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Restoration of Qaraoun Lake aquatic life based on wetland treatment concept

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ABSTRACT

Qaraoun Lake, the largest artificial lake in Lebanon, suffered severe environmental issues due to discharging untreated domestic and industrial wastewater into it, throwing garbage, which transformed this lake into waste storage instead of using the water for agricultural purposes and making the surrounding places attractive for tourists as was before. Moreover, the violations on Litany River, Lebanon's main artery, also affected Qaraoun Lake. Therefore, this main reservoir suffers from annual blooms of potentially toxic cyanobacteria. Recently, tons of fish are washed up at the surface of the water, agricultural areas are irrigated with polluted water and the Qaraoun Lake is no longer an attractive touristic place. Besides, the climate change represented in lower precipitation and higher evaporation rates in the past few years in addition to the increase in the water demand due to the growth in the local population and the refugees from nearby countries have affected the vulnerability of the water sector in Lebanon. All these issues have resulted in the deterioration of the water quality, generating environmental issues, and seriously affecting the ecosystem. The purpose of this research is to investigate possible remediation strategies, which could help in the restoration of the Qaraoun reservoir. For this purpose, the Litani River water quality and hydrological data are collected from the Litani River Authority (LRA). Moreover, a hydrodynamic water quality model has been developed using Mike21 in order to restore the lake's aquatic life by eliminating the Litani River nutrients through constructed wetland concept, which reasonably simulated the water quality parameters of Qaraoun Lake. Consequently, the wetland could remarkably reduce the Litani River pollutants by 85%, 43.7%, 57%, and 56% for BOD, Phosphorous, Nitrate, and Ammonia, respectively. The resulted treated water, after passing the wetland, successfully improved the lake water quality and may lead to re-originate its ecosystem.

1. Introduction

Water quality is thought to be the most significant component influencing wellness and illness in all kinds of life (fauna and flora). Moreover, since surface water is accessible and in close contact with humans, it is frequently contaminated [1]. Natural processes (weathering and desertification) and human factors (urban and industrial wastewater discharge) primarily govern pollution as major problems concerning surface water issues (Kiran et al., 2022) [2]. Qaraoun Lake is receiving continuous anthropogenic contaminants

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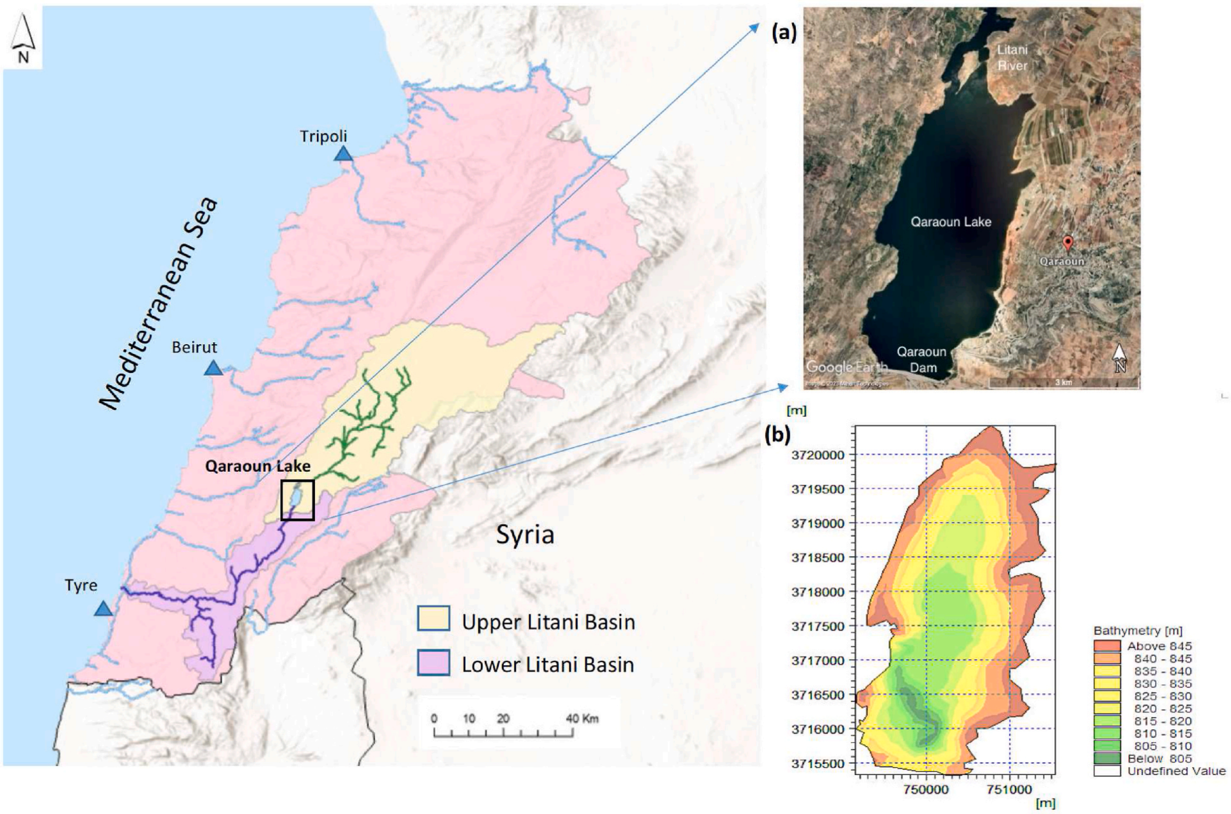

Fig. 1. (a) Layout of Qaraoun Lake, (b) Bathymetric data of the Qaraoun Reservoir [22].

and a periodical polluted surface runoff influenced heavily by weather inside its basin [3,4]. In addition to climate change, it is predicted to raise the temperature and increase water supplies scarcity in concerns of livelihoods. According to the Lebanese Ministry of Environment, changes in climate would reduce Lebanon's Gross Domestic Product (GDP) by 14% in 2040 and by 32% in 2080 [5]. This change will be an additional problem regarding the pollution of the Qaraoun Lake [6,7].

Moreover, Qaraoun Lake receives industrial effluents from the factories on its banks and agricultural pesticides where no project, local or international, seems to stop it. It suffered from a chronic pollution problem, and the fish have gradually died due to lack of oxygen. The discovery of a huge number of dead fish came after the Litani River's water turned into a brownish muck due to the ongoing pollution from sand quarries and villages [8,9]. Nowadays, millions of cubic meters of raw sewage flow directly into the Litani River [10], besides that, it becomes the dump of untreated municipal and industrial wastewater as well as solid waste along the riverbanks [11].

There have been few studies on the pollution in Qaraaoun Lake in comparison to those on Lebanon Rivers [12,13].); and [14] conducted investigations on the water quality of Qaraaoun Lake. Due to the circumstances that occurred for several years without any control and preventive actions, large stretches of the Litani River [15,16], and the Qaraoun Lake [7] have become highly polluted. Lake Qaraoun turned green in 2011 as cyanobacteria, which destroy marine life, spread due to the heat wave that hit Lebanon, but the bacteria's spread was limited at the time. However, the increase in pollution in 2019, coupled with rising temperatures and rainfall levels, led to the resurgence of these dangerous bacteria [17].

Global challenges to develop cost-effective, environmentally friendly solutions for water infrastructure and sewage treatment have increased. Wastewater is being treated and reused for a range of purposes. The wetland idea allows for long-term wastewater treatment. Wetlands are utilized for the treatment of household, industrial, and surface runoff wastes. It permits the removal of organic wastes and improves the efficiency of mineral removal, [18]. There are different forms of wetlands, but the most commonly employed are the floating wetlands systems and the constructed ones. However, choosing the right form of wetland while taking into account all aspects is difficult (Sudarsan & Kale, 2022).

The main objective in the previous studies that studied Qaraoun Lake water quality deterioration such as [19,20] (Chaden et al., 2018); was solely focusing on water evaluation without consideration for water sources contamination or understanding the natural dilution process in the Lake. To the best of the authors' knowledge; there were no previous studies that numerically simulated the Qaraoun Lake hydrodynamics or water quality system. Therefore, the goal of this study is to simulate Qaraoun Lake numerically using Mike 21 in order to determine the effect of Litani River pollutants on the Lake, further understand the pollutants' circulation and dilution within the lake body, and investigate how to restore the aquatic life by eliminating the Litani River nutrients based on wetland

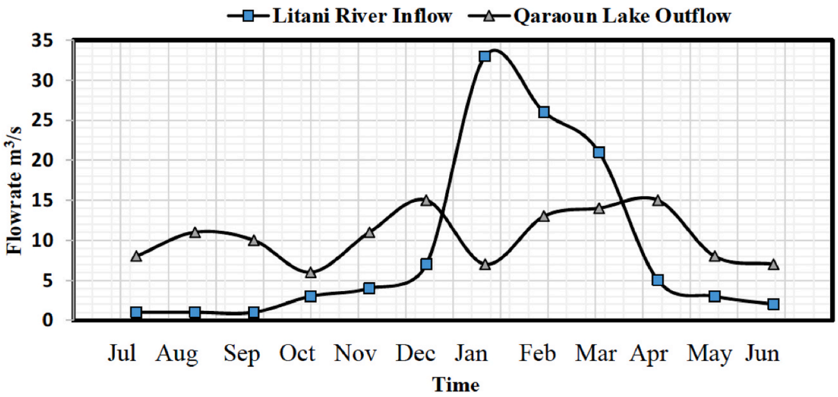

Fig. 2. Litani River hydrograph and outflow from Qaraoun Reservoir, [21].

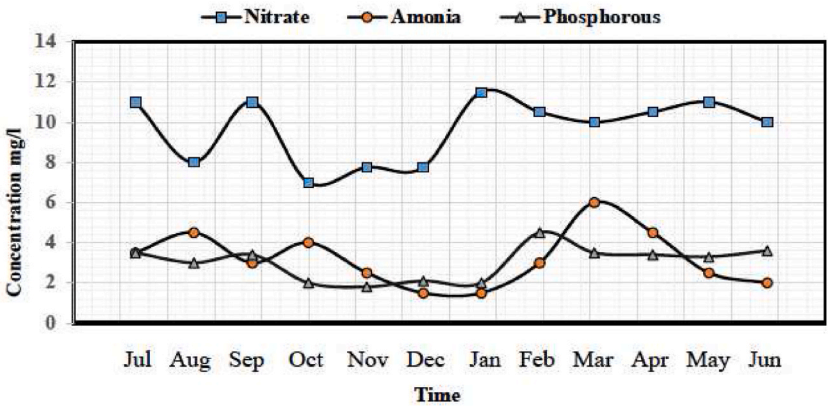

Fig. 3. Water quality parameters at the Litani River, 2010 [19].

treatment concept.

2. Study area and data

2.1. Study area

The Litani River basin is divided between two hydrologic basins, upper and lower. They are connected at Qaraoun Lake (33.34° N, 35.41° E), which is an artificial reservoir. It was built in 1962 across an area of 12.3 km^2 and has a total capacity of around 225 MCM [21]. fig. 1 (a) and Fig. 1 (b) show the layout of the Qaraoun reservoir and its bathymetric data. The reservoir depth varies between 5 and 50 m and it receives its water from the Upper Litani River, which is considered deteriorated. The major reservoir water source is the Litani River inflow. In addition, the inflow and outflow from the underwater springs, evaporation, precipitation, and infiltration because of the karstic geological formation are also factors in reservoir hydrologic equilibrium [21]. provided further information on the reservoir operation and hydrology shown in Fig. 2.

The climate near Qaraoun Lake is semiarid, characterized by moderately cold winters (the normal mean temperature is 13 °C in January and February) and dry, hot summers (the normal mean temperature varies between 25 °C and 27 °C from July to September). The average annual precipitation in the reservoir catchment is about 700 mm [23]. The heaviest rainfall period spreads from November to April. There is little or no precipitation between June and August.

2.2. Litani River

The Litani River is Lebanon's longest river, 178 km, with a basin area of around 2180 km^2. This major water resource in Lebanon has provided power production, irrigation, consumption of water, and a site for public recreational activities [6]. The studies [10,24, 25] revealed three main groups of pollutants in the upper basin of the river. Waste and pollutants are mainly produced by factories. Phosphorus and nitrate mainly result from agricultural activities and domestic waste. Ammonia levels in water can be high due to the seeping of chemical wastes and fertilizers in freshwater via precipitation. As stated, Litani River Basin is the main source of water and

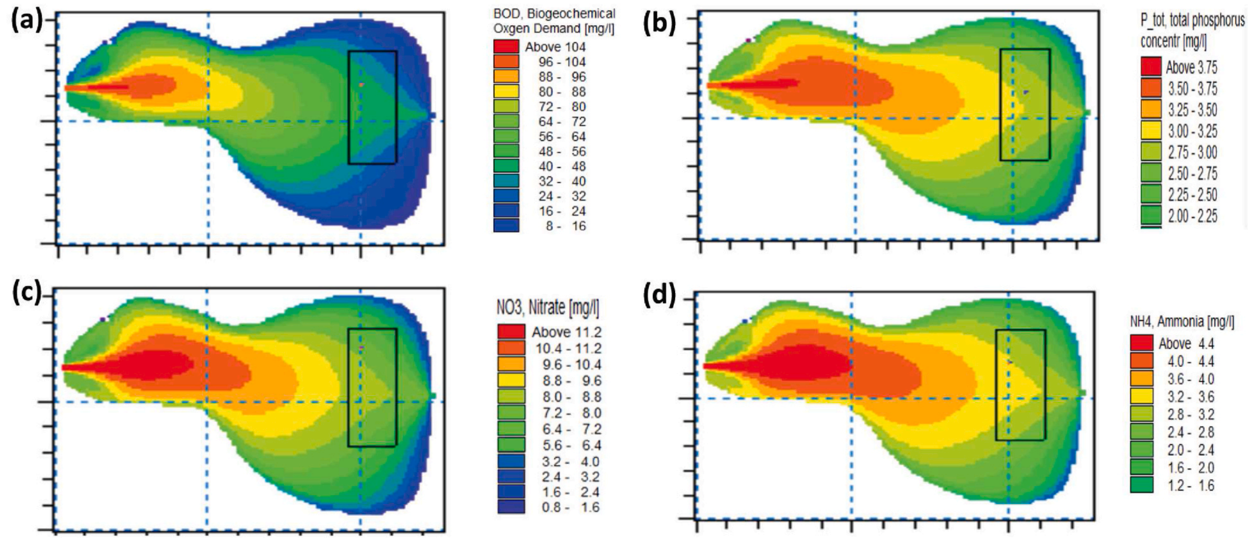

Fig. 4. Wetland simulation results (a) BOD, (b) Phosphorous, (c) Nitrate and (d) Ammonia.

pollution to Qaraoun Lake. Different water quality parameters abstracted from Litani River Authority annual reports are shown in Fig. 3 [19]. The concentration of phosphorous is of high concentration with an average of 3.7 mg/l for the Litani River throughout the year, which is 37 times higher than the allowable standards (0.01 mg/l) set by the Environmental Protection Agency [26]. However, throughout the year nitrate is averaged to be 11.5 mg/l, which is above the EPA limit in a slight manner (10 mg/l) for the solution of nitrate excess is easy to solve. In addition, the ammonia concentration is seen to be an average of 4.6 mg/l, which is 230 times higher than the EPA limit (0.02 mg/l). Furthermore, the Biological Oxygen Demand (BOD) is averaged to be around 547 mg/l, which is 110 times more than the EPA limit (5 mg/l), [19]. Other Pollutants such as heavy metals concentrations are also high in the Litani River, which is absorbed by plants and fauna [25]; (Kiran et al., 2022). Because of the water's high conductivity, the availability of free metals to plants and fauna is altered [27]. Thus, in this study, in order to identify the appropriate solution for the restoration of the Lake's aquatic life, nutrients such as Nitrate, Phosphorus substances will be eliminated during the dry season (from May to September) using a constructed wetland.

3. Methodology

In this study, a numerical model for the Qaraoun reservoir is developed to understand the effect of pollutants removal from the Litani River using the wetland concept. The model was first used to simulate a suggested wetland at the reservoir inlet to determine the percentage removal of such pollutants. Then the model is used to evaluate the Qaraoun reservoir water quality enhancement. Thus, a two-dimensional model using MIKE 21 FLOW MODEL FM [28] and ECO Lab (WQ Level 4) [29], is used to simulate the lake hydrodynamics and water quality, respectively. This investigation focuses on the variations of DO, BOD, P, NH_4, and NO_3 as indicators for reservoir restoration.

3.1. Wetland simulation

According to the Litani River hydrograph (water supply of Qaraoun Lake) shown in Fig. 2, it is divided into a dry season starting May to September with a flow rate of 1 m^3/s and a wet season with higher flow rates. In this case, the wetland will be designed based on the dry season only. Since high flow, rates during the winter season require a huge wetland area. Moreover, water quality concentrations are low during this period due to the Litani River flooding.

The wetland is planned as a free-water surface system in that influent water flows across a basin or a channel vegetated by reeds, which is available in the surrounding areas and can be used as livestock feed. The following equations (1) and (2) are used to determine the required Wetland area (m^2), A_s, and detention time (day), t. [18,30].

$$A_s = \frac{Q(\ln C_o - \ln C_e)}{K_t D n} \tag{1}$$

$$t = \frac{A_s D n}{Q} \tag{2}$$

where:

Q is the average flow rate (m^3/day), D is the water depth, which is assumed 0.6 m, n is the substrate medium porosity of (0.39), and

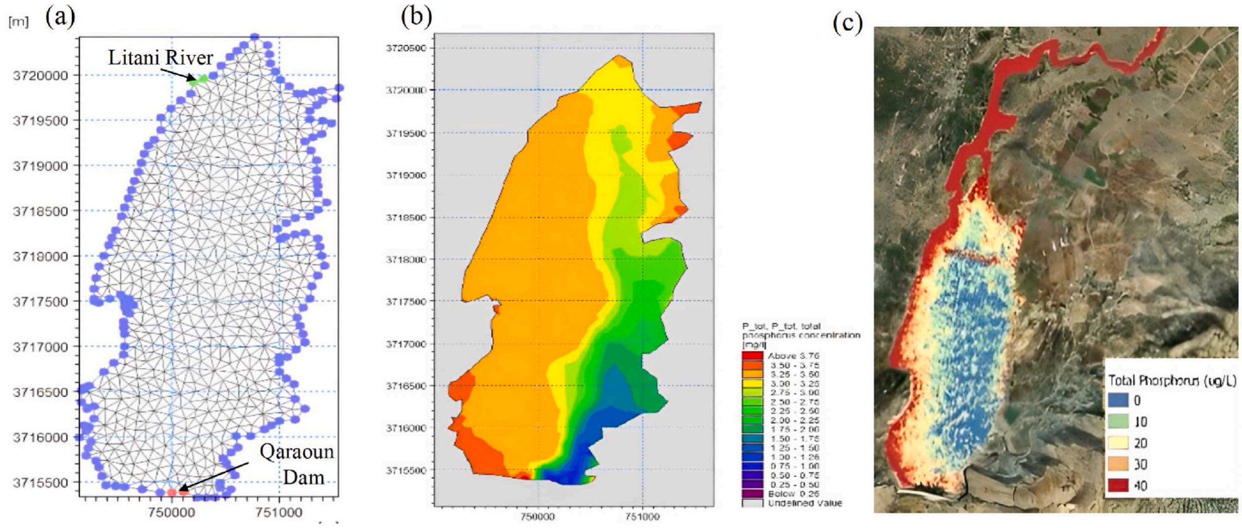

Fig. 5. (a) Qaraoun Reservoir computational domain and mesh, (b) Simulated Phosphorous distribution, and (c) Total Phosphorous using remote sensing [32].

C_o & C_e are the average influent & effluent concentrations (mg/l). K_t is a coefficient that depends on temperature (summer temperature equal to 33 °C) and pollutant type, which is considered BOD [31].

Based on the previous equations, an elliptical wetland area of 162000 m^2 to improve water circulation is proposed with a detention time of 10 h to eliminate the BOD by 85% as shown in Fig. 4 (a). Based on these criteria, the simulated wetland is calibrated to produce the same ratio. Then the other tested parameters were calculated using the model. The tested parameters for the inflow water quality were phosphorous, nitrate, and ammonia with concentrations of 3.75 mg/l, 11.5 mg/l, and 4.5 mg/l, respectively as shown in Fig. 4 (b), 4(c), and (d). As a result, the wetland could reduce the nutrients with about 43.7%, 57% and 56% for Phosphorous, Nitrate, and Ammonia, respectively.

3.2. Qaraoun Reservoir simulation

Qaraoun Reservoir as described before is highly affected by the polluted water supply from the Litani River. After wetland usage, a remarkable improvement in the Reservoir water quality is expected. For this purpose, a Hydrodynamics and water quality model is developed to assess the impacts of the suggested wetland on the reservoir. The hydrodynamic model included boundary conditions, Coriolis force, water flow rates of point sources of pollution (Litani River before and after the wetland), and outflow flow rates of Qaraoun dam. The lake bathymetry used is shown in Fig. 1 b. In this investigation, it is assumed that a strong vertical mixing exists so that the water characteristics of the surface and bottom are similar and 2D Simulation is valid for this study. The mesh size is about 100 m in the computational domain shown in Fig. 5 (a). Eddy viscosity and bed resistance are the main parameters, and the model could simulate the present hydrodynamics when these two parameters were set to 45 and 0.3, respectively. In order to check the model circulation, the comparison results shown in Fig. 5(b) and c shows that the simulation mostly agrees well with the remote sensing results obtained by Ref. [32] in August 2020. The simulation showed high concentrations of Phosphorous on the left side of the lake and lower concentrations on the right side, which matches the remote sensing results. There are some discrepancies in the middle part of the reservoir. Overall, the simulation result is reasonably able to represent the reservoir circulation and water quality parameters distribution.

4. Results and discussion

This study employs a hydrodynamic-ecological model to assess the impacts of Litani River polluted water influents on Lake Qaraoun water quality, and to investigate the effect of using wetlands to treat such contaminated inflow.

4.1. Water quality parameters for the original state

Qaraoun experiences an unsteady state flow regime due to inflow and outflow discrepancies shown in Fig. 2 with an estimated residence time of 0.77 year [21]. This gives some credibility to the assumption of neglecting wind forces and vertical acceleration in this study. In addition, water circulates directly from the water source to the outlet booming external nutrient loads into the lake water body. The simulated water quality parameters distribution for the original state (before the wetland), and the resulting parameters after water treatment using the wetland of lake water quality are represented in Fig. 6. Generally, the results revealed that the spatial variation of water quality at the Lake center is better than all the surrounding boundaries. It is clear that pollutants transported in

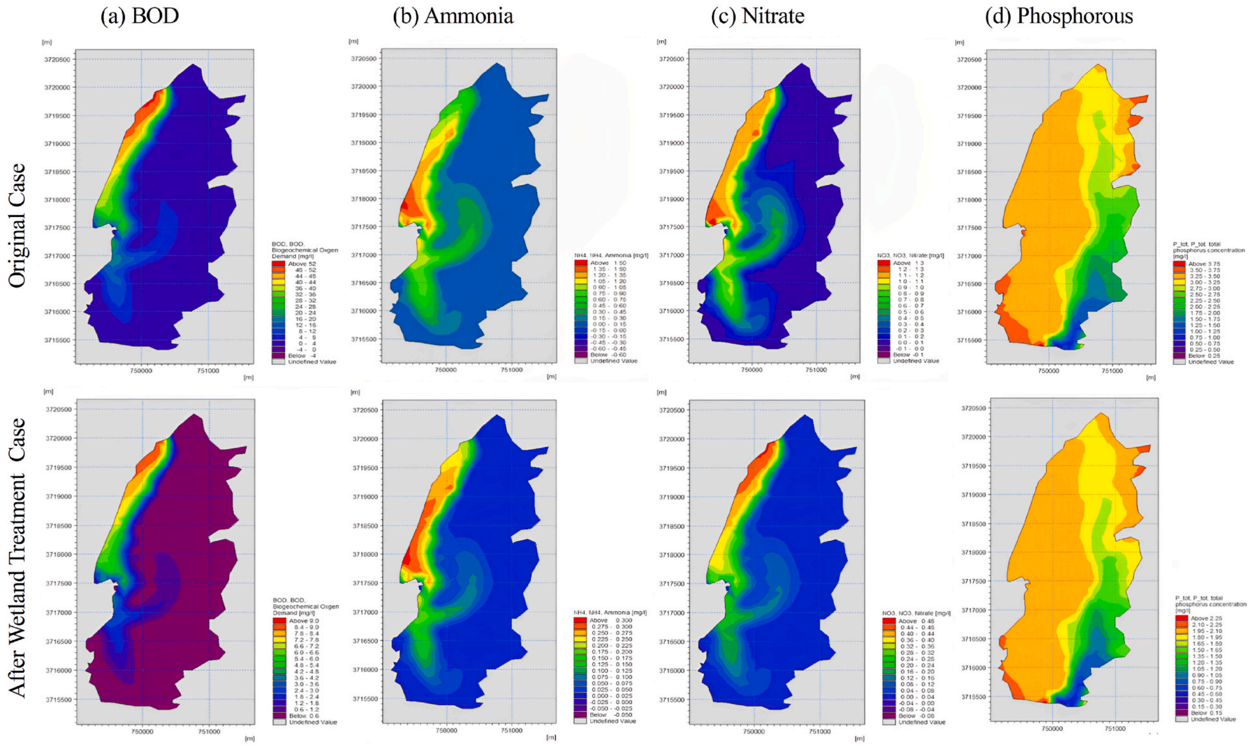

Fig. 6. Qaraoun Lake water quality simulation results before treatment (Top) and after wetland treatment (Bottom): (a) BOD, (b) Ammonia, (c) Nitrate and (d) Phosphorous.

blooms adjacent to the left side of the lake concentration decrease towards the outlet; it is considered a buffer zone that dilutes pollutants naturally which agrees with the results of [33,34]. However, the resulted contaminants at the lake outlet are almost above the EPA standards limits. The resulted concentrations for BOD, Ammonia, and Phosphorous shown in Fig. 6(a), (b), and 6(d) are 8 mg/l, 0.3 mg/l, and 1.5 mg/l, respectively, compared to their safe limits (5 mg/l, 0.02 mg/l, and 0.1 mg/l correspondingly). While the Nitrate output (Fig. 6c) is equal to 0.4 mg/l, which is within the safe bounds (1.5 mg/l).

4.2. Water quality parameters after treatment by wetland

The Lake water quality parameters are significantly enhanced due to nutrient removal by the wetland and natural diffusion of the contaminates. The simulated results revealed that BOD is decreased by 70%–85% at the lake effluents to be around 1.2 and 2.4 mg/l, which is within the safe limits. As for Ammonia, it ranged between 0.02 and 0.05 mg/l throughout the year, which is slightly above the EPA standards, but it is still acceptable within a reasonable margin. The use of the wetland reduced the Ammonia concentration by 76.67%–93.33%. Furthermore, the Nitrate output ranged between 0.08 and 0.1 mg/l throughout the year, which is equivalent to a 75%–80% reduction. Moreover, the outflow Phosphorous concentration is decreased by 80% to a value of 0.3 mg/l, which is slightly higher than the EPA standard but is in a reasonable range (after wetland treatment). The constructed wetland has proven to be effective in treating the polluted water of the Litani River; subsequently improving the water quality of the Qaraoun entirely, also it has proven to be very effective in the removal of excess nutrients and BOD. Having an elliptical shape, based wetland proves to reduce the number of dead zones and utilizes the entirety of the wetland. In addition, the limited area available in Qaraoun Lake allows for the construction of the perfect solution for water pollution, which is the elliptical Constructed subsurface wetland.

Based on this research, it is recommended to decrease agricultural pollution by promoting reduced use of fertilizer and integrated pest management practices among large farms located close to the Litani River. A treatment system to remove organic muck, significantly improving both of growth and health of the fish, and reducing aquatic weeds, algae, foul odors, and disease-causing bacteria.

Moreover, the construction of sewage networks and connecting them to wastewater treatment plants so that sewage is treated before it is discharged in the Litani River. That way, not only reduces the pollution entering the river but also makes treated water available for irrigation.

A proper monitoring system is strongly needed to gather critical information about changes in the lake ecosystems, including lake body, aquatics, surrounding soil, and groundwater conditions. This helps decision-makers and advocates take action, define local trends and risks, refine actual plans, and determine other management plans.

5. Conclusions

A hydrodynamic and water quality modeling system for the Qaraoun Reservoir is developed in order to investigate the effect of nutrient elimination of Litani River water using a constructed wetland. The developed model reasonably simulated the water quality parameters of Qaraoun Lake. Based on simulations, the wetland could remarkably reduce the Litani River pollutants. The wetland could eliminate about 85%, 43.7%, 57%, and 56% of BOD, Phosphorous, Nitrate, and Ammonia, respectively. The resulted treated water, after passing the wetland, successfully improved the lake water quality by at least 70%, which may lead to re-originate its ecosystem.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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