larger goal than any of these activities since it adopts an 'ecosystem approach' to management and can have several goals that include the simultaneous recovery of the system's ecological, cultural, and socio-economic assets (Figure 2) [28].

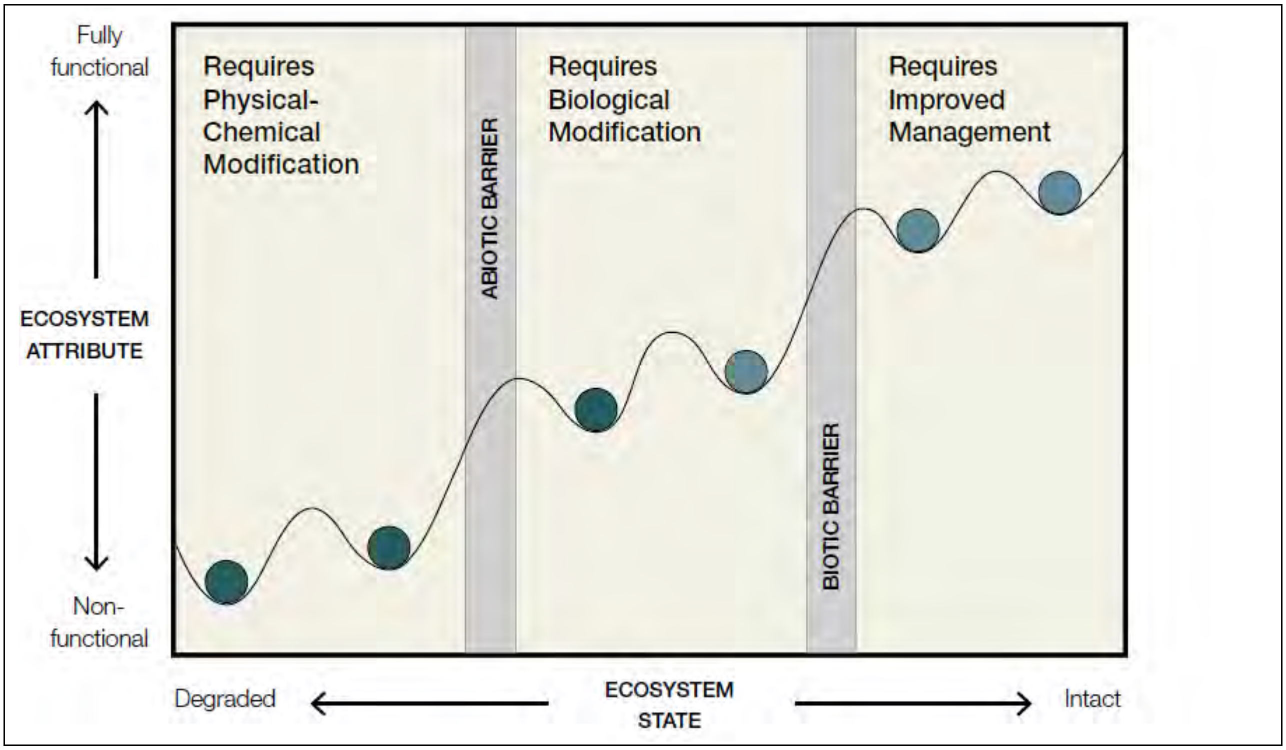


Figure 2 Simplified conceptual model for ecosystem degradation and restoration [after 28]

The method of restoration, as well as its timeframe, expenses, and possibilities of success, are determined by the threat to be addressed, as well as the surrounding biological and social conditions and the extent of degradation.

It is a science, which takes both knowledge and practice to restore the ecosystem to its natural state. In addition to integrating natural, physical and social science, it also incorporates traditional ecological knowledge (TEK) and lessons learned through practical experience to influence the design, implementation, monitoring, and communication of restoration. Nature and culture must be integrated in a collaborative endeavor that encompasses all segments of society, especially indigenous, local, and poor populations.

Indigenous peoples and local communities as well as various forms of shared governance are all examples of governance types that are utilized to make decisions about management. This makes them a vital part of the overall restoration process for any protected area, no matter what its institutional or social environment may be.

3.1.4 Principles

The basic principles involved in restoration process may include the followings: [28]

1. Effective ecological restoration that re-establishes and maintains the values of a specific area of interest.
2. Efficient ecological restoration that maximizes beneficial outcomes while minimizing costs in time, resources and effort.
3. Engaging ecological restoration that collaborates with partners and stakeholders, promotes participation and enhances visitor experience.

3.1.5 Best Practice

Restoration projects may apply specific best practices during the planning and design phases such as:

- Identify major factors causing degradation.
- Set clear restoration objectives.
- Ensure a participatory process involving all relevant stakeholders and partners in planning and implementation, facilitating participation and shared learning, contributing to acquisition of transferable knowledge, improving visitor experiences, and celebrating successes.
- Recognize that some objectives or motivations for restoration may conflict and work collaboratively to prioritize among them.
- Ensure that the time frame for the objectives is clear.
- Assess the possible impacts of climate change and other large-scale changes on the feasibility and durability of restoration and try to build resilience.
- Ensure that monitoring addresses the full range of restoration objectives and the intermediate stages needed to reach them.
- Use monitoring results and other feedback in adaptive management.
- Restore, where possible, ecosystem functioning along with physicochemical conditions and hydrology.
- Consider natural capital, ecosystem services, disaster risk reduction and climate change mitigation and adaptation.
- Identify potential negative impacts of the restoration program and take action to limit or mitigate them as much as possible.
- Identify and where possible control external factors such as pollution that may compromise restoration efforts

3.2. RESTORATION PROCESS

Figure 3 Restoration process phases

PHASE I

I.1. Problem Definition

Water Quality Deterioration (Closed System)

Lake Qaroun is one of the most important inland aquatic ecosystems in Egypt. The lake receives the agricultural drainage water from the surrounding cultivated land. The drainage water reaches the lake by two main drains, El-Bats drain (at the northeast corner), and El-Wadi drain (near mid-point of the southern shore) [6].

Multiple factors have an impact on Lake Qaroun's water supplies, both quantitatively and qualitatively. Pesticides and fertilizers, which are utilized in enormous quantities in agricultural fields in the region, are the most significant of these. Most of these compounds are found in agricultural wastewater, along with additional contaminants including heavy metals and anions that are released into the lake [20].

There are 450 MCM of untreated agricultural, industrial and domestic effluents flowing into the lake from Fayoum province every year. When compared to what it once was, the lake Qaroun is now roughly 44 meters below sea level. Fayoum's irrigation canals drain into the lake, making it vital to the region's agriculture and ecology.

According to recent studies, Lake Qaroun's water quality has deteriorated. Dissolved oxygen levels are low across the lake, and the water is generally alkaline, with a pH of 7.0 or below. Irrespective of the lake's western end, phosphorus and nitrogen levels are increasing. Pesticide residue levels and quantities increased, as did nitrate levels in the lake, which reached 46 mg/L. Zinc, copper, cadmium, lead and mercury were also found [20].

Water contamination is exacerbated by organic and microbial pollution resulting from the discharge of sewage water, resulting from some populated and untreated areas (where there is no sewage network currently) is discharged into the channels that eventually feed Lake Qaroun, but its percentage is still small. In addition to the majority of agricultural wastewater, domestic and agricultural solid waste is often also dumped in these canals.

In addition to the high organic and inorganic pollutant loads, the problem of runoff from irrigated fields has also led to a continuous increase in the salinity of the lake, creating a series of threats to the biodiversity and species populations of fish and birds, as well as threatening the socio-economic systems of the region.

Studies have shown the unique characteristic of the lake that it cannot be compared to any sea water or any natural alkaline spring, even if the total TDS appear to be identical. The lake water contains a high percentage of magnesium and sulfur, but it contains a lower percentage of chlorides and sodium ions. Thus, the lake water is exceptionally rich in sodium sulfate and magnesium salts, but slightly weak in sodium chloride.

Salinity Increase/Fresh Water Habitats Deterioration

Lake Qaroun has no outlet. Almost all the fresh water plants and animals die when a fresh water lake becomes increasingly salinized, but some adapt and survive until the salinity goes beyond their ability to adapt, at which point they too perish. A similar process occurs with nearby plants until eventually the entire region is lifeless. Hence, ecological destruction ensues, rendering the entire area uninhabitable for both nature and man. When it was first discovered in 1890, Lake Qaroun had a salinity of only 3.5 g/l. By the 1950s, it had risen to 26 g/l. In 1930s investigations noted that the Lake was changing from a fresh water lake to a saline one. Because of more extensive cultivation and irrigation, the situation has deteriorated, and if nothing is done, the lake would turn into a dead one, according to predictions [6].

Fisheries Deterioration

Qaroun Lake is one of the important sources for fish production in Egypt in general and Fayoum Governorate in particular. The fish production of Qaroun Lake was about 878 tons in 2016, and 832 tons in 2018, representing about 2.85% and 2.4% respectively of the total fish production from the inland lakes, and about 0.55% of the total Egyptian lakes fisheries [25, 26, 27].

The commercial total annual catch decreased from 4000 tons during 1920 to an average of 1- 2 thousand tons in subsequent years. Some marine fishes, such as *Mugil spp*., *Solea spp*., *Sparus aurata*, *Dicentrarchus labrax*, and shrimps, were brought and transferred to the lake to compensate for the decline in fish productivity. ***(Chelon saliens)***, *Solea spp*., and shrimps were successful in acclimating to the lake and reproducing. On the other hand, certain species, including as *Atherina spp*., were introduced accidently as fry mixed in with mullet fry [29].

Between 2002 and 2011, the average yearly total fish catch was over 3000 tons, with tilapias, mullets, soles, and shrimps accounting for the majority of the harvest. Catch per unit effort (CPUE) is 29.286 kg/boat/day, according to GAFRD fish statistics (2002-2011) [29].

I.2. Stakeholder Engagement

The restoration process would entirely count on stakeholder full collaboration and understanding. The Ministry of irrigation and water resources, Ministry of agriculture and land reclamation – General Authority for Fish Resources Development and Ministry of Environment – Egyptian Environmental Affairs Agency, Fayoum Governorate and Local Administration are the key players in the potential restoration program. The president of Egypt had appointed the Supreme Committee for The Development of Lake Qaroun likely headed by the Minister of Environment under the supervision of the President's Assistant for National projects. Fortunately, the committee will certainly offer the enabling environment and common grounds for such targeted restoration program to take place with appreciation of the key stakeholders. If the governance of the committee allows ease active participation of local community, the achievements will luckily reach its maximum benefits.

The Committee will represent the hosting platform that communicates and corresponds to the relevant involved stakeholders. The Minister of environment to share its implementation with the relevant parties will present the restoration program, where the study includes a comprehensive background review about the history of the lake problems and how it evolved through time.

PHASE II

II.1. Problem Assessment

Environmental Quality Condition of Lake Qaroun

In their study, A.M. El-Zeiny et al. in 2019, introduced the latest update for the condition of the Environmental quality of Lake Qaroun [1]. The study investigated quantitatively the quality of water as well as sediment quality. Tables 4 and 5 present statistics for the investigated water and sediment quality variables.

There are large fluctuations in most measured metrics due to variations in pollution sources' spatial distributions, as well as their intensity. Only a few factors, such phosphate and pH levels in water and sediment, exhibited significant fluctuation over time. Pollution sources and water flow direction have a substantial impact on water quality parameters. However, permanent sources of pollution have a substantial impact on sediment quality, resulting in the buildup of pollutants in the bottom sediments [1].

Table 4 Statistics of water parameters.

Water parameters	Min	Max	Mean
pH	7.80	8.80	8.43
Turbidity (NTU)	5.30	72.50	17.31
Conductivity (ms/cm)	10.30	54.10	48.83
Chloride (mg/L)	3103.00	25763.00	22344.67
Sulphate (mg/L)	2605.00	18064.00	15432.67
Ammonia (mg/L)	0.90	14.00	7.99
Nitrate (mg/L)	0.20	46.60	6.96
Phosphate (mg/L)	7.00	8.70	7.42
Cr (mg/L)	0.00	0.06	0.04
Pb (mg/L)	0.14	0.55	0.46
Cd (mg/L)	0.01	0.07	0.06
Ni (mg/L)	0.07	0.44	0.35
Organic Matter %	0.06	1.04	0.43

Table 5 Statistics of sediment parameters

Sediment parameters	Min	Max	Mean
pH	7.60	8.40	8.00
Conductivity	9.21	25.41	14.64
Cd (mg/kg)	0.49	2.95	1.61
Pb (mg/kg)	4.39	38.33	15.13
Cr (mg/kg)	1.07	52.11	16.01
Ni (mg/kg)	4.85	67.05	22.88
Organic Matter %	0.04	16.30	5.05

In Qaroun Lake, weak alkaline water and sediment samples were found, with pH ranging from 7.8 to 8.8 with a mean of 8.43 in water and 7.6 to 8.4 with a mean of 8 in sediment, respectively (Map 13). The pH distribution in water and sediments is essentially comparable, with both increasing from east to west; the most alkaline water and sediments were mostly found in the Lake's western portions. The EPA suggested that pH be classed in the range of 6.5–8.5 to protect aquatic life, which is exceeded in the water of Qaroun Lake in the western regions. The current average pH in water corresponds to the EEAA (2017) records (8.44). There is a substantial positive association between pH and these water parameters: EC (0.618), Cl (0.699), and SO_4 (0.679).

Both EC and related salts in water demonstrated a wide range of spatial variation, from the lowest levels in front of Bats drain to the greatest values in the west (Map 12). The EC of water ranged from 10.30 to 54.10 mS/cm, with a mean of 48.83 mS/cm, while the EC of chloride and sulphate ions were 3103 to 25763 mg/l and 2605 to 1864 mg/l, respectively, with mean values of 22344.67 mg/l and 15432.67 mg/l.

The turbidity of the water was likewise variable, ranging from 5.34 to 72.5 NTU with a mean of 17.31 NTU, with the highest values (40.2–72.5 NTU) in front of the El-Wadi drain (Map 13). The high levels of suspended particles in the El-Wadi drain, were a major factor in raising turbidity levels in Qaroun Lake, particularly in the center of the lake.

Wadi drain outflow had an impact on the levels of Organic Matter OM in water in the same location (i.e. the center of the lake), reporting high amounts of 0.659–1.04%. The amount of OM in water fluctuated moderately, ranging from 0.06 to 1.04 percent with a mean of 0.43 percent (Map 12). Because some organic matter in water contributed to higher turbidity levels, a positive connection between water turbidity and OM content (0.465) was discovered.

Bats drain gets a large volume of agricultural wastewater from the surrounding agricultural fields, which has a direct impact on nutrient levels in the water, such as nitrate and phosphate (Map 12). Phosphorus and nitrogen are the two nutrients that the lakes are most concerned about. The quantities of these nutrients in Qaroun Lake water fluctuated from 7 to 8.7 ppm for phosphate and from 0.2 to 46.6 ppm for nitrate, respectively. In Qaroun Lake, near the two mentioned drains, excessive amounts of nutrients, suspended particles, and organic load have been recorded.

Ammonia levels in water fluctuated a lot and were all over the place, ranging from 0.90 to 14 mg/l with a mean of 7.99 mg/l (Map 12). The majority of Qaroun Lake has high amounts of ammonia (>7.69 mg/l), which were found in various spots throughout the lake. Ammonia in high concentrations in water makes it difficult for aquatic species to remove toxicants, resulting in cancerous buildup in internal blood and tissues, and possibly death. The average measured value (7.99 mg/l) likewise exceeds the average value reported by the EEAA monitoring programs (2017) (1.4 mg/l). Ammonia levels in Qaroun Lake exceed the international permissible limits (0.05–2.2 mg/l). Furthermore, current nitrate, phosphate, Cr, Pb, Cd, and Ni in water averages are greater than the EEAA's 2017 values of 0.13, 0.075, 0.007, 0.022, 0.001 and 0.005 mg/l, respectively.

The regional distribution of four hazardous heavy metals in the water and sediment of Qaroun Lake was investigated (Map 12 & 13). Pb and Ni were the primary metals found in high concentrations in Qaroun Lake water. Pb concentrations ranged from 0.14 to 0.55 mg/l, with a mean of 0.46 mg/l, whereas Ni concentrations ranged from 0.07 to 0.44 mg/l, with a mean of 0.35 mg/l. Both metals have a similar spatial distribution because their levels rise from east to west and are closely tied to the Lake's salinity levels. Because of the low salinity of the water in this area, the lowest amounts of these metals were found in front of the El-Bats drains, east of the Lake. Cr and Cd levels in water were found to be comparatively low when compared to Pb and Ni levels. Cd levels varied from 0.01 to 0.07 mg/l, with an average of 0.06 mg/l, and Cr levels varied from 0 to 0.06 mg/l, with an average of 0.04 mg/l. Cr had a similar spatial distribution to Pb and Ni, however Cd metal had a distinct spatial distribution due to its high levels in the water in the middle of the Lake. These metals, are heavily influenced by water salinity, hence strong positive relationships were found between EC and all metals. Pb and Ni levels in Qaroun Lake water, on the other hand, surpass the EPA threshold requirements for aquatic life protection, as illustrated in Map 12 However, Cr and Cd levels are within EPA's approved limits.

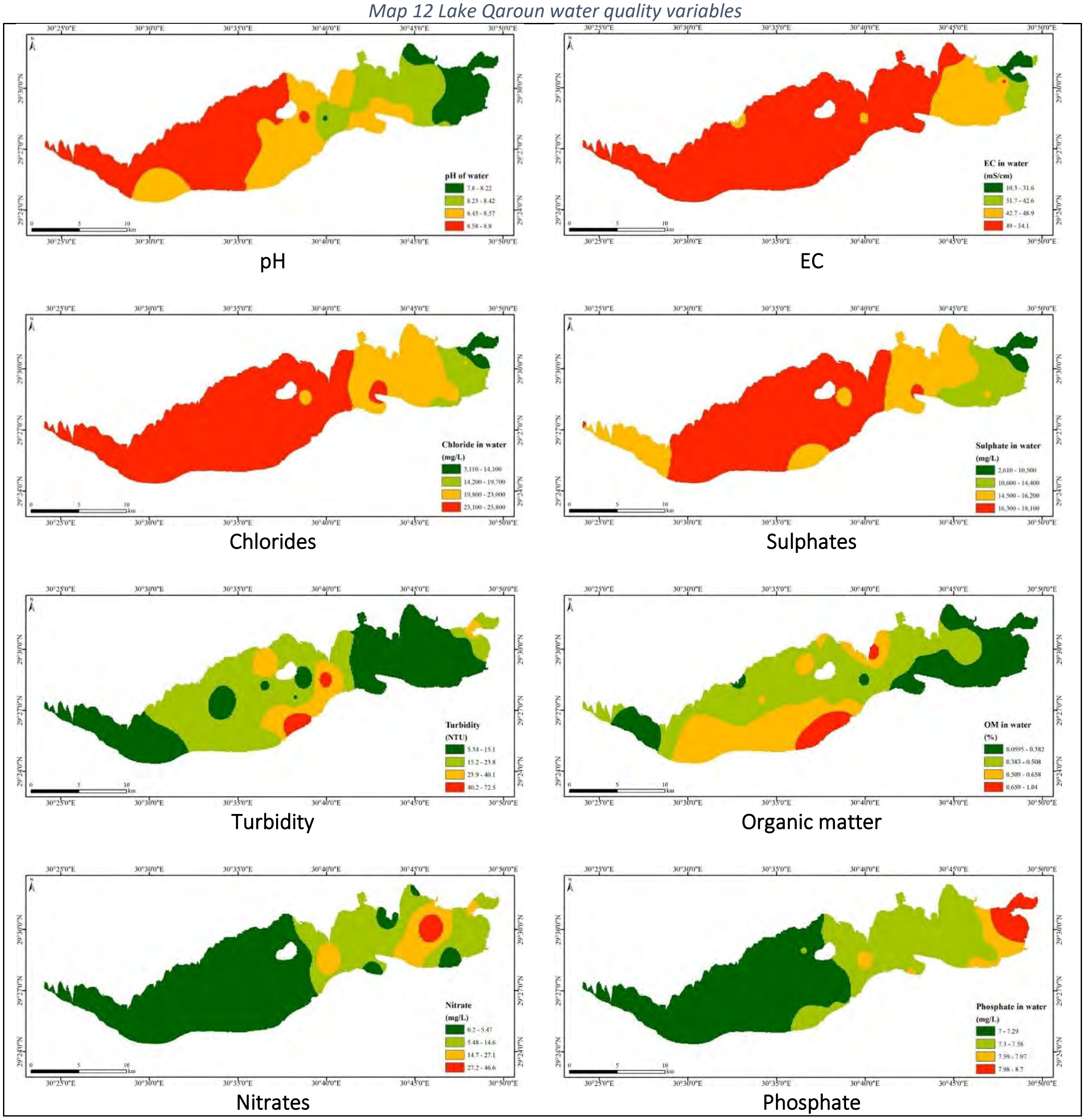
Unlike water salinity, salts in sediments build in front of the El-Bats and El-Wadi drains, where the highest levels of EC in sediments (19–25.4 mS/cm) may be found, as illustrated in Map 12.

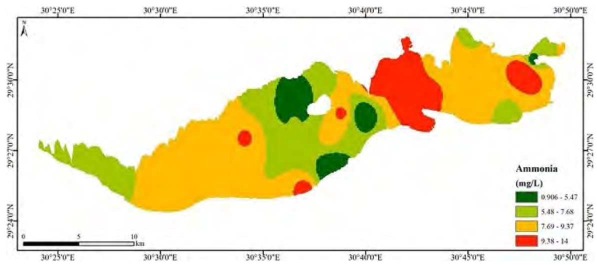
However, there is a large variation (0.04%–16.30%) and higher amounts of organic matter in the bottom sediments, particularly in front of the El-Wadi and El-Bats drains (Map 13). This shows that both drains have a significant organic load, notably from home and agricultural sources.

The regional distributions of the four hazardous metals were examined in the bottom sediments of Qaroun Lake. Except for the metal Cd, all of the metals tested had high amounts in the Lake's bottom sediments. Cd levels in Qaroun Lake's surficial sediments ranged from 0.49 to 2.95 mg/kg, with a mean of 1.61 mg/kg. Cr and Ni were the most abundant metals in the sediments, with concentrations ranging from 1.07 to 52.11 mg/kg with a mean of 16.13 mg/kg and 4.85 to 67.05 mg/kg with a mean of 22.88 mg/kg, respectively (Map 12).

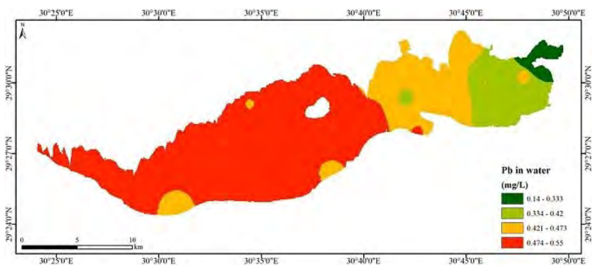
Pb levels varied dramatically from 4.39 to 38.33 mg/kg, with a mean of 15.13 mg/kg. Pb levels in Qaroun Lake sediments are very close to Cr levels. All harmful metals in the lake sediments appeared to have gathered in front of the Bats and Wadi drains, indicating high levels in the lake's eastern and center regions. The salinity of water has a substantial impact on the buildup of Cd and Pb metals in bottom sediments. As demonstrated in Table 6, positive relationships were found between EC and Cd (0.506) and Pb (0.708). The current averages of harmful heavy metals (Cd, Pb, Cr, and Ni) in sediments are much higher than EEAA's 2017 values (0.46, 7.83, 6.02, and 10.57 mg/kg, respectively).

Map 12 Lake Qaroun water quality variables

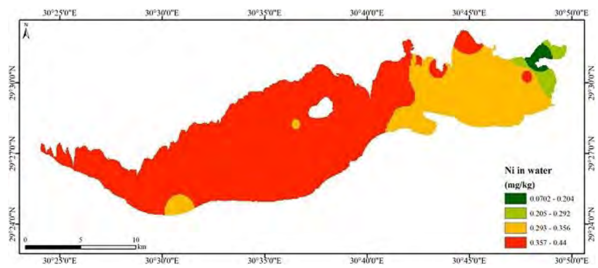




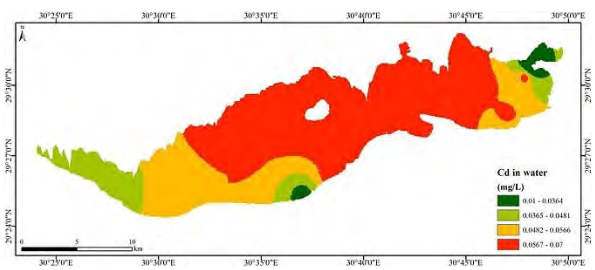
ammonia



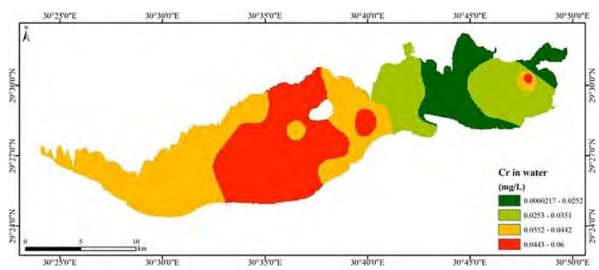
Lake water Pb



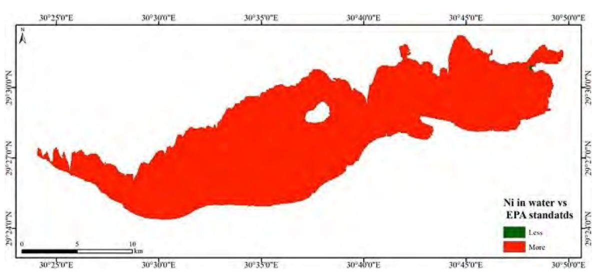
Lake water Ni



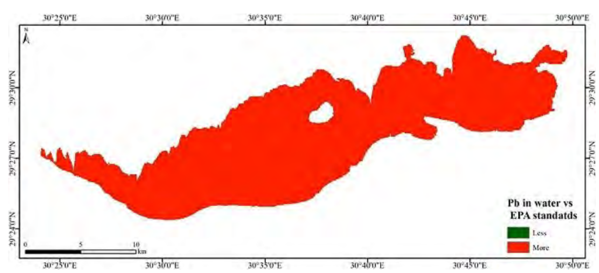
Lake water Cd



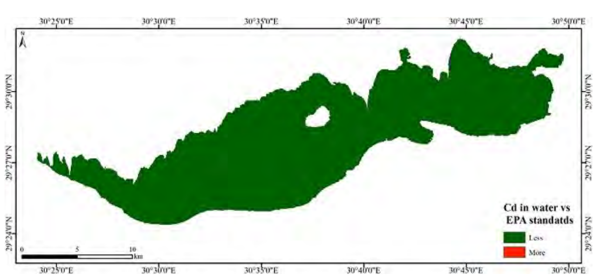
Lake water Cr



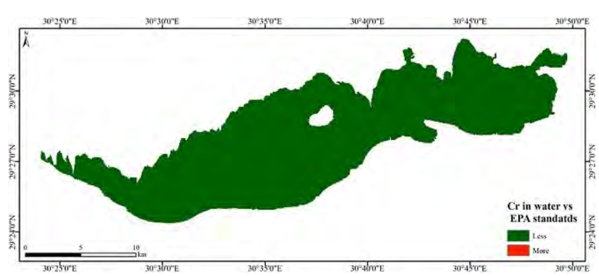
Lake water Ni (EPA standards)



Lake water Pb (EPA standards)



Lake water Cd (EPA standards)



Lake water Cr (EPA standards)

Map 13 Lake Qaroun Sediment variables

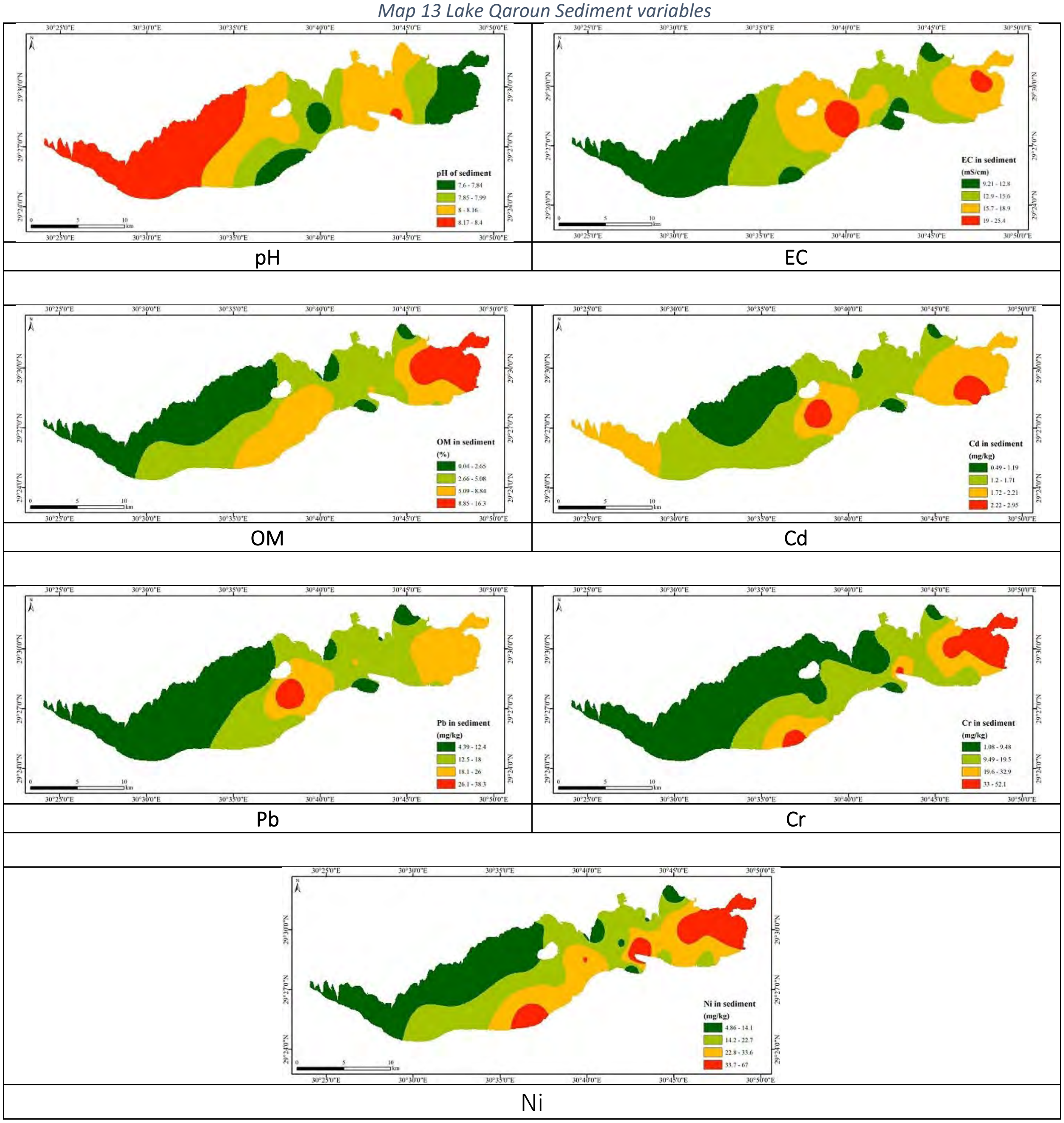
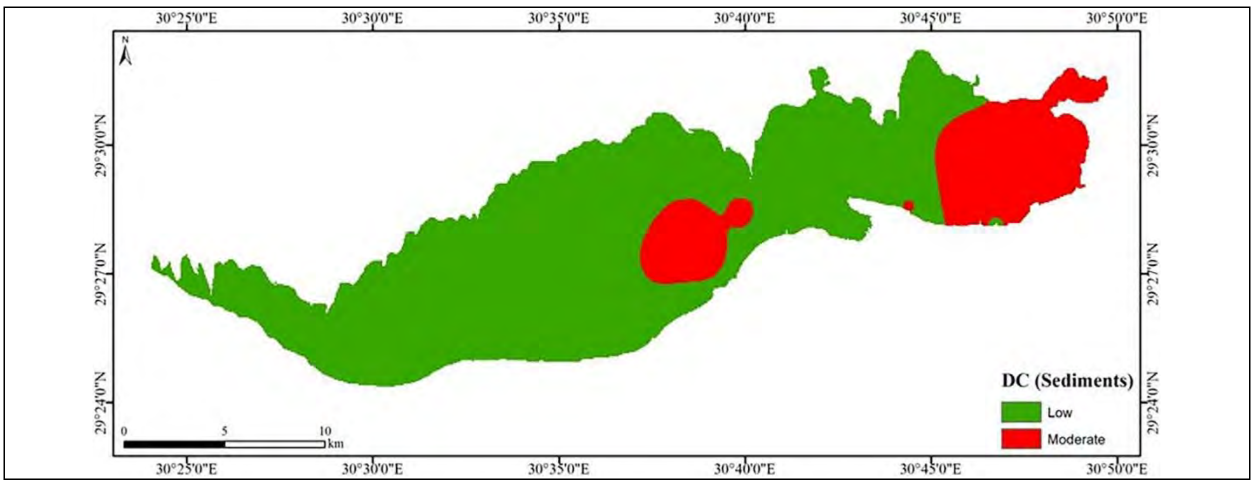


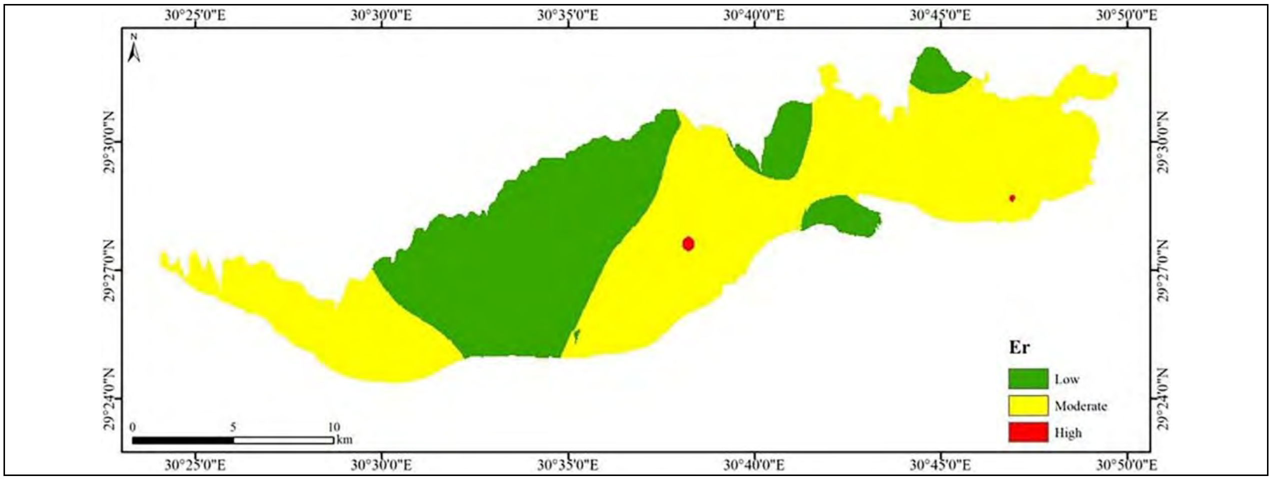
Table 6 Correlation matrix between sediment parameters (SQP).

SQP	pH	EC	Cd	Pb	Cr	Ni	OM
pH	1.000						
EC	−0.543	1.000					
Cd	−0.397	0.506	1.000				
Pb	−0.437	0.708	0.849	1.000			
Cr	−0.608	0.346	0.343	0.433	1.000		
Ni	−0.523	0.319	0.392	0.489	0.901	1.000	
OM	−0.695	0.594	0.591	0.669	0.859	0.764	1.000

To determine the overall extent of hazardous contamination of sediments the degree of contamination (DC) map for metals was created (Map 14). The DC depicted the sediment pollution as a whole exhibiting contamination levels that are modest and moderate. The front of Bats and Wadi drains, moderate quantities were discovered. This contamination has put the aquatic environment in jeopardy. The ecological risk map was used to assess the situation; Er (Map 15). The Er map revealed that the Lake's sediment contamination created three categories of risk: low, moderate, and high. The ecological danger has a minor impact on the bulk of the lake. The areas of moderate and high ecological risks were mostly near the drains. This assures that wastewater discharge from Bats and Wadi drains has a negative influence not just on the contamination of Qaroun Lake but also on aquatic life. Most of the analyzed contaminants are generated from the same source, according to quality maps, pollution indices, and statistical studies (Drains).



Map 14 DC in sediment of Qaroun Lake



Map 15 Ecological Risk Index in sediment of Qaroun Lake

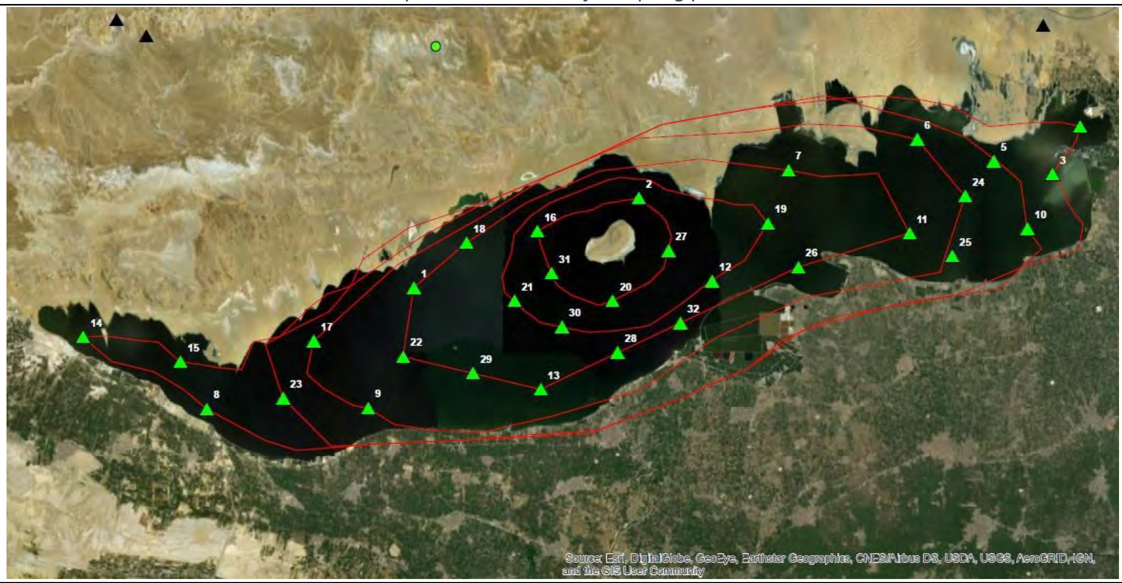
In 2019, the Nature Conservation Sector, of the Egyptian Environmental Affairs Agency (EEAA) had implemented a survey for Lake Qaroun salinity levels through a sampling program from 26-30 May. Sampling points were distributed to cover the entire lake from east to west and from north to south (Map 16). The electrical conductivity and concentration of total dissolved salts in each site were taken as follows:

- From the surface (depth zero) at a distance of 10-20 cm from the surface of the water;
- From depths 1, 2, 3, 4, 5, 6 and 7 m (the maximum depth reached in some locations)

A map was created for the distribution of salt concentrations in each of the previous levels up to 5 meters, and the rest of the depth measurements were excluded, as no representative number of sites in the depths was reached more than 5 meters.

The number of surface points (depth zero) was 48 points; depth 1m reached 44 points; depth 2m reached 39 points; depth 3m reached 32 points; depth 4m reached 19 points; depth 5m reached 9 points.

Map 16 Distribution of sampling points



Depth zero

Analyses of surface water at (Level zero) showed a clear gradation from east to west, where the salinity was at its lowest levels at the entrance point of Al-Bats drain and reached about 33.000 (ppm) and gradually increased until reached about 36,000 (ppm) in the far west of the lake.

Depth 1m

This shows a slight change in the salt concentration between this depth and counterparts in the water surface (depth zero). The gradient was clear from east to west with almost the same concentration from about 33,000 (ppm) in the east to about 36,000 (ppm) in the far west of the lake.

Depth 2m

Salinity levels at depth of 2 meters showed the division of the lake into 4 regions, including 3 main regions. The first is the easternmost of the lake which vary from 33.700 to 34.400 (ppm). The second gave readings from 34.400 to 35.300 (ppm). The third ranged from 35.300 to 35.600 (ppm), which is not far from the concentration level in the second section, that the second and third sections can be considered as one section. The fourth section represents a very small segment in which the salinity ranged from 35.600 to 35.900 (ppm), which means a great convergence between the last three sections approximately.

Depth 3m

The measurements at depth of 3 meters showed the division of the lake into two large parts, the Far East (34.263 ppm) and the rest of the lake (35.265 ppm), which gives a general indication of the homogeneity of water quality in the lake if we exclude the eastern part of the estuary.

Depth 4m

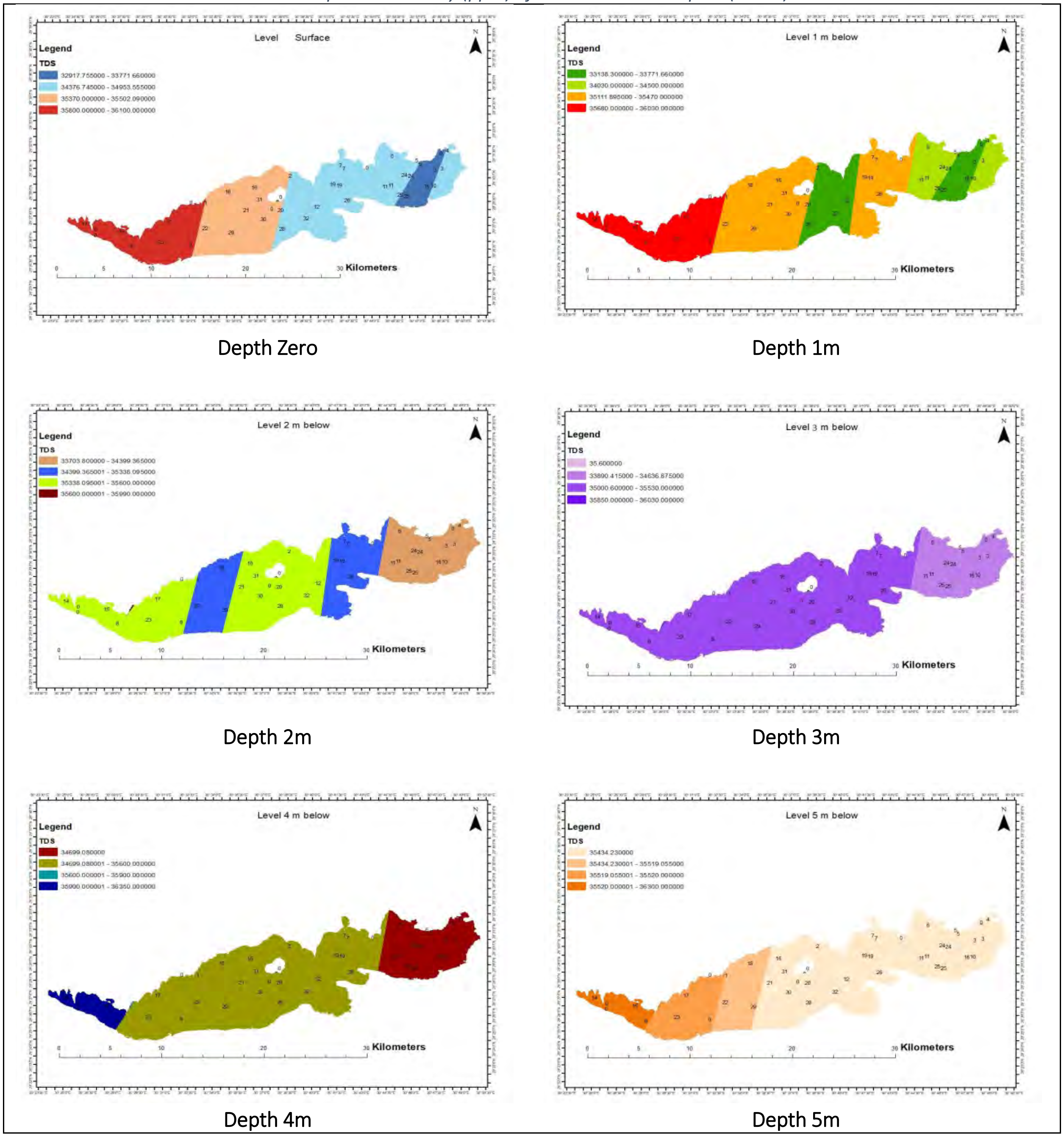
At this level, it appears that almost the entire lake falls under a concentration of 34.700 to 35.600 (ppm), while the eastern section ranged below the level of 34.700 (ppm) and the western section from 35.900 to 36.300 (ppm).

Depth 5m

This level showed another gradient, as the predominant part (east and far east of the middle of the lake) ranged from less than 35.400 (ppm), and the rest of the sections graded from east to West from 34.400 to 36.300 (ppm).

Map (17) shows the variation of salinity concentrations across lake Qaroun at depths 0, 1, 2, 3, 4 and 5 meters.

Map 17 the salinity (ppm) of Lake Qaroun at depths (0-5 m)



Depth Zero

Depth 1m

Depth 2m

Depth 3m

Depth 4m

Depth 5m

Fisheries

The commercial catch in Qaroun Lake dropped from around 4000 tons per year during the years 2010 to 2014 to be about less than 1000 tons in 2016 (GAFRD, 2017). Recently, Qaroun Lake undergo parasitic infection (Isopoda), on its fishery production, which has a bad impact on the lake production, fish quality and fishermen community (Fig. 4).

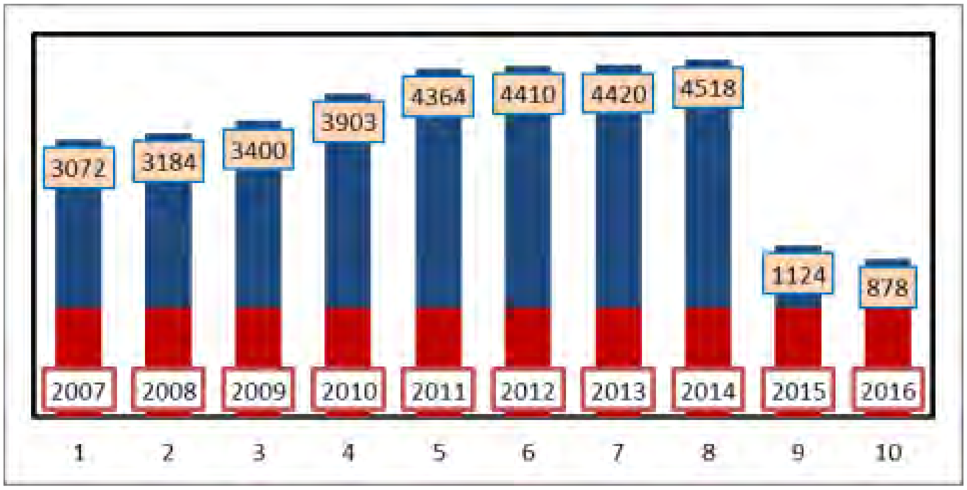


Figure 4 Development of Qaroun Lake fisheries (2007 – 2016) (GAFRD, 2017)

Poor fish productivity in Lake Qaroun is a direct outcome of unwise and unevaluated actions such as the introduction of certain species into the lake. Furthermore, in the last three years, invasive species such as isopods (*Nerocila orbigyni*) and jellyfish have had an impact on fish productivity and quality [29].

With the exception of *Tilapia spp*. and *Anguilla spp*., all freshwater species gradually disappeared from the lake due to their salinity tolerance. During the years 1970–1977, it was discovered that the primary reasons contributing to the collapse of fisheries in Lake Qaroun were dryness of the coastline area (area of spawning for most species) due to declining water levels. This loss was also caused by the introduction of some predatory marine fish species, as well as increased natural mortality owing to pollution and increased salinity in the water [29].

In the years 2010-2011, about 615 wooden non-motorized fishing boats were used in the lake, each boat has four fishermen working on it. The lake's fishing gear included: 1) Trammel nets, which came in four different types with different diameters and mesh sizes and were primarily used to catch *Mugil cephalus*, *Tilapia zillii*, *Solea spp*., and *Liza spp*., 2) Three varieties of seine nets for *M. cephalus*, anchovy, and shrimp, 3) Other ways of fishing (fishing aggregation system, traps, and hooks) mostly for *T. zillii* [29].

Interviews determined that each person caught about half a kilogram of mullet during the course of the two-night fishing trip. Fish production has declined due to pollution in the Lake, according to scientists. Isopod, a parasite that feeds on the fish's tongue, was also discovered. The parasite (locally known as the fish weevil) causes fish to lose a lot of weight and bites humans if they are touched, according to the researchers. Another jellyfish parasite was found in 2014, when the General Authority for Fish Resources Development (GAFRD) released a large number. Fishermen and their families no longer fish in any portion of the lake at this time. Fishing has become more popular in places like Aswan (Lake Nasser), Hurghada, Suez and Marsa Alam.

II.2. VALUES

In 2007, the Nature Conservation Sector (NCS) of the Egyptian Environmental Affairs Agency (EEAA), Ministry of Environment had performed an evaluation of management effectiveness on the site level for Qaroun Protected area including the lake and its surroundings. In 2021, the NCS had constructed a management plan for Qaroun Lake protected area for the period from 2021 up to 2026. Both documents had identified the values of the site under 3 categories as follows:

Category 1. Biodiversity/Natural /Cultural values:

Attributes:

- Jebel Qatrani Cultural/Natural (Qasr El-Sagha, Demaie, Ancient quarries, Basalt road/Fossils)
- North shore of Lake Qaroun
- Golden Horn Island

Category 2. Ecotourism/Recreational values:

Attributes:

- North shore of Qaroun Lake
- South shore of Qaroun Lake

Category 3. Community Well-being (socio-economic) values:

Attributes:

- Local communities inside QPA are mainly fishermen.
- Local communities outside QPA are represented in the surrounding villages of the south coast

II.3. Threat Identification and Analysis

The total area of Fayoum governorate is 6,068 km^2 and inhabited by around 3.784.666 million people (2020). The agricultural areas reached around 603.676 acres. It is famous for the cultivation of fruits such as grapes, figs and mangoes, as well as the traditional crops, the most famous of which are wheat, cotton, rice, sorghum, sugar beet, and blackcurrant the sunflower. (fayoum.gov.eg)

There are two industrial zones in Fayoum Governorate: Al-Fath Industrial City in Kom Oshim, with an area of 1102 acres (actual area 1.947.369 million m^2) and an extension of 2000 acres. Many projects have been established in Kom Oshim area including food industries - building materials - chemicals - metals - glass - Carton - plastic, in addition to the presence of other industries outside the industrial zone, such as Cotton spinning, fodder, pottery, sugar beet, kilim and carpet industries. The current number of producing factories is 205.

Lake Qaroun suffered from many problems that may be summarized in three main directions [2]:

Administrative:

- Conflicts among ministries and authorities (Agriculture, Irrigation, Tourism, Environment, Fayoum governorate).
- Water management issues (Water in-balance may lead to a variety of problems such as erosion, land subsidence, land encroachment, water logging…etc.).
- Overlapping of land and lake uses

Environmental

- The increased water salinity of the lake.
- Sources of Lake contamination (point and non-point sources).
- Diminish of biological life in the lake that led to declining of fish communities both in volume and variety
- Low public environmental awareness.

Economic and Urban

- Unemployment
- Health problems
- Overfishing
- Declining of fish community in the lake
- Irregular irrigation and drainage system
- Un-planned urbanization in the areas surrounding the lake
- Fishermen immigration with negative social impact on families leading to family separations and increase of deviant behaviors
- Cultural and environmental unawareness

According to IUCN 2011 threat classification scheme, the threats on Lake Qaroun area were as follows:

Residential & commercial development

- Housing & urban areas
- Commercial & industrial areas
- Tourism & recreation infrastructure (hotels, beach resorts and other related activities on the south coast)

Agriculture & aquaculture

- Annual & perennial non-timber crops (farms, crops and plantations)
- Livestock farming activities
- Aquaculture

Energy production & mining

- Oil & gas drilling (Oil wells)
- Mining & quarrying

Transportation & service corridors

- Roads & railroads (secondary ways)

Biological resources use

- Hunting & collecting terrestrial animals (hunting for Migratory birds)
- Fishing & harvesting aquatic resources (overfishing)

Human intrusions & disturbance

- Recreational activities (uncontrolled off-road vehicles, birdwatchers, temporary campsites)
- Work & other activities (research, exploration)

Pollution

- Household sewage & urban wastewater (discharge from municipal waste treatment plants, leaking septic systems, untreated sewage, outhouses, oil or sediment from roads, fertilizers and pesticides from agriculture)
- Industrial effluents (chemicals from factories, leakage from fuel tanks)
- Agricultural effluents (nutrient loading from fertilizer run-off, herbicide run-off, manure from feedlots, nutrients from aquaculture, soil erosion)
- Garbage & solid waste (municipal waste, litter from cars, waste that entangles wildlife, construction debris)

Geological Events

- Earthquakes (Jebel Qatrani earthquake 1992)

Climate Change

- Temperature extremes
- Flooding

Threat Analysis

The pre-indicated threats will be analyzed against Timing, Scope and Severity as follows:

Table 7 Threat Analysis

Threat	Timing (Ongoing)		Final Score	Timing (Future)		Final Score
	Scope	Severity		Scope	Severity	
Housing & urban areas	2	2	7			
Commercial & industrial areas	2	2	7			
Tourism & recreation infrastructure	3	2	8			
Annual & perennial non-timber crops	2	3	8			
Livestock farming	2	3	8			
Aquaculture	2	3	8			
Oil & gas drilling	1	0	4			
Mining & quarrying	1	1	5			
Roads	2	2				
Hunting & collecting terrestrial animals	1	1	5			
Fishing & harvesting aquatic resources	3	3	9			
Recreational activities (uncontrolled)	3	3	9			
Work & other activities	2	2	7			
Household sewage & urban waste water	3	3	9			
Industrial effluents	2	3	8			
Agricultural effluents	3	3	9			
Garbage & solid waste	2	2	7			
Earthquakes				1	1	3
Temperature extremes				2	2	5
flooding				3	2	6

Impact Coding

- High impact
- Medium impact
- Low impact
- Negligible / No impact

a) Ongoing threat (score = 3)

Scope		Severity:	Very rapid Score 3	Rapid Score 2	Slow Score 1	Fluctuating Score 1	Negligible/No Score 0
Whole	Score	3	9	8	7	7	6
Majority	Score	2	8	7	6	6	5
Minority	Score	1	7	6	5	5	4

b) Future threat (long term) (score = 1)

	Very rapid Score 3	Rapid Score 2	Slow Score 1	Fluctuating Score 1	Negligible/No Score 0
3	7	6	5	5	4
2	6	5	4	4	3
1	5	4	3	3	2

Figure 5 Threat Analysis key and options

Timing options	Scope options	Severity options
• Only in the past and unlikely to return • In the past but now suspended and likely to return • Ongoing • Only in the future • Unknown	• Affects the whole population (>90%) • Affects the majority of the population (50-90%) • Affects the minority of the population (<50%) • Unknown	• Causing or likely to cause very rapid declines (>30% over 10 years or three generations; whichever is the longer) • Causing or likely to cause rapid declines (20–30% over 10 years or three generations; whichever is the longer) • Causing or likely to cause relatively slow but significant declines (<20% over 10 years or three generations; whichever is the longer) • Causing or likely to cause fluctuations • Causing or likely to cause negligible declines • No declines • Unknown

SWOT analysis, Lake Qaroun Issues

Strength	Weakness
• Large water surface of Lake Qaroun. • Adequacy of Lake Qaroun to active fish production and tourism activities. • The presence of a branch of the National Institute for Oceanography and Fisheries (NIOF) and a branch of the General Authority for Fisheries Development, which include many scientific and research expertise in addition to officials and practitioners. • The abundance of licensed fishing boats and trained labor in the neighboring villages of the lake. • Existence of a complex of factories to extract salt from the lake.	• The high concentration of salts in the lake water • Water contamination quantitatively and qualitatively and the spread of parasites and predators in the lake • Decrease in fish production from the lake • Inadequate / inappropriate transportation / acclimatization of proper fish fry • The use of primitive methods of fishing and overfishing behavior. • Migration of trained fishing labor to work in urban areas
Opportunities	**Threats**
• The availability of agricultural wastewater, loaded with organic matter and nutrients. • Government interest in production development of fisheries in the lake. • The ability and good governance to deal with the needed financing to purchase, transfer and acclimatize fish fry through enhancing the role of NIOF in Fayoum. • Innovative solutions to enlarge the evaporation surface of the lake to receive more fresh agricultural water less loaded with untreated domestic/industrial effluents. • Lake Qaroun and its north cost is among the network of national protected areas system and a RAMSAR site as well as IBA. • Enhancing the public awareness for environment and health problems.	• The shortage of necessary funding to Purchase, transfer and acclimatize fries. • The damage caused by the decreased amounts of agricultural drainage incoming to the lake due to water mismanagement. • The domestic/industrial untreated waste effluents flushed into the agricultural drains. • Illegal land grapping for agriculture without regulated rate of irrigation water. • The shortcomings of the role of the key actors involved and the high costs of creating a supply market production and fish products. • Poor planning for urban and touristic developments around the Lake Qaroun. • Poor governance mechanisms implemented by the government.

Phase III

III.1. RESTORATION GOALS & OBJECTIVES

Since there are no clear and definite documents released from the Supreme Committee for Developing Lake Qaroun found available that outlinee the potential projects/outputs/ with any details, this document set out and define goals and objectives for the proposed restoration plan. Consultation with key stakeholders such as the irrigation department of Fayoum; Fayoum governorate, Fayoum fisheries department, on the level of local decision making, had produced the coming achievements as the most desirable from restoration:

- Water balance (Quantities)
- Water Quality Improvement
- Fish Stock improvement
- Enhancing the socio-economic status for Lake Qaroun inhabitants and Fayoum as a whole.

The goal is to invest money on projects with multiple benefits such as improved water quality and increased public use, while taking into account feasibility of restoration. Science based prioritization has been the most effective tool in targeting projects of value to the area, funding for restoration projects must achieve the following:

- Ensure a cost effective, positive return on investment for the community.
- Ensure local community commitment to lake restoration and protection.
- Ensure significant improvement in water quality and safety of Lake Qaroun.
- Provide for a sustainable, healthy, functioning lake system.
- Result in the removal of the lake from the impaired waters state lakes.

The construction of Restoration program objective in this document is subjected to the identified high - medium impact threats that had been analyzed in the previous phase. When formulating the desirable main achievements in a holistic approach, and in the framework of Egypt's National Water Resource Plan and Egypt Vision 2030, the next goals may be presented:

- To keep the natural integrity, characteristics and landscape of lake Qaroun through sustainable actions and policies.
- To improve the ecosystem functions and resilience against climate change.
- To enhance the socio-economic conditions for the surrounding inhabitants and improving their quality of life.
- To enhance the public environmental awareness for the local communities living around the Lake Qaroun.
- To restore the water balance of the lake and improve the environmental quality.
- To improve the fish stock of the lake, restoring the fish resources.

The main Objectives will be:

Technical

1. Improve water quality and restore the water and salt balance of the Lake, with keeping up the maximum safe water level (-43.30).
2. Improve and renovate fish stock in the Lake up to the maximum productivity reached in 2014 (4518 tons/year).
3. Restore/ repair the wetland habitat around the lake area through a proper intervention of reintroducing the suitable vegetation cover.

Administrative

1. Develop an administrative system of the lake to avoid the conflict between responsible authorities and contributing association. This administrative system will be the Supreme Committee for Developing Lake Qaroun, which is currently in place.
2. Establish a management system for the environment depends on linking research centers in the bodies involved in the management of the lake and one database containing all the information and help in decision support for designers and planners to develop plans and architectural designs.
3. Develop the local communities around the lake to participate in the development process
4. Develop a system to purify water drainage before it reaches the lake with the conversion of some of the paths of banks to stations far from the lake
5. Increase publicity and media awareness about the importance of environmental restoration.
6. Promote environmental industries that depend on the outcomes of the lake and surrounding villages.
7. Promote investment opportunities in the field of eco-tourism and the development of plans for the implementation of these projects.

Each of the main 3 technical objectives will have its own complete project that will be implemented to achieve and restore set of values, which all together will support the ecosystem to restore to big extent its functions and dynamics. In case of wise implementation of the proposed projects, the main outcomes of improving the quality of life and enhance the socio-economic status of the inhabitant community might be achievable.

Taking the advantage of moderate climate in Qaroun region, followed by benefiting from the advantage of the availability of agricultural wastewater carrying organic materials and phosphate residues, and reducing the damage caused by the contamination of water by industrial drainage and sewage, all must be considered as strategic objectives to develop Qaroun Lake.

Process and Criteria

The specific projects need to follow the guidelines and directives of the implementing department according to their specific laws, goals, process and criteria (e.g. Department of Irrigation and water resources; Fisheries; Environment).
The costs of lake restoration will include the future maintenance costs of improvements to the lake.
Delivery of domestic wastewater from the surrounding villages must be controlled parallel to lake restoration actions.
The related department will evaluate the joint action plans and prioritize the implementation of actions required based on the criteria required by the program.
The water quality benefits of the restoration efforts will be sustained for at least fifty years.

III.2. RESTORATION APPROACH

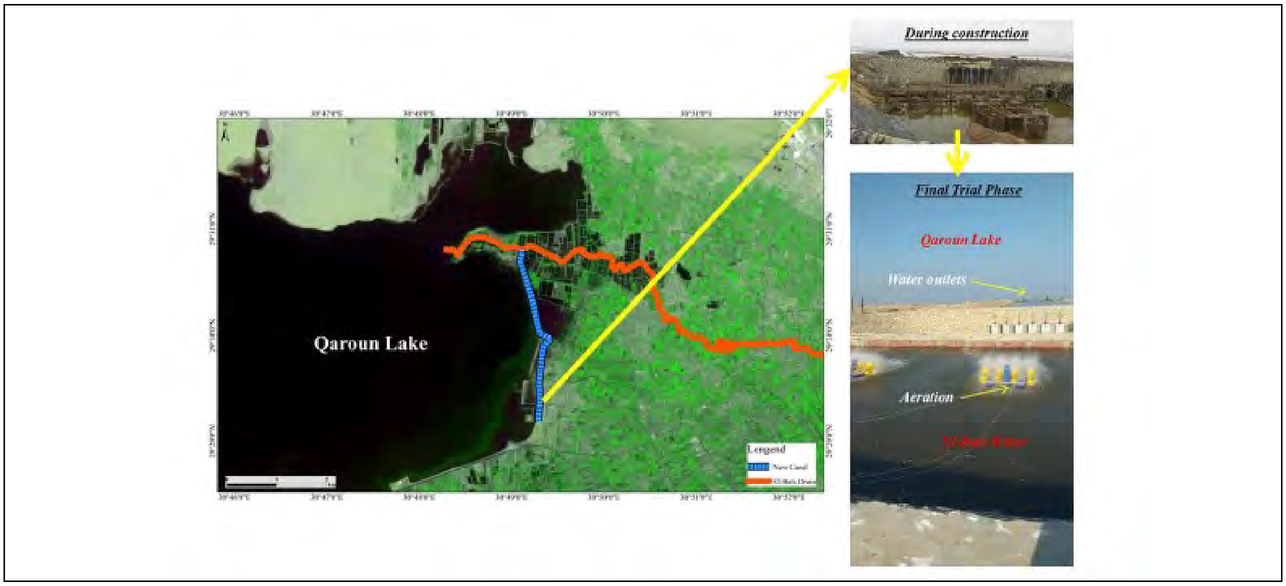
The restoration objectives in this document are mainly attainable through short to medium-term interventions. Sometimes, the intervention will be short-term, however, the achievable objective may be reached through half to a complete decade. The proposed restoration to repair the status of the Lake is closely connected to other actions that must be taken outside the Lake area, e.g. The establishing of domestic sanitation network and wastewater treatment plants for the surrounding villages that mostly have no such networks.

To Fix the Lake, Start on Land

The majority of lake restoration projects involve construction phases of the water sources or in-lake Implementation. Lake restoration starts in the surrounding areas and relies on strong local involvement and landowner participation. Successful lake restoration projects involve many partners; have strong local involvement and landowner participation.

In 2017, the government, the Ministry of Agriculture – General Authority for Fisheries Resources Development - started a mechanical treatment process at the end of Bats drain as an initial attempt seeking for the Lake recovery. The project entitled "The Safe Belt" and aimed to offer mechanical treatment for the huge influx from Bats drain through extending the pathway of the drain before entering the lake east and west of the estuary of the drain to the lake. This method involves directing some budget from Bats drain to a new transverse canal that is about 9 kilometers long on both sides, as indicated in Fig. 21. Theoretically, moving wastewater a greater distance allows suspended particles and solid wastes to settle and increases oxygen dissolution, allowing more biodegradable organic matter to oxidize. After that, the water is subjected to extra artificial aeration before passing through sand and gravel filters for further purification. This was done through digging around long channel extended east and west of Bats to receive the water from the drain in both directions then applying a sedimentation pond followed by mechanical coarse filtering with aeration before flushing into the Lake. Since the project was implemented without deep studies by the

GAFRD not by the Ministry of irrigation, several mistakes had occurred which led to ending the project. Some of the mistakes are a) the main course of the drain was not directed to the belt canal but it kept flushing into the lake, which led to a stagnant state of the water at the end of both channel ends; b) the digging works were not implemented properly from an engineering point of view in terms of calculated slopes, depth,….etc., hence no regular circulation is guaranteed; and c) sedimentation ponds were not designed appropriately in terms of area, frequency and other necessary inputs. All these factors led to a worst quality of water at the ends of the channel than that in the main course of Bats drain.



Map 18 Present mechanical treatment on Bats wastewater

However, the concept idea of the “Safe Belt Project” is good and necessary to dilute the load of water effluents flushed into the lake and decrease sediment load, the poor design and implementation plans make it non-feasible, and lost amount of money had spent.

In addition, through the presidential initiative in Egypt “Hayah Karima” (good life), most of the Egyptian villages will be supported for better life style and quality, through providing/enhancing the basic main infrastructure elements that are lost in those villages such as sanitation and drinking water projects and health programs. Priority is given to those lost the basic infrastructure such as most of Fayoum villages. The villages around Lake Qaroun in Sinnuris, Ibshaway and Youssef El-Seddik will receive around 9.6 Billion EGP for providing sanitation project services.

The ecological restoration projects proposed in this document will be basically supported by the implemented governmental plan for providing basic sanitation projects in the areas surrounding Lake Qaroun that will surely decrease the contamination sources discharged in the lake. The strategy of ecosystem restoration is based on real engagement of the key players in the area and strong and effective collaboration as a main concept of restoration.

Since the responses of ecosystems to restoration cannot be predicted with certainty, therefore restoration embraces the concepts of engagement and adaptive management.

The restoration program will include in-lake restoration actions, as well as wider water sources measures influencing, for example, domestic waste diffuse pollution to water. The restoration program demonstrates multi-task approach to many of the projects, with feasibility work included in the early stages of restoration work at individual sites.

III.3. RESTORATION CONCEPTUAL DESIGN

Objective 1. Action 1-1 DEAD LAKE ZONE

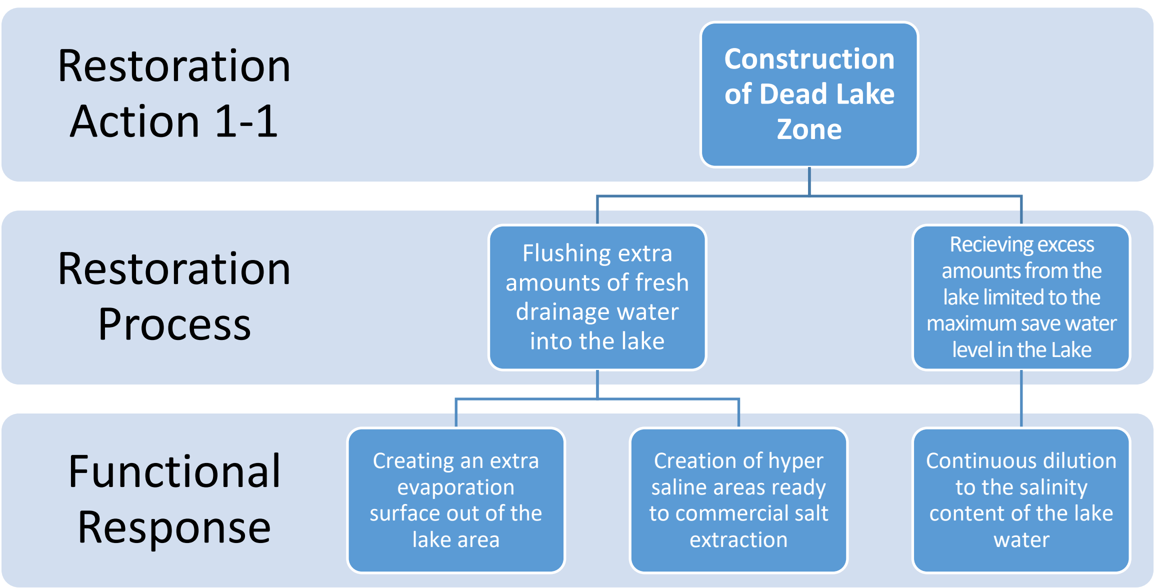


Figure 6 RESTORATION PLAN -DEAD LAKE ZONE

Action 1-2 SEDIMENTAION STRUCTURES AT THE ESTUARY ZONE (EARTH EMBANKMENT)

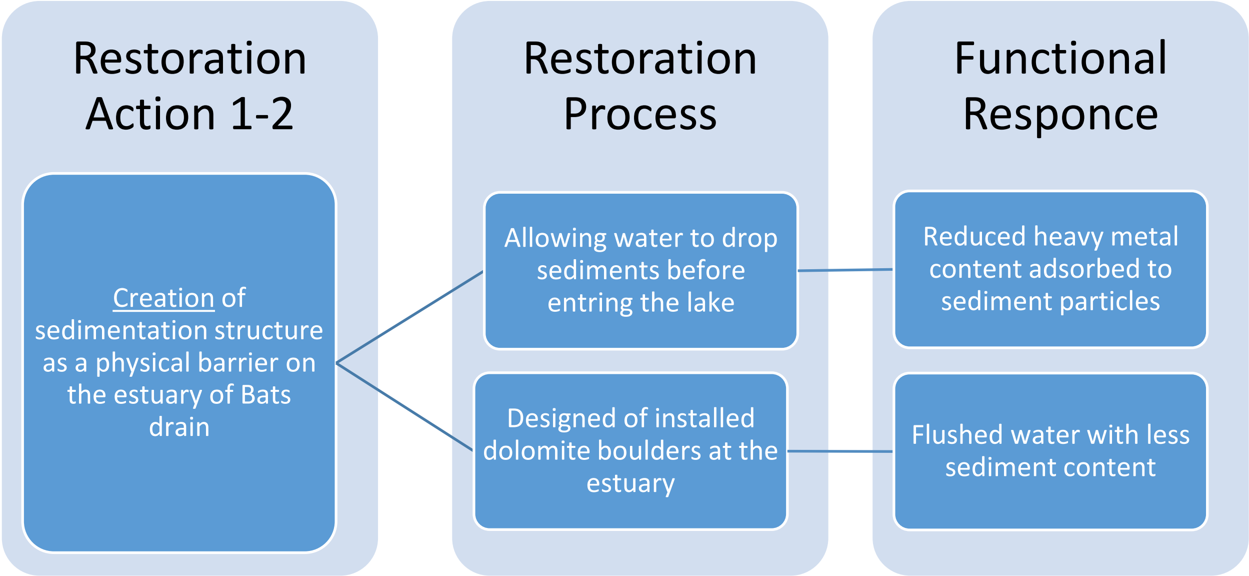


Figure 7 SEDIMENTAION STRUCTURES AT THE ESTUARY ZONE (EARTH EMBANKMENT)

Action 1-3 DREDGING

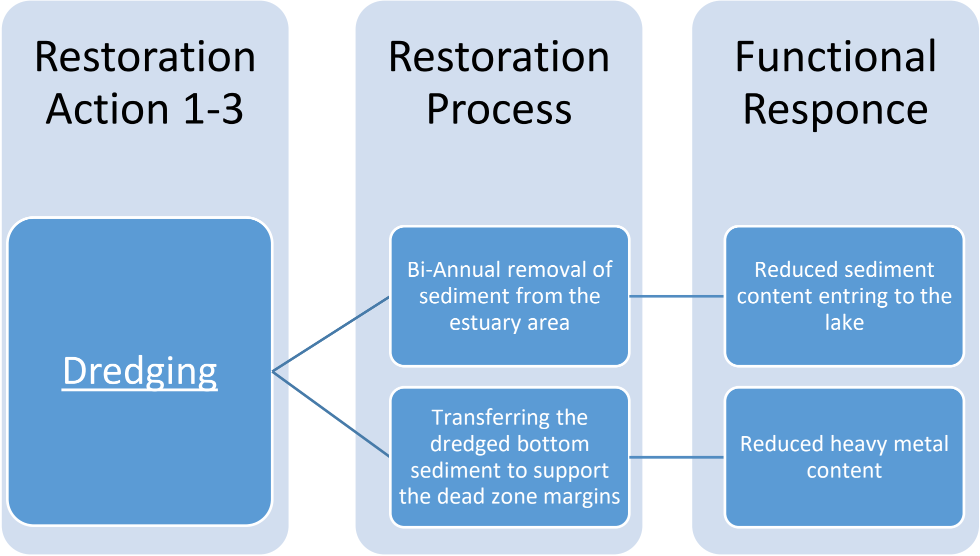


Figure 8 DREDGING PROCESS

Objective 2. Action 2-1 BOTTOM & SHORE LINE (RIPRAP) STRUCTURES

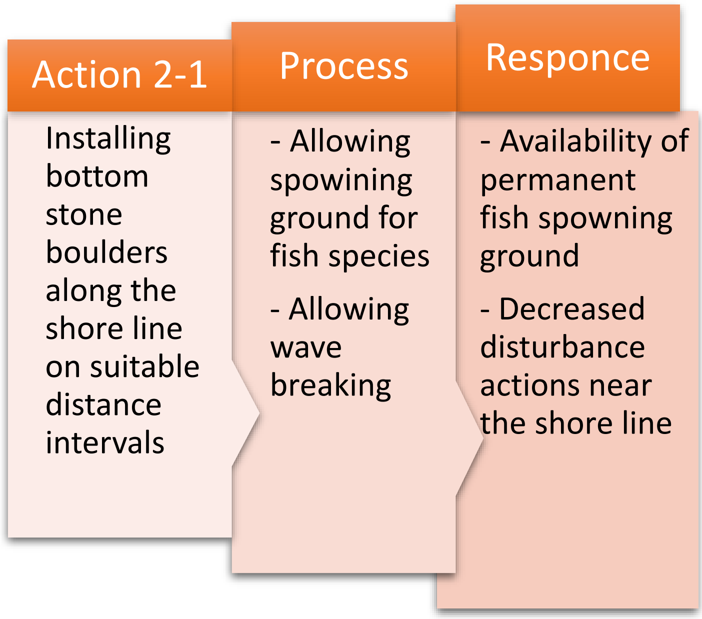


Figure 9 BOTTOM & SHORE LINE (RIPRAP) STRUCTURES

Action 2-2 FISH STOCKING

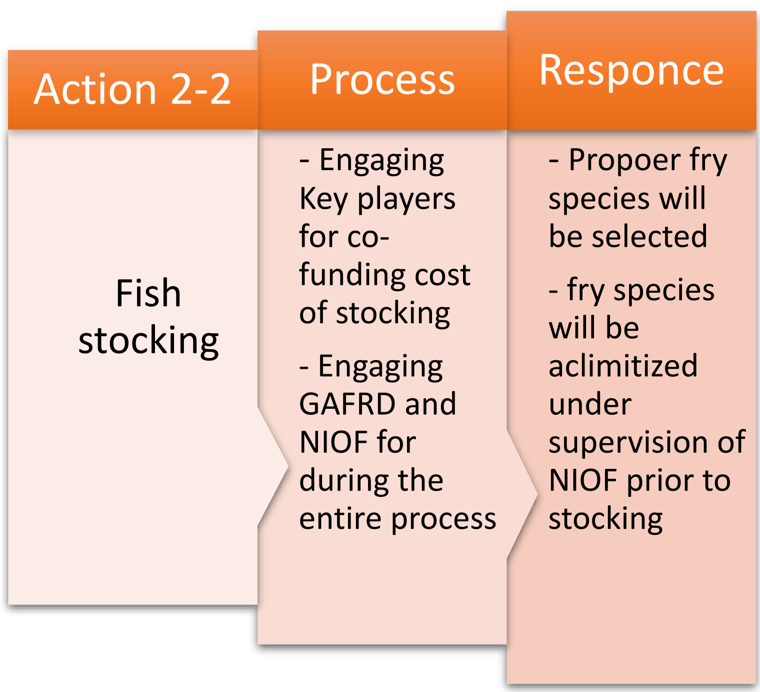


Figure 10 FISH STOCKING

Objective 3. Action 3-1 WETLAND REPAIR/RESTORATION

Action 3-1
- Transplanting mangrove species around the north cost of the lake

PROCESS
- Nuresy sites in the original community location in the Red Sea.
- Nursery locations for aclimatization of nseedlings in Lake Qaroun.
- Monitoring program for mangrove developments and for soil/water.

RESPONCE
- Green belt wetland habitat along the northern frings of Lake Qaroun
- Wild life commumnity in the north coast area enhanced

Figure 11 WETLAND REPAIR/RESTORATION

Action 3-2 ENVIRONMENTAL AWARENESS

Action 3-2
- Developing environmental awareness for ecosystem restoration programs for local community

PROCESS
- Campaigns targeting local communities surrounding the Lake area for the importance of ecosystem restoration.
- Awareness programs for students developed, assisted with necessary materials about ecosystem restoration.

RESPONCE
- The local communities and otehr key players appreciate and support the ecosystem restoration and its role boosting socio-economic development.

Figure 12 ENVIRONMENTAL AWARENESS

PHASE IV

IMPLEMENTATION OF RESTORATION ACTIONS

Actions for Objective 1.

Action 1-1 DEAD LAKE ZONE

Scope

The scope of the project is to:

- Establish water balance in Lake Qaroun that allows continuous flow of fresh drainage water parallel to keeping the lake water under the maximum safe level.
- Reduce salinity levels in the lake water.
- Support the decision-making process through improving the ability to maneuver in-out flow of the water into-out of the lake area with the water level under control, in case of future developments in Agriculture and/or aquaculture projects.

Water management challenges of Fayoum depression area:

- Water quantity
- Water level
- Water salinity
- Future developments

The concept and Idea

The idea of this project is totally extracted from a published paper [4] by El-Gamal, et. Al., 2017. The idea for this project is to establish new evaporation areas (Dead Zone) added to the surface area of the Lake, and detached from the body of the lake without any change of the physical nature of the Lake's body.

The lake's dead zone will be developed into an aesthetic and recreational space, with eco-tourism facilities like walking/ jogging pathway around the lake perimeter, a cycling track, an amphitheater for cultural performances, and pergolas and toilets.

Project location

The suitable area for the new evaporation areas is located in the northeast of the lake, which is approximately 36 square kilometers between the level (-42.00) and (-34.00), which is mostly flat except for some high places.

Details of restoration activity

When large amounts of fresh water (including low concentrations of salts) are discharged into a basin with limited natural drainage capacity, the imported salts will build in the soil, groundwater, and surface water.

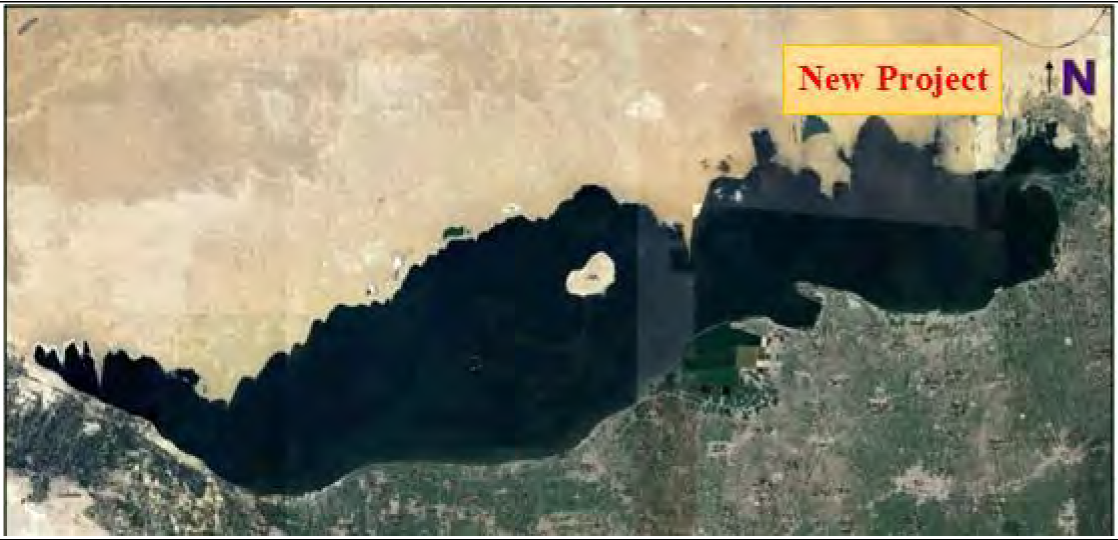
The saline drainage water in the Fayoum region is disposed of in Qaroun Lake and Wadi El-Rayan depression. The overall disposal volume was anticipated to be 650 MCM in 1996. Except for a low-lying area of 12,000 feddans near Lake Qaroun, which requires pumped drainage, Fayoum's drainage is gravity-based.

El-Gamal, et al., 2017 combined SOBEK Rural-1D combined with SOBEK-2D models that used for simulating drains as 1D and lake area as 2D. Rural-1D SOBEK Flow is a one-dimensional model that can be used to mimic the flow and quality of water in canals, rivers, and estuaries. SOBEK-2D (Overland flow) is a two-dimensional modelling system that aids hydrologists in their flood research by simulating flood progress, water depths, velocities, and directions inside the flood zone. The flow module can simulate erratic flow in drains, while the overland module can simulate the water surface and depth in lakes. SOBEK is based on high-performance processing technology, allowing it to handle a wide range of water networks, from simple to sophisticated.

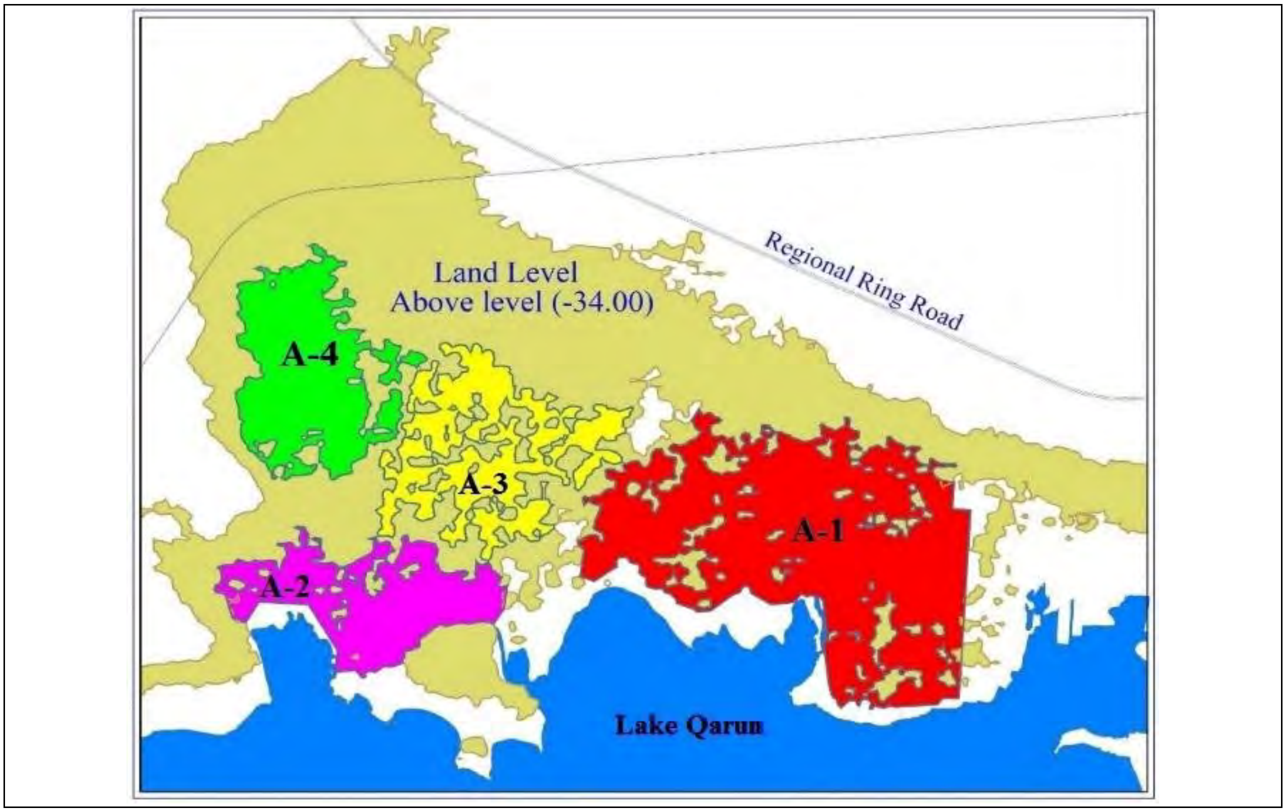
The combined 1D 2D model has been built in order to:

- determine the water level of the Qaroun lake under different scenarios;
- determine the volume of the lakes at different elevations and
- determine the salinity of Qaroun Lake.

The proposed location will be separated into four different basins based on land levels and at the lowest possible cost. Some ponds require the construction of a number of earth banks to separate the basins from Lake Qaroun's ridge (Map 19 & 20).



Map 19 Aerial map for Qaroun Lake and surrounds



Map 20 New proposed evaporation ponds

The acreage, levels, and amount of evaporation of each basin's new ponds were calculated and summarized in Table. 8.

	Min. Level	Max. Level	Area	Earth Bank		
	(m)	(m)	(Km²)	Level -m	Length-km	Height-m
A-1	-44.00	-36.00	12.67	-40.00	7.50	4.30
	-44.00	-38.00	8.43	-40.00	7.50	2.30
A-2	-44.00	-36.00	4.03	-40.00	3.33	4.30
	-44.00	-38.00	2.66	-40.00	3.33	2.30
A-3	-38.00	-34.00	4.50	-	-	-
A-4	-48.00	-32.00	6.02	-34.00	0.56	2.3
	-48.00	-34.00	4.88	-	-	-

Table 8 Areas and levels of the proposed evaporation ponds

The sum of the evaporation area calculated as follows:
The Maximum evaporation area with earth bank of 2.30 m = 27.24 km^2
The Minimum evaporation area with earth bank of 4.3 m = 20.48 km^2.

Scenarios of water and salt balance of the Lake Qaroun:

Scenario	Balance type	Status Description	Reference Cases
1	Water Balance	Simulating the current state of Qaroun Lake by SOBEK program, using drainage water inflow to the lake, the amount of water withdrawn EMISAL, and the evaporation rate, to Calculate the annual variation of the lake's level.	
	Salt Balance	Applying the salt balance equation between the amount of salt entering with the agricultural drainage water and the amount of salts extracted by the EMISAL, to estimate the change in lake's salinity.	
2	Water Balance	Simulate water balance as scenario-1, after adding the minimum area of the new evaporation ponds.	
	Salt Balance	Calculate salinity rate after adding the minimum area of the new evaporation ponds.	
3	Water Balance	Same as scenario-2, with the maximum area of the new evaporation ponds.	
	Salt Balance	Calculate salinity rate after adding the maximum area of the new evaporation ponds.	
4	Salt Balance	Calculation of salinity in the case of the minimum area of the new evaporation ponds with the additional quantity of agricultural drainage water to stabilize the water volume of the lake	
5	Salt Balance	Same as Scenario-4 with the case of maximum area of the new evaporation ponds and the addition of a quantity of agricultural drainage water to stabilize the water volume of the lake.	

Table 9 Scenarios of water and salt balance

Water Balance

On SOBEK, a simulation was done to determine the variability of water levels in Qaroun Lake in the following scenarios (Figure 13):

Scenario-2: Study the balance between the current discharges entering Qaroun Lake, the amount of water withdrawn to EMISAL, evaporation rate, and the quantity of water withdrawn to the new evaporation ponds with minimum area.

Scenario-3: Same as scenario-2 with the amount of water withdrawn for the evaporation ponds with the maximum capacity.

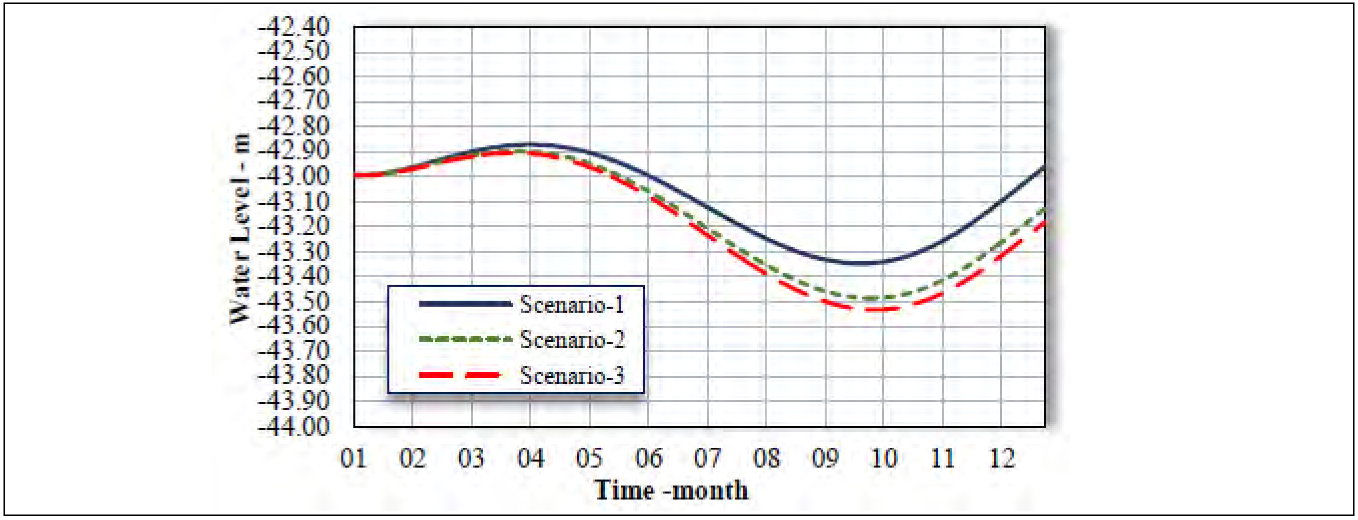


Figure 13 Fluctuation of water levels in Qaroun Lake in the case of new evaporation ponds

Simulation results were summarized in Table 10, it is included scenario-2 and scenario-3, comparing the two scenarios with the original state results in scenario-1.

Simulation cases	Start level (m)	Max. level (m)	Min. level (m)	End level (m)	Level change Δh (m)
Scenario-1	-43.00	-42.88	-43.33	-42.956	0.044
Scenario-2	-43.00	-42.90	-43.47	-43.124	-0.124
Scenario-3	-43.00	-42.91	-43.51	-43.179	-0.179

Table 10 Evaporation ponds simulation results

The lake level plummeted 12.40 cm/year after the minimum area of new evaporation ponds was added, while the lake level dropped 17.90 cm/year when the maximum evaporation area was added. As a result, we suggest that new evaporation ponds are required to collect surplus water from Qaroun Lake in order to reduce the lake's water level and restore safe water levels. Increase the potential of Qaroun Lake to receive fresh quantities of drainage water, estimated at around 42 million cubic meters of water, providing tremendous optimism for future expansions and extending agricultural land by about 18000 feddans, as well as the development of evaporation ponds.

A six-year simulation of water balance scenarios 1, 2, and 3 of Qaroun Lake was conducted to determine the consequences of adding new evaporation surfaces to the lake.

The comparison of the three scenarios with the clarification of the lake levels at safe, extreme, and dangerous states is shown in Fig. 14.

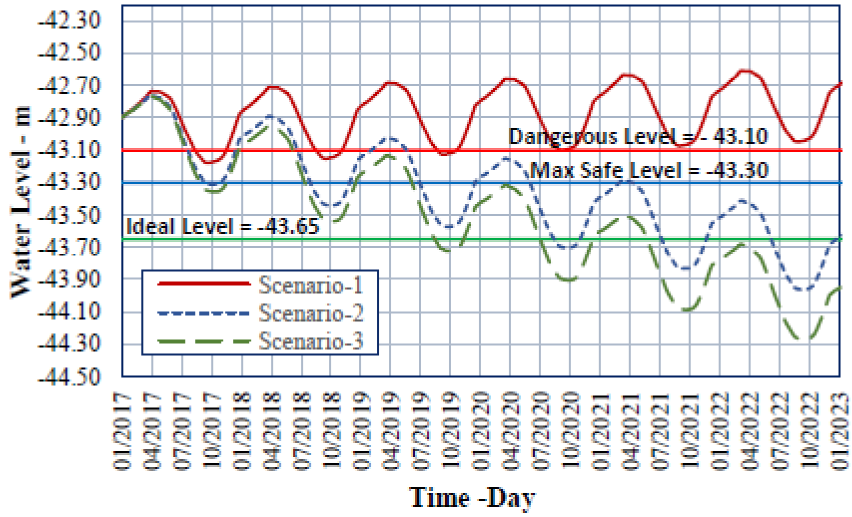


Figure 14 Water levels in Qaroun Lake at future period of 6 years

In the case of addition of evaporation surfaces at a minimum area, the maximum lake level drops to the safe level at the beginning of the fifth year from the beginning of the addition of evaporation areas.

In the case of addition of evaporation surfaces at a maximum area, the maximum lake level drops to the safe maximum level at the beginning of the fourth year.

It is clear that there is no way to solve the problem of Qaroun Lake other than to add new evaporation areas.

Salt Balance

The first scenario: salt balance between the amount of salt entering with agricultural drainage water, and the amount of salt extracted by EMISAL Company, and calculate the change of the salinity of lake (Fig. 16).

The second scenario: the same as the first scenario with the addition of salt water withdrawn through the new evaporation pond at minimum capacity.

The third scenario: is the same as first scenario with the addition of salt water withdrawn through the new evaporation pond at maximum capacity.

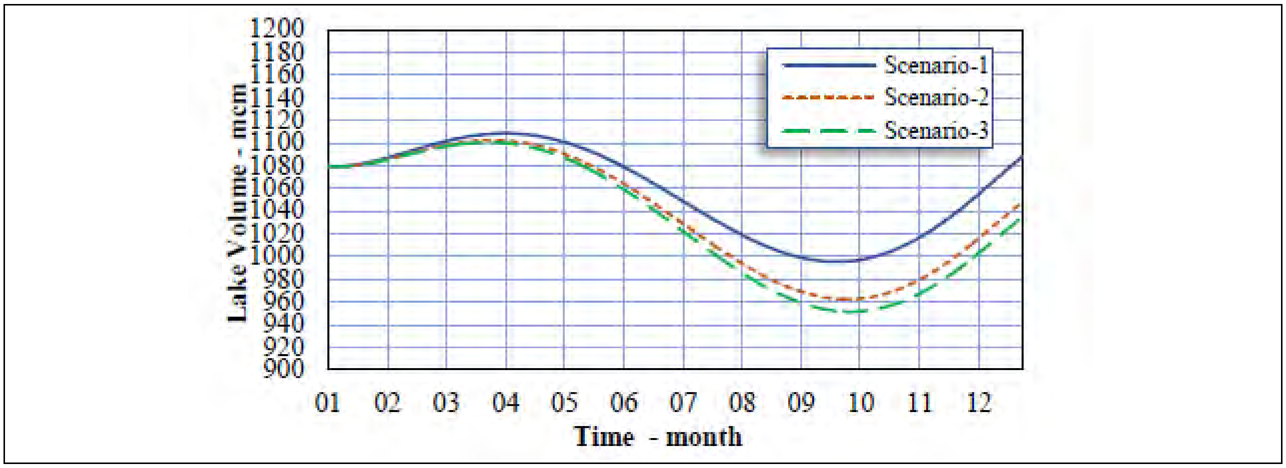


Figure 15 Qaroun Lake volume at current state, and after adding the proposed evaporation ponds

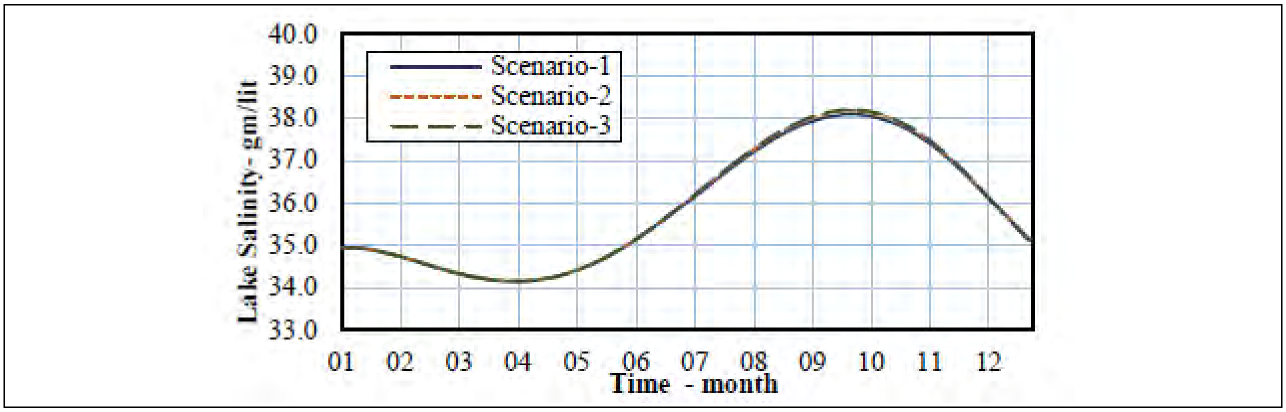


Figure 16 Qaroun Lake salinity fluctuation after adding evaporation ponds

According to past scenarios, the rate of salinity has remained relatively constant because the amount of salt retrieved from the lake is accompanied by a huge volume of water, resulting in a reduction in the lake's size.

The salinity ratio is stabilized when the saline load of the lake is reduced in proportion to the lowering of the lake's water volume. To lower the lake's salinity, a quantity of agricultural drainage water equivalent to the amount drained by the evaporation ponds must be added. This entails keeping a steady water level and volume in the lake.

Simulation cases	Start volume	End Volume	Volume Change	Start salinity	End salinity	Salinity change
	mcm	*mcm*	*mcm*	*gm/lit*	*gm/lit*	*gm/lit*
Scenario-1	1078.0	1088.41	10.41	35.0	35.069	0.069
Scenario-2	1078.0	1048.51	-29.49	35.0	35.033	0.033
Scenario-3	1078.0	1035.35	-42.65	35.0	35.020	0.020

Table 11 QARUN LAKE SALT BALANCE RESULTS

Application of Salt Balance Equation to Scenarios (4 and 5):
In this section, new quantities of agricultural wastewater will add to the lake, equivalent to the quantities withdrawn for the new evaporation ponds, in order to study the resulted salinity rate of the lake.

In the fourth scenario, the amount of water added to Qaroun Lake 29.50 million cubic meters per year to maintain the stability of lake's size.

In the fifth scenario, the additional quantity is 42.7 million cubic meters per year.
The figure below Fig. 17 shows the daily variation of the size of Qaroun Lake, and results of salinity equation were represented in Fig. 18.

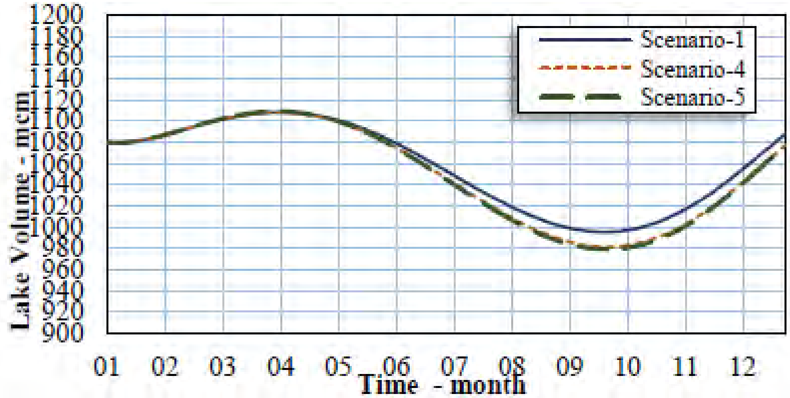


Figure 17 Fixing Qaroun Lake volume by adding new quantities of drainage water

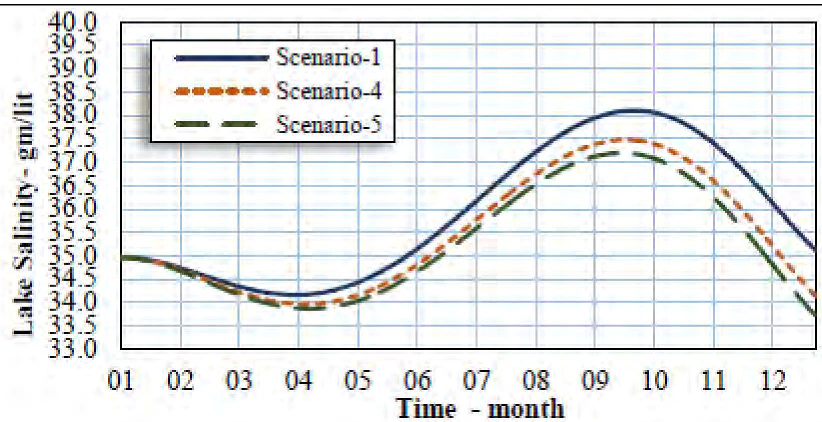


Figure 18 Qaroun Lake salinity after adding the new drainage water

After adding a new quantity of agricultural drainage water, the effect of the addition of new evaporation ponds on the salinity rate of Qaroun Lake was clearly emerged. All results are summarized in Table. 12.

Simulation cases	Start volume	End volume	Volume Change	Start salinity	End salinity	Salinity change
	mcm	*mcm*	*mcm*	*gm/lit*	*gm/lit*	*gm/lit*
Scenario-4	1078	1078	0.00	35.0	34.091	- 0.91
Scenario-5	1078	1078	0.00	35.0	33.665	- 1.335

Table 12 SALT BALANCE RESULTS AFTER ADDING NEW QUANTITIES OF DRAINAGE WATER

When <u>the minimum evaporation</u> areas were used, salinity decreased by 0.91 gm/lit/year. In this case, the amount of salt extracted from the lake is approximately 1437 tons per year.
<u>In the case of maximum evaporation</u> volume, salinity decreased by 1.335 gm/lit/year, and salt extracted from the lake is approximately 1911 tons per year.

It is concluded that we need to create additional evaporation areas to Qaroun Lake to restore water and salt balance.

Advantages:

The advantages of establishing the new evaporation ponds could be summarized as follows:

- The proposed land for the new project is uninhabited and there are no costs of expropriation and there is no conflict with the residential areas either.
- According to the exploratory maps of the area, the soil in this place is not suitable for agriculture, and there is no conflict between the project and the current or future agricultural activities.
- Proposed land with a slight slope of 1 m / km, enabling the formation of evaporation basins in the form of terraces.
- Access to the stage of water balance of Qaroun Lake, due to the amount of water withdrawn to the project.
- Exploit new evaporation basins in the establishment of a factory to extract salts like EMISAL.
- From previous studies, it is clear that the concentration of salinity on the northern side of the lake is higher than the southern side, which enhances the economic feasibility of the project.
- The amount of salt extracted from evaporation ponds is 4 to 5 times the amount extracted by EMISAL.
- The proposed area is very close to the regional ring road and Cairo-Fayoum road, which can facilitate product commercialization.
- Maintaining salinity of the cumulative increase and turn it into gradual decline.
- Providing the opportunity to increase the water share of Fayoum governorate to cultivate new areas, this is due to increased capacity of the lake to receive more amounts of agricultural drainage water.

Conclusions

The discharges coming to Qaroun Lake, and the amount of water withdrawn to the EMISAL plant has collected, as well as the volume of evaporation of the lake. A simulation was conducted on the SOBEK 1D2D program for the past year's discharges. The drainage water discharged into Qaroun Lake exceeds the outflow of the lake and the quantity of evaporation by about 10.40 MCM annually, which means increasing the level of the lake by about 4.40 cm /year.

With the help of digital elevation maps and satellite images, a place has been set up to allow the construction of new evaporation ponds, to discharge the amount of water that exceeds the capacity of the lake. The proposed areas for evaporation ponds are divided into four basins according to the contour lines.

In the case of establishment of an earth bank between Qaroun Lake and the evaporation ponds with a height of 2.30 m, the area available to the area of basins is 20.48 km2. When added to the lake, the withdrawn water helps reduce the level of the lake by 12.40 cm/year, the maximum lake level drops to the safe maximum level at the beginning of the fifth year from the beginning of the addition of evaporation areas.

When the bank's level rises to 4.30 meters, the area of the evaporation ponds is expected to reach 27.24 km2. This area contributes to reducing the lake's level by 17.90 cm/year. The maximum lake level drops to the safe maximum level at the beginning of the fourth year from the beginning of the addition of evaporation areas.

The establishment of evaporation ponds increase the ability of Qaroun Lake to receive new quantities of drainage water, which are estimated at approximately 42 MCM of water per year, which gives great hope for future expansions and increasing agricultural land.
The equation of salt balance of Qaroun Lake applied after addition of the new evaporation ponds. After adding the minimum evaporation area of 20.48 km2, there is an increase in salinity rate by 0.033 gm/lit/year. As well as for the evaporation area of 27.24 km2, salinity rate has increased by 0.020 gm/lit/year.

Due to the fact that the salinity of Qaroun Lake was not affected by the added evaporation ponds, a simulation of the lake was performed after adding a new quantity of agricultural drainage water in the fourth and fifth scenario. The result of the fourth scenario show a decrease in the salinity rate by 0.910 gm/lit, moreover salinity of the lake has decreased from 35.00 to 30.03 gm/ lit in the next six years. In the fifth scenario, the salinity rate was reduced by 1.335 gm/lit per year, as well as salinity of the lake has decreased to 27.92 at the end of the six years.

Activities & Responsibility

Activity	Responsibility	Time Frame
Cadastral	Ministry of irrigation, Fayoum Dept.	2 months
Earth banking	Ministry of irrigation, Fayoum Dept	6 months
Gates and gages	Ministry of irrigation, Fayoum Dept	4 months
Water release	Ministry of irrigation, Fayoum Dept	Continuous

Table 13 Action 1-1 Activities & Responsibility

Proposed budget

To be determined by Ministry of Irrigation.

Action 1-2 SEDIMENTAION STRUCTURES AT THE ESTUARY ZONE (EARTH EMBANKMENT/WEIR)

Scope

The scope of the project is to:

- Establish a sediment retention structure (natural stone boulder / Earth Embankment / dam) for silt control and retention before entering into the lake.
- Drop clay sediments at the estuary location
- Ease sediment removal and periodic maintenance only in the estuary zone.

Project location

Estuary area of Bats drain at the Lake Qaroun.

Details of restoration Activity

The idea of the project is to establish a permanent structure, at a proper distance of the estuary of Bats into the lake. The shock of dumbing water into the lake when meeting the dam/weir will lead to much precipitation of sediment in addition to creating aerobic (oxygenation) of the water before entering the lake. Using boulders, sand and coarse, a natural filter will be created at both ends of the dam for receiving the incoming water by building a bund at both ends of the earth embankment structure (dam).

Detailed Restoration Activity

A model must be created for:

- Specific appropriate location of the dam (distance from the direct inlet).
- The extension of the dam (east and west from the inlet)
- The proper dimensions that allow maximum sedimentation and creation of hydraulic jumps to improve water status.

The construction of the dam will be through installing low terrain stone boulders of non-soluble component (such as Dolomite). The dam will be built using relatively unsophisticated design procedures and equipment (low cost). It will require minimal maintenance and is best able to withstand foundation and abutment movements than the more rigid concrete and masonry structures. Construction on a layer-by-layer basis will allow for good compaction and stability.

The dam will be constructed using farm machinery for installing stone boulders in the specific location. When farm machinery is used, it is wise to allow for a complete overhaul of all mechanical and hydraulic systems following completion of the dam when working out costs.

Advantages of Earth Embankment Dam/Weir

- Local natural materials are used.
- Design procedures are straightforward.
- Comparatively small plant and equipment are required.
- Foundation requirements are less stringent or even not found. The broad base of an earth dam spreads the load on the foundation.
- Earth fill dams resist settlement and movement better than more rigid structures.
- It can be easily removed by the same farm machinery in case of undesired effects on environment or in hydrology issues.

Since permeability/seepage and compactness is not necessary in case of Lake Qaroun case, because the aim is to drop as much as sediment material in front of the structure, again the cost will be much less. In addition, it is not a high structure (just highest than water level), which lead more ease in cost and implementation.

Materials to be avoided for keeping water quality uncontaminated

- Organic material
- Decomposing material.
- Material with a high proportion of mica, which forms slip surfaces in soils of low clay percentages.
- Calcitic soils such as clays derived from limestone which, although generally stable, is usually very permeable.
- Cracking clays that fracture when dry and may not seal up when wet in time to prevent piping through them.
- Sodic soils, which are fine clays with a high proportion of sodium. They are difficult to identify in the field, so any fine clay should be analyzed.

The best materials used is Dolomite. It may also be Gabion provided in case of specific technical issues. However, it is not generally necessary.

Activities and Responsibilities

Activity	Responsibility	Time Frame
Model	University Consultant	1 month
Cadastral	Ministry of irrigation, Fayoum Dept.	2 months
Material transfer	Ministry of irrigation, Fayoum Dept.	2 months
Earth works	Ministry of irrigation, Fayoum Dept.	6 months
Eco-tourism facilities around the artificial lakes	Ministry of Environment	1 year

Table 14 Action 1-2 Activities & Responsibility

Budget

When built properly, such homogeneous downstream embankment can still be cheap and reliable. The budget can be calculated on the daily use of machinery plus the cost of importing the material and transport.

Action 1-3 DREDGING

Scope

Dredging is the physical removal of contaminated sediments in the bottom of the lake to conserve environment.

The digging scope depends on the distribution of polluted sediments and the digging surface must match the distribution of polluted sediments. In order to avoid removing natural lake sediments, reduce the processing quantity, and to lower disposal expenses, it needs to remove the polluted sediments and to reduce the excess digging of non-polluted sediments as much as possible.

The scope of the project is to:

- Remove the surface layer of sediment contaminated with heavy metals
- The volume of area dredged will add an equivalent quantity of water to the lake.

Project Location

Stage 1: The eastern section of the Lake with an area of 72 km^2.
Stage 2: The middle section of the lake with an area of 91 km^2.
Stage 3: The western section of the lake with an area of 82 km^2.

Details of restoration activity

The least thickness of dredging layer is suggested to be 10 cm. The amounts of sediments can be increased using different thickness of dredging as the decision maker wants according to the available budget.

The equivalent volume of dredged sediment will be 7.2, 9.1, 8.2 million cubic meters for the eastern part (72 km^2), middle section (91 km^2), western section (82 km^2) respectively. Due to the severity of the dredged materials, it must be transferred by some options:

- To a safe dumping site
- To use as earth banking for the dead lake zone in action 1-1

Activities & Responsibility

Activity	Responsibility	Time frame
Cadastral	Ministry of irrigation, Fayoum Dept.	2 months
Dredging operations (stage 1)	Ministry of irrigation, Fayoum Dept.	1 year
Dredging operations (stage 2)	Ministry of irrigation, Fayoum Dept.	1 year
Dredging operations (stage 3)	Ministry of irrigation, Fayoum Dept.	1 year
Transferring operations	Ministry of irrigation, Fayoum Dept.	6 months
Earth banking	Ministry of irrigation, Fayoum Dept	6 months

Table 15 Action 1-3 Activities & Responsibility

Proposed Budget

To be determined by Ministry of Irrigation.

Actions for Objective 2.

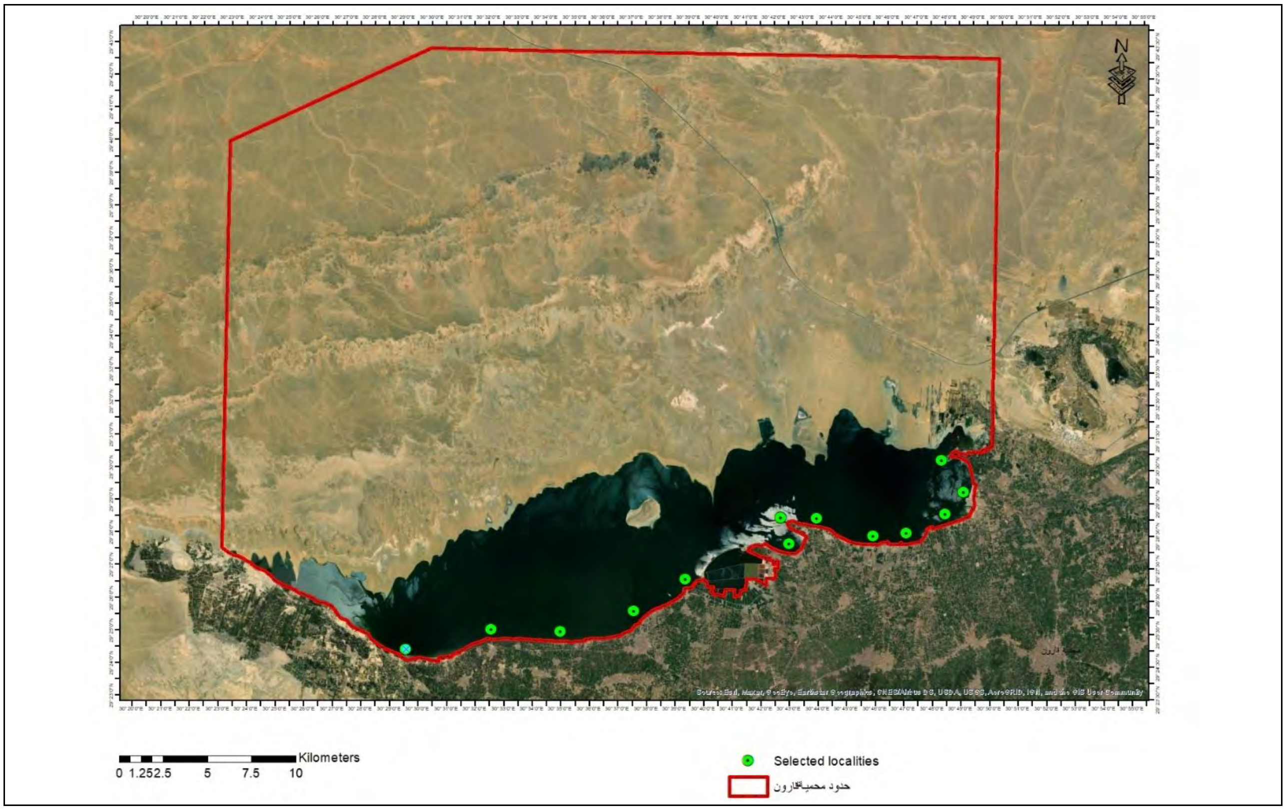
Action 2-1 BOTTOM & SHORE LINE (RIPRAP) STRUCTURES

Scope

The idea is to establish and enhance fish barrier (riprap structures) to increase the chance of spawning and stabilize shores of the Lake.

Location

Selected random locations will be selected according to the Piezometeric characteristics of the lake south shores and bottom (Map 21).



Map 22 The distribution of riprap structures along the south cost of Lake Qaroun

Details of restoration activity

Installed shoreline riprap as fish barrier system along the southern shore of the lake may enhance the fish life in the lake through offering a suitable spawning ground and stabilizing the sediment at the bottom of the lake.

The structures will be installed at definite spots of 5 Km distance intervals (at least 10 spots). Each of the spots will be at least 100 meres long and 2 meters deep with on layer of dolomite stone boulders of nearly 50X50 cm or larger.

Activities and Responsibilities

Activity	Responsibility	Time Frame
Stone transferring operations	GAFRD, Fayoum Dept.	2 months
Installing operations	GAFRD, Fayoum Dept.	4 months

Table 16 Action 2-1 Activities and Responsibilities

Proposed Budget

To be determined by the GAFRD Department.

Action 2-2 FISH STOCKING

Scope

Tilapia zillii and *Solea vulgaris* were considered as the main fishes in Qaroun Lake as they compose more than 65% of the annual total catch of the lake, beside they spawn in it. On the other hand, *Mugil* species, *Anguilla vulgaris, Sparus aurata* and shrimp are transported as fries from their spawning regions in the Mediterranean Sea to the lake.

The length and age composition of mullets in Lake Qaroun was found to be higher, ex. weight of *Mugil Cephalus* were better in the lake than in any other coastal areas of Egypt. Fisheries biology of *T. zillii* and *Solea vulgaris* in Lake Qaroun were studied, it was concluded that decline in the value of condition factor (K) and disappearances of older age groups of both two studied species reflect the drastic condition of Lake Qaroun which had a profound effect on its fauna and flora.

Studying lake fisheries; fishing gears, species composition and Catch per unit effort, concluded that the species composition for the mostly used gear in Lake Qaroun were as follow: *Mugil cephalus*, *Chelon ramada* and *Chelon Saliens, Solea spp., Tilapia zillii, Gobius niger, Dicentrarchus labrax* and *Engraulis encrasicolus* and shrimps.

Since most of these species no longer existed due to the variety of factors explained previously, the need to re-stock the lake with historic big catch species is an urgent need to restore the fish stock in the Lake. This action will go parallel with other actions detailed in the restoration programs and connected to the improved lake water quality and management

Location

The entire lake area.

Details of Restoration Actions

The next table is the basic species list of fish that need to be re-stocked in the lake.

Scientific name	Local name
Mugil cephalus (Linnaeus,1758)	Bouri
Chelon ramada (Risso, 1826)	Tobara
Solea spp.	Moussa
Dicentrarchus labrax (Linnaeus,1758)	Qarous
Anguilla Anguilla(Linnaeus,1758)	Hannash
Engraulis encrasicolus(Linnaeus,1758)	Anshouga
Tilapia zillii(Gervais, 1848)	Bolti akhdar
Oreochromis niloticus (Linnaeus,1758)	Bolti sultani(nily)
Sarotherodon galilaeus(Linnaeus,1758)	Bolti Ain Salem
Metapenaeus stebbingi (Nobili, 1904)	(Gambari abiad)
Bagrus *spp* .	Shamoth
Lates niloticus(Linnaeus,1758)	Keshr Bayad

Table 17 Basic Species list of fish

- The recommended source of fry is El- Bardawil Lake, since different studies recorded that this lake is less polluted comparing with other Egyptian lakes.
- Law enforcement must be strictly applied for the use of proper fishing gear by fishermen through water police and applying of legal fishing methods.
- Giving the responsibility to NIOF to establish/use fish ponds where fish fry is placed for a specific period of time before being transferred to Lake Qaroun and Wadi El-Rayan to ensure that they are free from any parasites or unwanted fish species and for acclimatization purposes.

Activities and Responsibilities

Activity	Responsibility	Time Frame
Capturing Fry	GAFRD, Fayoum Dept./NIOF	Continuous
Acclimatization	GAFRD, Fayoum Dept./NIOF	

Table 18 Action 2-2 Activities and Responsibilities

Actions for objective 3.

Action 3-1 <u>WETLAND REPAIR/RESTORATION</u>

Scope

The scope of this action is to restore the wetland system that defines the lake fringes. However, the fresh water vegetation that was characterizing the lake borders and the surrounding swamps had disappeared gradually due to the change of water quality to saline conditions, some salt tolerant species may be grown to restore the vegetation cover habitats.

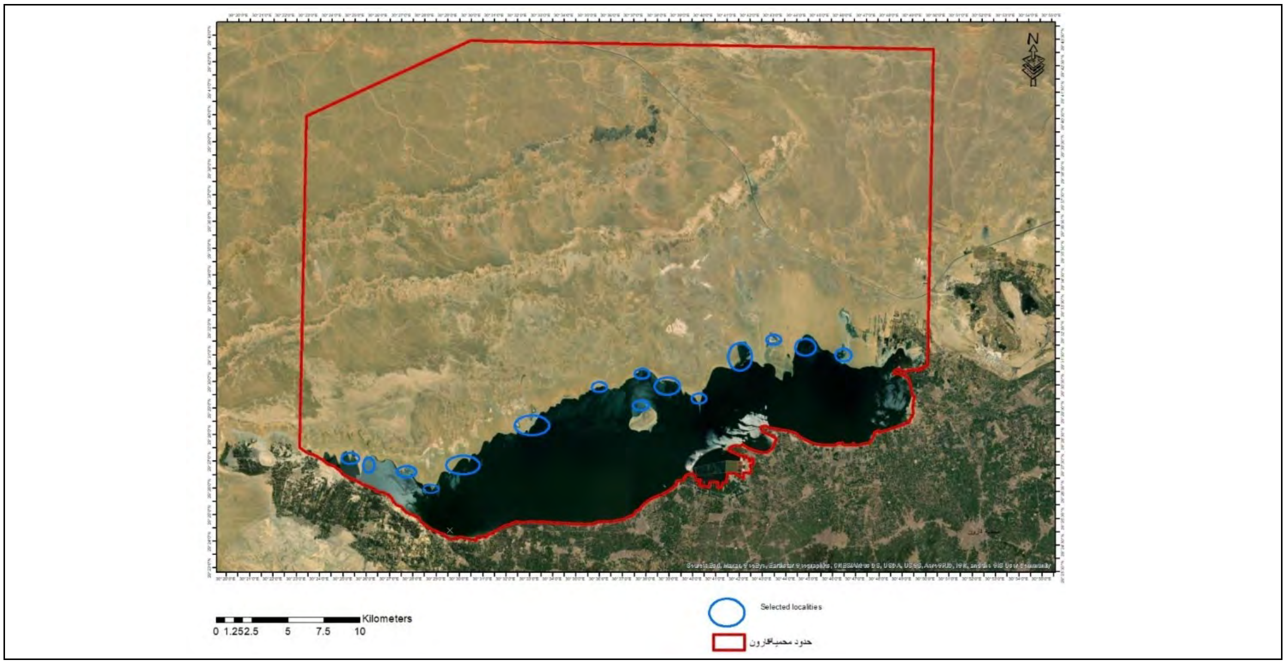
The 2-mangrove species that grow in Egyptian habitats (mostly Red Sea), *Avicennia marina* and *Rhizophora mucronata*, may be introduced in the north cost of Qaroun Lake and tested for growth, vitality and vigor. A mangrove fence may be constructed around the lake in line with its administratively and cartographically demarcated boundary. Thereafter, the lake periphery was afforested to improve water quality and prevent soil erosion.

Concept Idea

The idea is to establish a protected wetlands corridor restoring the wetland habitat that was surrounding the lake and disappeared due to water quality and salinization issues. Since the area of Lake Qaroun, is an IBA and a RAMSAR site, the rehabilitation and repair of wetland habitat will be much appreciated.

Location

The entire north cost of Lake Qaroun (Map 23).



Map 23 The distribution of proposed sites for mangrove plantation along the north cost of Lake Qaroun

Challenges

The main challenge of growing mangrove in Lake Qaroun area is the time zone (coordinates) as a climatic factor. The north most end of mangrove growing in Eastern Africa is 22° North. However, the Lake Qaroun is located at 29° North. In addition, a group of edaphic limitations for mangrove growth is also present, as follows:

1- Mangrove can be grown in the semi-closed bays, where the wave action is minimal, or in other areas protected from severe wave action;

2- The embayment used for mangrove planting must have a thickness of at least one meter of sediments;

3- Soils used must be of fine sand and mud, with low carbonate content, high organic matter and relatively low salinity;

Except the climatic factors, the rest of factors to grow mangrove in Lake Qaroun area nearly exist. However, the climate north shift that is currently occurring for Equator is encouraging to test the experiment of mangrove plantation.

The details of Restoration Action

Activities and responsibility

Activity	Responsibility	Time Frame
Nursery construction	Ministry of Env.	2 Months
Mangrove planting	Ministry of Env.	5-year program
Mangrove monitoring Soil and water monitoring	Ministry of Env.	Bi-annual
Public Awareness program: It will include an educational program for school children and conservation campaign for villagers.	Ministry of Env.	5 years-program

Table 19 Action 3-1 Activities and Responsibilities

Planting Schedule

Activity	
Total Planting Area	0.5 acre for each plantation spot
Planting Season and Timing	January ~ February
Seed/ Seedlings Supply Source and Location	Seed from existing mangrove in Red Sea Seedling from temporary nursery to be constructed in Red Sea
Planting Method	Start in the selected localities of the northern shore. After finishing on landward shore, move to waterward shore.

Table 20 Action 3-1 Planting Schedule

Required Actions for Conservation and Management

Activity	Action
Inspection	Daily observation by PA staff, 2 to 4 times of inspection
Cleaning	PA staff
Replantation of Seedlings Growing Bad, Dead or Washed Away	5 years after plantation.
Patrol and Enforcement	Daily ordinary patrol by PA staff is required, to inspect facilities conditions and littering and waste disposal to the ground and water.
Restoration and Rehabilitation Work	The mangrove plantation work in the planting area described in the previous section is necessary. The pedestrian bridge is reconstructed to improve the water environment in the existing mangrove area.
Facilities Required for the Conservation and Management Activities	Directional signs along the asphalt road and entrance to the PA, guide signs in the PA, and information boards in the planting area to explain the significance of the reserve and major flora and fauna. Footpath and boardwalk for observation of wildlife as well as mangrove are also necessary.

Table 21 Required Actions for Conservation and Management

Monitoring

Mangrove

Activity	Action
Monitoring Method	First 4 years: tree height, canopy X:Y After 4 years: follow the monitoring sheet.
Frequency	First 4 years: annual monitoring After the first 4 years: every 2 years
Monitoring Target	Select 20 trees at random and monitor them. Trees to be selected should have distinct characteristics such as (PV) locating at the panoramic view point, (EF) locating at the edge of existing forest stretch, (OT) outstanding tree (size, shape, history, health, etc.) and (RP) a tree stand at remarkable point.
Baseline Data	Base line data of tentatively selected trees

Table 22 Monitoring Process of Mangrove

Water and soil

Activity	Action
Monitoring Method	Monitor soil and water in and around mangrove vegetation by using attached table
Frequency	• Soil: (New plantation area) Before plantation and Every two years after the new plantation • Water: Every year (Outflow water should be measured)
Baseline Data	See attached table

Table 23 Monitoring Process of Water and Soil

Figure 19 Field Monitoring Sheet for Mangrove

Mangrove Observation Records

1) Identification No.

2) Location by GPS (WGS 84, UTM)

Easting: ____________

Northing: ____________

3) Photograph No. ____________

Memo:
(specific information or data significant for the tree will be written here)

4) Observation of tree size and shape

a) Tree Height (cm) [ ]

b) Trunk diameter near bottom (cm) [ ]

c) Live branches at the position about 1.3m off the centre of tree bottom (painted)

Branch/ limb diameter measured in cm

1		2		3		4	
5		6		7		8	
9		10					

5) Observation of tree history, health and environment

a) History

Tree shape: ____________

Sign of cut in the past: ____________

b) Health

Nodes with leaves: ____________

Inter-node length: ____________

Leaf length: ____________

Leaf colour: ____________

Looks / die back: ____________

c) Environment

Soil depth / texture: ____________

Surface water Salinity: ____________

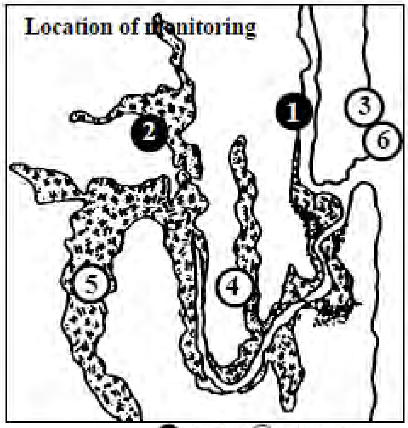
Ground level: ____________

Position: ____________

Note:

Figure 20 Field Monitoring Sheet for Soil & Water

Location	
Date / time:	/ ,200 :
Recorder	



●Soil ○ Water

General Condition in plantation area:

(garbage, rubbish, leaf, alga, crab, shell, etc)

(1) Soil Condition

		New planted area ( )	New planted area ( )	Exist. Mangrove① young seedlings	Exist. Mangrove② Dense bush
Coordinate	Easting			446950	446730
	Northing.			2734510	2733710
Surface condition					
Soil Texture	0-10cm				
	30-40cm				
	50-60cm				
Soil Colour	0-10cm				
	30-40cm				
	50-60cm				
Root development					
Depth of surface humus					
Free water	GWL* (cm)				
	pH				
	Salinity (%)				

Soil colour by Munsell notation, GPS*:by UTM of WGS84 GWL: Ground water level

(2) Surface Water Quality

(Observation time: :)

		Khawr mouth ③	Mid khawr ④at bridge	Upstream Khawr ⑤	Sea water ⑥
Coordinate	Easting	447365	447172	446710	447510
	Northing.	2734190	2733227	2733380	2734120
Surface waste					
pH					
Salinity (%)					
Temperature (C)					
DO (mg/l)					
Turbidity / Colour					

Action 3-2 PUBLIC ENVIRONMENTAL AWARENESS PROGRAM

Scope

This program is vital to gain the appreciation and support of the local communities surrounding the Lake Qaroun and other key players on different levels for the ecological restoration concept/projects and assisting in its implementation.

Details of activity

The targets of this program will be:

- Local community villagers surrounding the lake area (Sinnuris, Ibshaway & Yosef El-Seddiq) centers, with special reference to women.
- Local administration officials who are responsible for management of basic services (Irrigation, sanitation, fisheries, tourism, water police)
- Tourism investors
- Local eco-tourism guides and operators
- Basic education schools

Environmental awareness program materials must contain:

- Biodiversity
- Protected areas as a main tool to conserve biodiversity
- Eco/Responsible/sustainable tourism basics
- Natural habitats
- Clean water and environment
- Solid waste

Location of activity

Centers of Sinnuris, Ibshaway & Yosef El-Seddiq.

Activities and Responsibility

Activity	Responsibility	Time frame
Preparing the course program content package	MOE/EEAA	5 years continuous
Preparing the printed education material (brochures, posters, signs…etc.)	MOE/EEAA/ Eco-tourism NGO	
Delivering the package campaigns year after year.	MOE/EEAA/MIWR	
Organizing field visits for the targeted group.	MOE/EEAA/Eco-tourism NGO	

RESTORATION PROJECTS AND ACTIONS PORTFOLIO

Action/Project	Potential Partnership	Indicative Coast LE	Priority	Time to deliver
Dead Lake Zone	MIWR/MOE		High	2 years
Estuary Earth Embankment/Weir	MIWR		High	1 year
Dredging	MIWR		Medium	Once/year
Bottom &Shore line (riprap) Structures	GAFRD		Medium	1 year
Fish Stocking	GAFRD/NIOF		High	Continuous
Wetland Repair/Restoration	MOE		High	5 years
Public Environmental Awareness	MOE		Medium	5 years

Table 24 Restoration Projects and Actions Portfolio

RECOMMENDATIONS

Objective 1.

1-1- "The minimal “evaporation pond” area required to start water dumping must be calculated through a professional on the ground survey".

1-2- A model must be created for:

- Specific appropriate location of the dam/weir (distance from the direct inlet).
- The extension of the dam (east and west from the inlet)
- The proper dimensions that allow maximum sedimentation and creation of hydraulic jumps to improve water status, without back wave in the body of Bats.

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