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FACTS ABOUT THE DEGRADATION OF LAKE QARAOUN, LEBANON, AND CYANOBACTERIAL HARMFUL ALGAL BLOOMS (HABS)

Hamza Yazbek[1]
Ali Fadel[2]
Kamal Slim[3, 4]

[1]Lebanese University, Department of Environmental Geography Hadath, Lebanon
[2]National Center for Remote Sensing, National Council for Scientific Research, Beirut, Lebanon
[3]Laboratory of Microorganisms and Food Irradiation, Lebanese Atomic Energy Commission, Beirut, Lebanon
[4]Lebanese University, Faculty of Sciences, Hadath, Lebanon

Lake Qaraoun is the largest reservoir in Lebanon, which benefits from the reservoir in several different ways: flood control, fishing, irrigation, power generation, and recreational activities. In this paper, we present facts about the water quality in the hypolimnion, the deepest layer in this reservoir. Results showed that the temperature at hypolimnion is rather constant at 7°C. During stratification, the lake exhibits a strong thermocline (8–11 m) with an anoxic hypolimnion (1 PPM O_2) containing hydrogen sulfur (8 ppm), ammonium (11 ppm), chloride (1938 ppm) and BOD5 (46 ppm) concentrations in a recovered sediment. Microcystis aeruginosa and Aphanizomenon ovalisporum still dominates the reservoir in 2017. At the end of this paper, we suggest different management options to reduce the pollution and improve the water quality in the reservoir.

INTRODUCTION

Lakes and reservoirs are an essential source of freshwater for human populations. They provide several human services such as hydropower, water supply for domestic and industrial use, hydropower, irrigation, drinking water production, fisheries and recreational activities (Fadel et al., 2014; Temsah et al., 2016). However, as a consequence of several human factors, erosion (Darwish et al., 2018) and land degradation (Darwish & Fadel, 2017), these ecosystems have been suffering from degradation of their water quality. Agricultural, urban and industrial discharges are causing a marked increase in the nutrient inputs to inland lakes and reservoirs thereby favoring their eutrophication (Fadel & Slim, 2018).

Monitoring and management of lakes and reservoirs became crucial to maintain high water quality. Many lakes and reservoirs throughout the world are contaminated by harmful algae and toxic cyanobacteria species such as Microcystis aeruginosa (Paerl, 2008; El Hourany et al., 2017; Vinçon-Leite et al., 2017). The proliferation of this cyanobacterium can have numerous harmful consequences (Fadel et al., 2015). It secretes microcystin, a toxin, which can be lethal to livestock, pets, wildlife and humans that ingest water contaminated with toxic cyanobacterial cells, or toxins released from decaying cyanobacterial cells (Azevedo et al., 2002; Fadel et al., 2014). In addition, the growth and proliferation of this toxic cyanobacterium produces bad smell and scum, preventing recreational use of water bodies, clogging irrigation pipes and causing side effects on hydropower generation equipments (Fadel et al., 2017).

The control of lake water quality is based on monitoring of the environmental status of aquatic ecosystems, management practice in relation to the required water uses and a reasonable, preferably detailed, knowledge of the limnological characteristics and processes of the water body of interest. The basic information required to characterize the ambient condition of a lake is based upon surveys of the various components of the lake system. These surveys provide the scientific basis for the development of the lake in order to meet the most specific requirements, and sensitive uses, to which it is subjected. Such monitoring is not only used to assess the evolution of the environmental status of aquatic ecosystems but also to understand ecological processes, including the growth and succession of phytoplankton species (Fadel, 2014). Once this has been established, a management protocol can be determined and implemented.

Lake Qaraoun, Lebanon's largest freshwater body, is used for power generation, irrigation, fishing and touristic activities. Harmful algal blooms of toxic cyanobacteria species have occurred annually since 2009. The reservoir has experienced a continuous rise in nutrient level due to regular polluting activities on the catchment of the upper Litani River, the main inflow to Lake Qaraoun and is considered to be eutrophic. Therefore, it is very crucial to monitor its water quality.

MATERIALS AND METHODS

Study area

Lake Qaraoun, also known as "Karaoun Reservoir", is the largest reservoir in Lebanon was constructed in 1965 (Error: Reference source not found). It is located in the Bekaa valley, between the two Lebanese mountains ranges and 86 km upstream from the mouth of Litani River into the Mediterranean Sea. The reservoir was built mainly for agricultural irrigation and power generation (Fadel et al., 2016). However, professional fishing and sport activities are also established in this reservoir. It has a surface area of 12.3 km2 at full capacity, with a maximum depth of about 60 m and 860 m crest elevation. Lake Qaraoun dam is 62 m high, 1090 m long, with 162 m width at the bottom and 6 m width at the top. The reservoir capacity is 230.106 m3. The main input to Lake Qaraoun is the Litani River that has an average discharge rate of 9.09 m3/s between 2009 and 2011. Springs, another input resource, also discharge at the bottom of the reservoir. There are not precise recent studies about their contribution in the input to Lake Qaraoun. However, in summer 1952, the flow rate of a spring that discharges before the dam site was 0.69 m3/s (United Nations Development Program, 1970). About 180.106 m3 are used annually (for the irrigation of 310 km2 of farmland in South Lebanon and another 80 km2 in the Bekaa valley, for the industry and for hydropower production). About 40.106 m3 remain in storage over the dry season.

Lake Qaraoun has three main outputs:

1) The bell-mouth spillway which is located near the dam and used to evacuate the overflow into the Litani river at the bottom of the dam, and avoid the water overtopping, damaging or even destroying the dam.

2) Two evacuation towers that were originally used to empty the reservoir into the Litani River, but which currently supply canal 900 that was constructed for irrigation purpose. (Figure 2)

3) The power generation tunnels located at an altitude of 810 m above sea level, with a total capacity of 22 m^3/s.

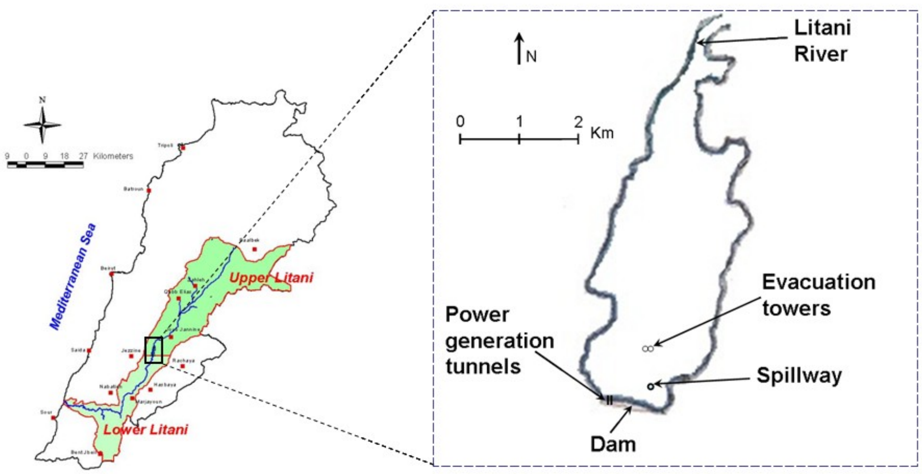

Figure 1. Map of Qaraoun Lake

The environment disaster that took place in the Qaraoun Lake has become the only occupation of all the working in public affairs from responsible to local administration, civil and scientific sectors, for the huge damages that occurred to this vital source, such as: electricity production, agriculture, tourism and fisheries. The sources of pollution belong to the solid wastes, industrial remnants and wastewater from homes, agriculture and insecticides where they all flow in the lake without deterrent. It became for real a “tank of wastes” liquid and solid, as well as a burden for the society instead of being their source of livelihood.

Studies on phytoplankton do not exist for the Lake Qaraoun. Mainly, there are isolated reports concerning the floristic data of a sparse number of samples from this lake (Slim 1996; Saad *et al.* 2005). By the end of year 2009 phytoplankton samples were collected once a month from the same site at the Lake Karaoun (Figure 1). Phytoplankton samples were harvested with a plankton net (20 µm mesh size) at 0.5 m depth and fixed with formaldehyde at a 5% (v/v) final concentration. The cyanobacteria species were determined according to taxonomic keys based on cell structure and dimension, colony morphology, and mucilage characteristics (Komarek & Anagnostidis 1999; 2005). Microscopic observations were carried out under a phase contrast microscope (Nikon TE200).

RESULTS AND DISCUSSION

Aphanizomenon ovalisporum was detected and settled down in the lake for the first time and took over the upper level of water completely after killing all other kinds of plants and animals, and it is known to produce cylindrospermopsin which is poisonous substance that causes huge damages to the water environment. Bloom conditions continued in summer and autumn with a reduction of the lake water level with emanation of smelly odor resulting from the poisons produced after the appearance of a new type of *Microcystis aeruginosa* which produces microcystin, the most damaging substance for water and it is one of the causes of death of a huge number of small fishes (Figures 2 and 3).

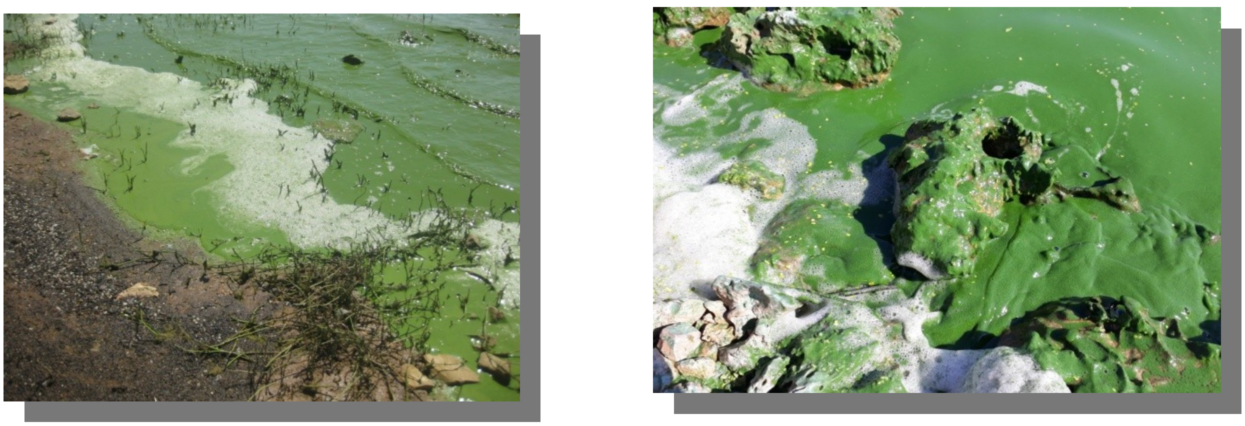

Figure 2. Blooms of cyanobacteria: *Microcystis aeruginosa*

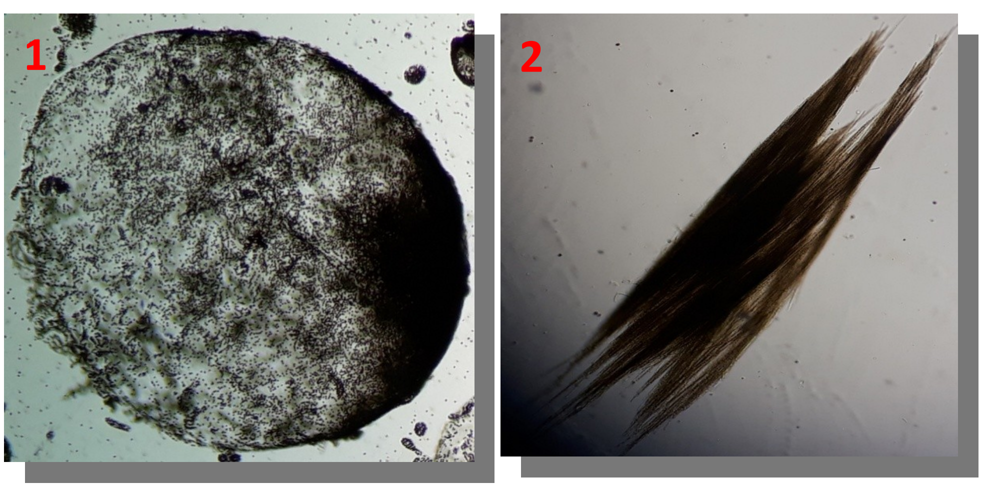

Figure 3. (1)*Microcystis Wesenbergii*: October –november 2017 (thick bloom) (2) *Aphanizomenon_ ovalisporum*: 2012-2013

Historical evolution of phytoplankton community in Lake Qaraoun

Phytoplankton are microscopic, single-celled photosynthetic plants that use chlorophylls and carotenoids to absorb light for photosynthesis. The name “phytoplankton” consists of two Greek words meaning “plant” (phyto) and “wanderer” (plankton) meaning a collective of organisms that are adapted to spend part or all of their lives in apparent suspension in the open water of the sea, reservoirs, lakes, ponds and rivers. Chlorophyll *a*, or a derivative, is present in all types of phytoplankton and is commonly used as an indicator of the phytoplankton biomass enables living phytoplankton to be distinguished from zooplankton, detritus and dead phytoplankton. It is highly fluorescent and can be measured in unconcentrated samples. Other chlorophylls and carotenoids are present in phytoplankton, many of which have restricted taxonomic distribution. These pigments can be used as quantitative markers for particular taxonomic groups.

Phytoplankton consists of 4 groups: cyanobacteria (blue-green algae), chlorophyta (green algae), diatoms and cryptophyta. However, the most interesting in our case is the toxic cyanobacteria that occur in many over the world including Lake Qaraoun. *Microcystis aeruginosa* is a toxic cyanobacterial species that occurred recently in Lake Qaraoun. This cyanobacterium (*Microcystis aeruginosa)* secrete cyanotoxin (microcystin) that can be lethal to livestock, pets, wildlife and humans that ingest water contaminated with toxic cyanobacterial cells, or toxins released from decaying cyanobacterial cells preventing the usage of this reservoir as a source of drinking water (Codd, Bell et al. 1999; Azevedo, Carmichael et al. 2002; Codd, Morrison et al. 2005). In addition, the growth and proliferation of this toxic cyanobacterium produces bad-smelling and scum, preventing recreational use of water bodies, clogging irrigation pipe and causing side effects on hydropower generation equipments (Yoshinaga, Hitomi et al. 2006).

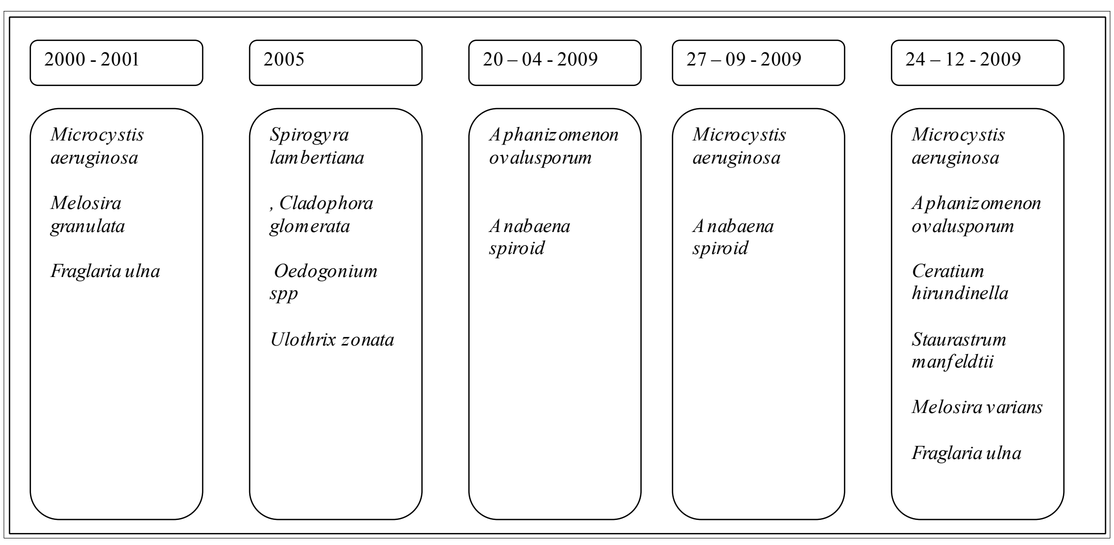

Figure 4. Phytoplankton succession in Lake Qaraoun 2000-2009

Before 1996, the phytoplankton of the Lake Karaoun has been dominated by diatoms bloom which represented about 80 % of the total species. A phytoplankton study was then performed in 2005; it showed the dominance of filamentous green algae (*Spirogyra lambertiana*, *Cladophora glomerata*, *Oedogonium* spp and *Ulothrix zonata*) and the complete disappearance *Ceratium hirundinella* between 2002 and 2003 (Saad *et al.* 2005).

Due to the external nutrient loading, cyanobacterial blooms became obvious in summer 2009. Two cyanobacterial species (*Aphanizomenon ovalusporum* and *Microcystis aeruginosa*) were detected to be the cause of these blooms.

During the year 2010, phytoplanktons become dominated by cyanobacteria as the temperature increases (Slim et al., 2014), the *Aphanizomenon ovalusporum* is a cyanobacterium that has an optimal temperature less than the optimal temperature of *Microcystis aeruginosa*. That's why this cyanobacterium (*Aphanizomenon ovalusporum*) is mostly seen at the beginning of spring and autumn seasons. There exist another phytoplankton species (species of *Chlorophyceae* including *Pediastrum duplex, P. boryanum, Micrasterias sp. Coelastrum microporum* and the dominance of *Staurastrum manfeldtii*) at the beginning of spring and autumn. However, they appear in low concentration and for a short period before and after the bloom of Microcystis aeruginosa when the temperature reaches its higher values in summer season.

Hypolimnion

Sediment is the important habitat for organisms living in the surface and into the bottom ground. Characteristics of the sediment play an important role in determining the population structure, abundance and distribution boundary of organisms. Environmental factors influence sediment, and water qualities are mainly consequence of the activities in the lake.

Lake surface temperature is controlled by atmospheric temperature, while the hypolimnion is rather constant at 7°C. During stratification, the lake exhibits a strong thermocline (8–11 m) with an anoxic hypolimnion (1 PPM O_2) containing hydrogen Sulfur (8 ppm), ammonium (11 ppm), chloride (1938 ppm) and BOD5 (46 ppm) concentrations in a recovered sediment (Table 1, Figure 5)

The sediments consist of a mixture of humus material, fine plant fragments, algal remains, grains of quartz and mica, diatom frustules, exoskeleton fragments from aquatic arthropods, and spore and pollen relics. This mixture of materials that are largely derived from plankton is mixed and modified by the bottom fauna that both consume and contribute fecal matter to the sediments. Bacterial decay of dead plankton material in eutrophic lakes often causes long periods of anoxia in bottom sediments. Sediments subjected to such conditions are known as sapropel. Sapropel is a glossy, black, watery material that emits H_2S, resulting in characteristic "rotten egg smell" of hydrogen sulfide. High concentrations of sulfide can affect the respiratory and metabolic depression of organisms in the ground such as fish.

Table 1. Lake Analysis from the bottom of the lake on 14/11/2017

Analysis 14-11-2017	
CL-	1938 PPM
COT (Carbon Organic total)	342 PPM
Ammonium	11 PPM
BOD5	46 PPM
Dissolved Oxygen	1 PPM
BIOMASS (*Microcystis wesenbergii*)	6.44 g/l
TN (total nitrogen)	10.5PPM

In 4/9/2016, the Litani River Authority, for urgent reasons, had to open a drain towards the south for three days after the malfunctioning of the electricity turbines and it is known that the algae and the remains that accumulated at the bottom of the dam caused a chemical change in the water. The environmental state was catastrophic on the area and surrounding villages, which affects directly in corroding metal and concrete installations. The awful smells and black color of the water showed the high degree of pollution and the presence of gases and toxic products such as ammonia, methane and sulfur (Figure 5).

Figure 5. Poor quality of water if we pump the water to canal 800 (in construction) to South Lebanon

Using remote sensing and 3D modelling to monitor, understand and manage cyanobacterial blooms at Lake Qaraoun

Remote sensing is a useful cost effective technique to estimate spatial and temporal distributions of water quality properties within lakes where limitations of field sampling are avoided. In a new launched project funded by CNRS, we will set up a near real-time warning system to predict the dynamics of harmful algal blooms in the Lake Qaraoun and enable the Litani River Authority to adapt its management. This system consists of a near real time satellite images from Landsat 8 and Sentinel-2 that can provide information on water temperature and the concentration of algal blooms in the water bodies. The validated data provided by these images and the weather forecast will be then used as input to 3D hydrodynamic-ecological model called Delft3D to predict the evolution of the water quality of the water body, more precisely the dynamics of the blooms. The results will therefore help local authorities in monitoring and managing Lake Qaraoun to provide better water quality for the different uses by the residents of the villages around the Qaraoun.

CONCLUSION AND RECOMMENDATIONS

Lake Qaraoun is highly polluted and the hyploimnion water quality is bad. Effective management of Lake Qaraoun starts by treating wastewater effluents along the lake to control the levels of enriching nutrients (mainly phosphates and nitrates) in order to prevent eutrophication.

According to LRA, this can be only achieved by managing Litani River water quality through:

Preventing the "complete" tapping of springs and tributaries water flow for irrigation;

Controlling the drilling of new wells and the overexploitation of ground water aquifers;

Enforcing onsite treatment of major industrial wastewater effluents discharging into the Litani River and its tributaries, or into the domestic sewage networks which in turn flow directly into the river;

Preventing the discharge of untreated domestic sewage directly into the river and its tributaries;

Regulating the discharge of municipal and industrial solid wastes along the river water flow;

Raising awareness to reduce the over-application of pesticides.

Suction of sedimentation from the bottom of the lake where there is a huge block of poisonous sedimentations which exceeds 11 million m3 with 5 meters of length in some places and these sedimentations were composed throughout half a decade and composed of a mix of organic dissolute substances and poisonous chemical materials such as methane, sulfur materials, ammonium, lack of oxygen. Moreover, the dangerous cyanobacteria even if it looks dead but it could be revived and entered a new life cycle even after a long time, it is impossible to return the lake to its normal status without removing this sediment layer.

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ADDRESSES FOR CORRESPONDENCE
Ali FADEL
National Center for Remote Sensing
National Council for Scientific Research (CNRS)
P.O. Box 11-8281, Riad El Solh, 1107 2260 Beirut, Lebanon
Email: afadel@cnrs.edu.lb

Hamza YAZBEK
Faculty of Arts and Humanities
Doctoral School of Literature Humanities and Social Science.
Email: Hamzayazbek97@gmail.com

Kamal SLIM
National Council for Scientific Research (CNRS)
P.O. Box 11-8281, Riad El Solh, 1107 2260 Beirut, Lebanon
Email: kslim@cnrs.edu.lb